MAJOR FACTORS AFFECTING CAPACITY UTILIZATION OF THERMAL POWER PLANTS IN INDIA

A thesis submitted to the
University of Petroleum and Energy Studies

For the Award of
Doctor of Philosophy
in
Management

BY
Alok Kumar Tripathi

Jan 2023

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DECLARATION

I declare that the thesis entitled [Major Factors Affecting Capacity Utilization of Thermal Power Plants in India] has been prepared by me under the guidance of [Dr Neeraj Anand], [Dean - SCM & General Management, Chitkara Business School, Chitkara University, Formerly-Prof of LSCM, School of Business, UPES] and Dr Sushanta K Chatterjee, [Chief (Regulatory Affairs), CERC]. No part of this thesis has formed the basis for the award of any degree or fellowship previously.

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Date : 01.01. 2023

CHITKARA UNIVERSITY

PUNJAB

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"MAJOR FACTORS AFFECTING CAPACITY UTILISATION OFTHERMAL POWER PLANTS IN INDIA"

is being submitted by **ALOK KUMAR TRIPATHI** in fulfilment of the Award of **DOCTOR OF PHILOSOPHY in (MANAGEMENT)** to the University of Petroleum and Energy Studies. The thesis has been corrected as per the evaluation reports dated 10/10/2022 and all the necessary changes/modifications have been inserted/incorporated into the thesis.

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ABSTRACT

Thermal power plants in India are operating at very low Utilization Factors. The national average Utilization Factor of thermal power plants was 77.5 % % in the year 2009-10 which has come down to 53.37 % in 2021-22[1]. Many studies and reports indicate that in business-as-usual situation, average Utilization Factor may drop to 48% in next 1-2 years [2], [3].

On top of this, 62000 MW [4], [5] worth of capacity new thermal power plants are in pipeline in different stages as on June 2021. There is strong possibility that these new plants will also run at very low PLFs. This is an irony. When country needs power, there exists demand which is unmet, thermal power plants are capable and ready to meet the demand, yet they are not being utilized optimally. Of course, the environmental footprint of thermal power plants is a matter of major concern, but there should be systematic, well thought out utlisation, greening and exit policy for these valuable assets. These plants are mainstay of power generation today and likely to remain so at least in the medium term. This unique situation of falling PLF of thermal plants is therefore an issue that must be dealt with by all key stakeholders.

In the above context, this research has three major objectives. Firstly, to identify the Major Factors responsible for falling Capacity Utilization (PLF) of thermal power plants and discusses future outlook of these factors. The method employed for this part is to first do exploratory research, framing of questionnaire containing 25 factors, seeking response of professionals, academicians, regulators, grid operators, consultants (253 respondents) through a Likert Scale as to which are the major factors affecting Capacity Utilisation (PLF) of thermal (coal based) power plants, then checking through Hypothesis Testing (of proportion) to find out which of the factors (out of 25 identified during exploratory research) emerge as Major Factors by opinion of the majority of the responders. This analysis created the first shortlist of 14 Major Factors.

Further, as the main tool to reconfirm and finally arrive at the Major Factors, all the 25 factors were analysed using *Factor Analysis*. As an outcome, ten factors emerged as Major Factors. All these ten Factors were common in both the analysis results i.e., Hypothesis Testing and Factor Analysis.

The ten factors so identified are (i) *Bad financial health of power procuring companies (Discoms), (ii) Bad financial health of power utilities of state sector (State Gencos), (iii) Generating electricity from coal is no longer attractive business due to rising cost*
(iv) Substantial addition of renewable energy (solar and wind) having must-run status in the grid (v) Grid conditions demanding flexible operation (vi) Low growth of power demand in the country (vii) India reaching a stage of being power surplus (on most days in a year) (vii) Although India is power deficit on totality basis (viii) many regions in the country actually becoming power surplus (ix) Low fuel (coal) availability and (x) Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available.

In the next step, the research has progressed to know what the future trends could be for the coal-based plants in terms of PLF. For this purpose, choosing the four most important (empirical) factors identified through Objective -1 as independent variables, the future projection of PLF (dependable variable) was done under four different scenarios, using PLS regression technique. (This completed the Object II of this research). Four different scenarios have been considered here. The regression shows that, if the business goes as usual (we have termed this scenario as Scenario – III, where the independent factors are assumed to be changing at the current CAGR of last five years). We find that, in such case, the PLF might dip to unsustainably low level of 37.8% by as early as 2023-24. This will lead to a difficult situation for thermal (coal based) power plants. Out of the total four scenarios considered in the research, there is one scenario, that shows a promising positive future trend of PLF.

We have named that scenario as Scenario -II in this research. In this scenario, our projection is based on fuel mix and power demand as per the projections suggested by the Central Electricity Authority's (CEA) in their draft report on optimal generation capacity mix for 2029-30 [6]. If this path is followed, the average national PLF of thermal power plants has a chance to rise to a level of 62.03 % by the year 2024-25. Under this scenario, thermal plants will run at a level of Utilisation Factor (PLF), which seems optimum and sustainable in terms of technical and financial performance. If we follow this path, policymakers and developers will also get the much-needed time to prudently plan the best suited generation mix in the country and thereby take prudent investment decisions.

The next part of the research has dealt with the technical and financial impact of falling PLFs, study of global scenario in terms of Utilization Factor or PLF of thermal (coal based) plants. Then the research goes on to create future road map/ recommendation / remedial actions. These steps finally complete the Objective II&III. The research finds that, to survive in the above situation, flexible (frequent ramp up- ramp down) operation of thermal plants (Flexibilization) has become an imperative. However, flexibilization has substantial bearing on costs and profits of the thermal plants. In this research, the direct impact of falling PLF in terms of loss of profit and Return on Equity on three different types of power plant units (660 MW, 800 MW, 500 MW) has been calculated. The (ROE) loss occurring due to deterioration in performance parameters like Heat Rate, Aux Power Consumption, Generation Incentives and Startup Costs have been considered here. Calculations show that if PLF drops from 90 % to 35 %, it will result in reduced profits by Rs 46.63 Cr/ 6.26 (US$ Mn), Rs 49.26 Cr/ 6.61 (US$ Mn) and Rs 30.31 Cr/ 4.07 (US$ Mn) and will hit the ROE by 31 %, 22 % and 26 % respectively for one unit of 660 MW, 800 MW and 500 MW (on annual basis). Taking average of the three typical plants, the ROE will be impacted (negatively) to the tune 26 %. Attention must be given on this aspect to keep the thermal power plants economically sustainable.

We find that the Grid needs thermal (coal based) power plants for survival and meeting the power demand. In the later part of this research, the global context was also studied to understand what is happening to thermal (coal based) power plant's Utilization Factors (PLF) in other countries. For the purpose of this work, countries which have significant amount of thermal power in their installed capacity portfolio (> 20 %) have been considered. Keeping this in consideration, the countries- Australia, Germany, Indonesia, USA, Japan and China have been studied.

Based on the analysis of Objective-I (Major Factors), Objective-II (PLF Projections, Technical & Financial Impact and study of Global Scenario (six countries), Recommendations / Remedial Actions were prepared by the researcher. These Recommendations / Remedial Actions were validated with 15 senior industry experts. Delphi method was used for arriving consensus on the recommendations / remedial actions.

The consensus Recommendation / Remedial Actions, which evolved using Delphi method (three rounds) became the final culmination of this research (Objective -III of this research.)

The research also discusses about its contribution to literature, limitations and avenues for further research in this area. The research elaborates how different theories have dealt with the subject. Relevant theories which give guidance or value to this research are – Theories dealing with Capacity Utilisation, Theory of Market Failure, Theory of Disruptive Innovation by Clayton Christenson, Resource Based Approach to Strategy by Robert M Grant and Theory of Generic Competitive Advantage by Michael Porter.

The research has been acknowledged as a quality work. Three publications have come up in reputed journals (Scopus indexed) from this work. A significant portion of this thesis therefore has been published and the thesis contains references of self-published papers wherever applicable.

The first publication is through Preprints, a professional platform to share scholarly work before it is published in journals- *Tripathi, A.K., Factors Affecting Capacity Utilization of Thermal Power (Coal) Plants in India, Version 1: 19 August 2020 (11:38:11 CEST), Preprints 2020, 2020080414* [7]. This publication has 524 views and 228 downloads till April 2022. Other publications are in Scopus Indexed Journals, *Crisis of Survival of Thermal Power Plants in India due to Consistently Falling Capacity Utilization, Alok K Tripathi - International Journal of Energy Economics and Policy- Vol 11, No 3, 2021-328-337* [8], *Falling capacity utilisation of thermal power plants in India- Projection of future scenarios- Alok K Tripathi- International Journal of Energy Production and Management (WIT Press)- Volume 6, No 1, 2021-94-104-10.2495/EQ-V6-N1-94-104* [9] and Falling Capacity Factor of Thermal Power Plants in India and its Financial Impact- Alok K Tripathi and Neeraj Anand, - *International Journal of Energy Economics and Policy- 2022, 12(5), 209-216* [80]

These are the most recent works published in connection with this thesis.

ACKNOWLEDGEMENT

The journey to the degree of Doctor of Philosophy (PhD) is long, arduous but very rewarding. No doubt it is very challenging for a working professional. Challenges are on every front. Even the beginning is so daunting. Determining the right topic for the research itself looks like a full PhD. Then starts the long, convoluted path, with unending literature review, with the research further moving through the thick and intimidating forests of research methodology, course work, exams, residency, synopsis, revised synopsis, numerous presentations, family responsibilities, official engagements and abstract presentation and then revised abstract presentation. Finally, the *Thesis* is like attaining true *Nirvana*. Midway in the journey, many souls leave the pursuit and decide to do something more practical in life. I also had similar feelings at least one dozen times. Thank God, I survived the onslaught of this journey and have reached this level of submission of thesis.

I have learnt that first and foremost, you need a strong determination. Then, you need sound understanding of the subject. But that is only half the arsenal. For moving further, you need help of real experts who show you the right path. Beside this, keeping yourself motivated through the long journey and understanding the intricacies of research methodology are the other two big challenges that you need to deal with.

Those who motivate, cajole or pressurise you to complete the PhD are your real well-wishers and those who help you understand the subject and the research methodology are your true mentors in this journey. Have gratitude towards them.

In my journey, I got the valuable guiding light from mentors like my internal guide Dr Neeraj Anand, Dean – SCM & General Management, Chitkara Business School, Chitkara University (Formerly Prof of LSCM, School of Business, UPES), external guide Dr Sushanta Chatterjee, Chief of Regulatory Affairs, CERC, Dr Anil Kumar, Prof and Head, Power, School of Business, UPES, Shri R S Sharma, ex CMD NTPC and ex MD, Jindal Power & Bajaj Power, Shri Sharat Kumar Acharya, Ex CMD, NLC and many other professionals whom I am unable to name here due to space constraints.

The PhD support group from UPES including Ms Rakhi Ruhal, Sh Yogesh, Sh Mohit, Sh Arjun and Ms Sanjukta have also helped me immensely and responded positively in all hours of need. I am grateful to each one of them for their time, support and guidance.

On several occasions during this seven year’s long Ph.D. path, when I used to nearly give up, my wife Ranjana Tripathi always persuaded and inspired me and at times, cajoled and forced me to walk the path. If there is someone who deserves the highest credit for the completion of this work, it is her. Her contribution to this journey is invaluable and worthy of a separate PhD in psychology and sociology. I express heartfelt gratitude to her. My two loving daughters Saumya, Tanya and son in law Karan also motivated me throughout, discussed various aspects with me, helped in thesis drafts, and supported me in learning new tools to complete this PhD. I have no doubt that this work would not have been completed without their loving motivation.

I also thank my company NTPC and all seniors and colleagues, who gave me the ability, opportunity and support to pursue this academic pursuit.

At last, but most importantly, I want to express gratitude to my late mother, who was a scholar herself and who always believed in my abilities. She always showed me the path of learning. She would not see the completion of this journey in this world, but I am sure she would be blessing me from wherever she is!!

With these words of gratitude, I humbly submit my work in the form of this thesis to the learned world of academics and hope that this work shall serve some worthy cause.

TABLE OF CONTENTS

THESIS CHAPTERS

List of Tables, Charts and Figures

Tables

Charts

List of Abbreviations

PLF - Plant Load Factor

UF - Utilization Factor

DC - Declared Capacity

RPO – Renewable Purchase Obligation

CEA- Central Electricity Authority

RSD- Reserve Shutdown

URS- Un Requisitioned Surplus

BAU- Business As Usual

RG- Reduced Growth

LCARND - Low Coal, Aggressive Renewable, Normal Demand

CEAP- CEA Projection

CEAP+PHOUT- CEA Projection and phasing out of old capacity

OEM – Original Equipment Manufacturer

LDO- Light Diesel Oil

ROE- Return on Equity

CERC- Central Electricity Regulatory Commission

DISCOM – Distribution Company

GENCO- Generating Company

1 CHAPTER 1- INTRODUCTION

चिन्तनीयाहि विपदं, आदावेव प्रतिक्रिया,
न कूप खननं युक्तं, प्रदीप्ते वहनिना गृहे II

- Shubhashitani

The above verse in Sanskrit from *Shubhashitani* (a collection of ancient wisdom in Indian scriptures) says that "It is futile to show concern and take remedial steps only after facing a calamity because then it is too late. To commence digging a well is not appropriate when the house is already on fire".

This research shows how we need to be concerned and take timely remedial action for optimal utilization of our valuable thermal power generation resources before it becomes too late and several high capital investment assets become stranded and the grid suffers due to not availability of sufficient power.

1.1 CHAPTER OVERVIEW

This chapter contains the context of research, background, the business problem, motivation for research, and outline of the thesis chapters.

1.2 IMPRESSIVE TRAJECTORY OF THERMAL POWER IN INDIA

The power sector in India has seen an impressive growth in installed power capacity since independence of the country. From a very modest level of 1362 MW (as on 31.03. 1947), India's total installed capacity rose to 370.106 GW/ 370106 MW (as on 31.03.2020). [1] [7], [8], [9], [10], [11], [12], [13]. The tables below (Table 1.1, 1.2) depict the current fuel wise breakup of the installed power capacity (as on 31.03.2020), and how the installed capacity has grown over years -

Table 1.1 : Installed Capacity in India as on 31.03.2020

Fuel	GW	% of Total
Total Thermal Power	230.600	62.8%
Coal based	198.525	54.2%
Lignite based	6.610	1.7%
Coal + Lignite based	205.135	55.40%
Gas based	24.937	6.90%
Diesel based	0.510	0.10%
Hydel Power (Renewable)	45.699	12.40%
Nuclear Power	6.780	1.90%
Renewable Energy Sources	86.028	23.50%
Grand Total	370.106	100 %

Source- Government of India (GOI), Ministry of Power (MOP), CEA published data and website [1] [7], [8], [9], [10], [11], [12], [13].

1.3 PORTFOLIO WISE GENERATION MIX IN INDIA : 1947- 2020

The following table shows the fuel-wise installed capacity growth since 1947. As can be seen. At the time of country's independence, the installed capacity was only 1.362 GW. On 31st March 2020 the installed became a staggering 370.106 GW. As is evident from the table, coal-based generation has been the most prominent contributor to this growth story.

Out of the 370.106 GW as on 31.03.2020, coal-based capacity is 205.135 GW, which forms 55.4 % of the total capacity.

If we look at the past ten years data, the coal-based capacity shows rapid increase till 2016 (@13.39 % CAGR between the period 2010-11 to 2016-17), but the rate of capacity addition seems to have slowed down after 2016-17 (@2.2 % CAGR between 2016-17 to 2019-20).

Table 1.2 : Installed power capacity in India between 1947 to 2020

ALL INDIA POWER SECTOR GROWTH AT A GLANCE FROM 1947 to 2020 (GW)										
Sl No.	Date	Year	Hydel	Thermal Capacity			Total Thermal	Nuclear Capacity	RE	Grand Total
				Coal/ Lignite	Gas	Diesel				
1	31.12.1947	1947	0.508	0.756	0	0.098	0.854	0	0	1.362
2	31.12.1950	1950	0.560	1.004	0	0.149	1.153	0	0	1.713
3	31.03.1956	1956	1.061	1.597	0	0.228	1.825	0	0	2.886
4	31.03.1961	1961	1.917	2.436	0	0.300	2.736	0	0	4.653
5	31.03.1966	1966	4.124	4.417	0.134	0.352	4.903	0	0	9.027
6	31.03.1969	1969	5.907	6.640	0.134	0.276	7.050	0	0	12.957
7	31.03.1974	1074	6.966	8.652	0.165	0.241	9.058	0.640	0	16.664
8	31.03.1979	1979	10.833	14.875	0.168	0.164	15.207	0.640	0	26.680
9	31.03.1980	1980	11.384	15.991	0.268	0.165	16.424	0.640	0	28.448
10	31.03.1985	1985	14.460	26.311	0.542	0.177	27.030	1.095	0	42.585
11	31.03.1990	1990	18.307	41.236	2.343	0.165	43.764	1.565	0	63.636
12	31.03.1992	1992	19.194	44.791	3.095	0.168	48.054	1.785	0.032	69.065
13	31.03.1997	1997	21.658	54.154	6.562	0.294	61.010	2.225	0.902	85.795
14	31.03.2002	2002	26.269	62.131	11.163	1.135	74.429	2.720	1.628	105.046
15	31.03.2007	2007	34.654	71.121	13.692	1.202	86.015	3.900	7.760	132.329
16	31.03.2012	2012	38.990	112.022	18.381	1.200	131.603	4.780	24.504	199.877
17	31.03.2013	2013	39.491	130.221	20.110	1.200	151.531	4.780	27.542	223.344
18	31.03.2014	2014	40.532	145.273	21.782	1.200	168.255	4.780	31.692	245.259
19	31.03.2015	2015	41.267	164.636	23.062	1.200	188.898	5.780	35.777	271.722
20	31.03.2016	2016	42.783	185.172	24.508	0.993	210.675	5.780	45.924	305.162
21	31.03.2017	2017	44.478	192.163	25.329	0.838	218.330	6.780	57.260	326.848
22	31.03.2018	2018	45.293	197.171	24.897	0.838	222.907	6.780	69.022	344.002
23	31.03.2019	2019	45.399	200.704	24.937	0.637	226.279	6.780	77.641	356.100
24	31.03.2020	2020	45.699	205.135	24.937	0.510	230.582	6.780	87.028	370.106

Source- Government of India (GOI), Ministry of Power (MOP), CEA, published data and website [1] [7], [8], [9], [10], [11],[12], [13].

1.4 PLANT UTILIZATION FACTOR (PUF) OR PLANT LOAD FACTOR (PLF) OF THERMAL POWER PLANTS

The Plant Utilization Factor (PUF) of a given period, known more commonly in India as Plant Load Factor (PLF) (*hereinafter term PLF has been used for describing Plant Utilization Factor in this paper)* is the ratio expressed in percentage terms, of actual electricity produced by the power plant compared to the electricity generated by the power plant if it were operating at its full rated capacity.

This ratio, therefore, indicates how well the generation asset is being utilised. If the plant operates at full capacity for the entire year, the PLF of the year will be 100 %. However, a plant howsoever well maintained, cannot achieve 100 % PLF over the course of full year because of various reasons.

The reasons could be many, like - the plant being under forced shutdown (*Forced Outage*) due to equipment problems, shut down for planned maintenance (*Planned Outage*), shut down due to non-availability of fuel (coal), low demand of power, competitive sources like renewable getting preference to meet the demand (*because renewable energy has "must run" preferential status to generate and sell power*), power transmission constraints etc.

For a reasonably well-maintained plant, the *Forced Outage* and *Planned Outage* together account for around 8-9 %, which together bring a reduction in PLF by 8-9 % in a year. Therefore, a reasonably healthy power plant should be able to operate at 91-92 % utilization (PLF) if other factors are favourable. However, the following chart depicts a disturbing trend.

As can be seen from the chart, PLF of thermal power has been falling consistently in last 12 years. The national average PLF in the year 2019-20 was 55.4 %. [7],[8]

PLF of thermal power plants in the country (Coal & Lignite based) from 1985-86 to 2019-20 is as under.

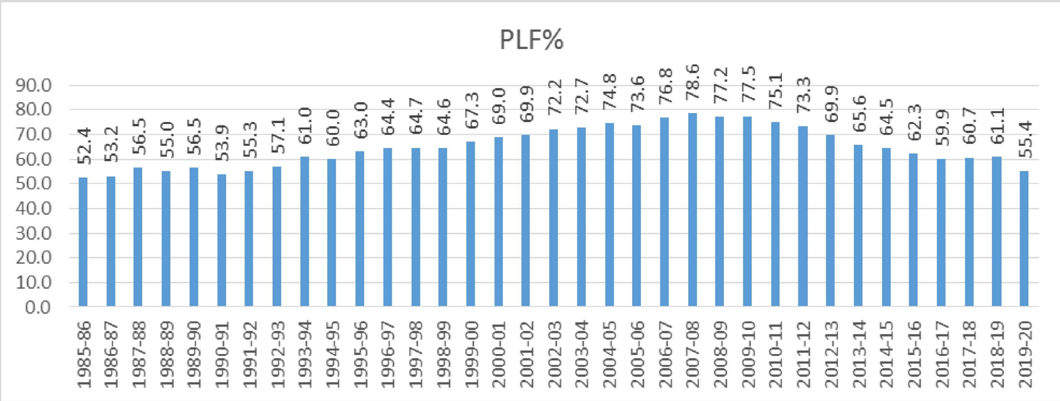


Chart C1.1 - PLF of thermal power plants in India 1885-86 to 2019-20.

Source- Central Electricity Authority, New Delhi, Power Sector Report, 1947-2015 development of power sector and Ministry of Power. [1], [7], [8], [9], [10], [11],[12], [13].

The fall in PLF is observed in all the three sectors (Private, State, and Central Sector) which is evident from the following table. It is also observed that the central sector has recorded highest PLF, followed by the Private and State sectors. Based on last 11 years average data as given below, the Central sector plants have maintained higher PLF than national by about 10.08 %, the State sector is lower by 5.55 % and the Private sector is lower by 2.13 %.

Table 1.3 : Sector wise Plant Utilization Factor (PUF or PLF) of thermal power plants in India

Year	PLF % National	PLF (%) Sector-wise		
		Central Sector	State Sector	Private Sector
2009-2010	77.50%	85.50%	70.90%	83.90%
2010-2011	75.10%	85.10%	66.70%	80.70%
2011-2012	73.30%	82.10%	68.00%	69.50%
2012-2013	69.90%	79.20%	65.60%	64.10%
2013-2014	65.60%	76.10%	59.10%	62.10%
2014-2015	64.46%	73.96%	59.83%	60.58%
2015-2016	62.29%	72.52%	55.41%	60.49%
2016-2017	59.88%	71.98%	54.35%	55.73%
2017-2018	60.67%	72.35%	56.83%	55.32%
2018-2019	61.07%	72.64%	57.81%	55.24%
2019-2020	56.08%	65.36%	50.26%	54.73%
Average of 11 Years	65.99%	76.07%	60.43%	63.85%

Source- Government of India (GOI), Ministry of Power (MOP) and CEA published data and website. , [1] [7], [8], [9], [10], [11], [12], [13].

For critical infrastructure sector like *electricity*, where large capital-intensive projects are set up, one of the important considerations is that the capacity utilization should be optimal. This is to ensure that the assets created with enormous cost are utilised optimally, electricity prices are kept optimal and there are reasonable returns generated for thermal power generators to sustain and invest in new technology. However, the above trend shows all is not well. [7], [8]

1.5 ENERGY AND PEAK DEMAND DEFICITS IN INDIA

The increase in installed capacity of power in India has been propelled by the demand and supply gap of electricity in the country. The following table gives energy and peak shortages of power in the country since 2009-10. Data shows that the country has consistently faced energy and peak shortages. In the year 2019-20, energy shortage was 0.5 % of the demand and peak shortage was 0.7 % of the demand. [1], [7], [8], [10], [11], [12]

Table 1.4 : Energy and Peak Deficit in India

Yr	Power Generation				Peak Demand			
	Required	Available	Surplus (+)/ Shortage (-)		Required	Available	Surplus (+)/ Shortage (-)	
	(MU)	(MU)	(MU)	(% Short)	(MW)	(MW)	(MW)	(% Short)
2009-10	830594	746644	83950	-10.1%	119166	104009	-15157	-12.7
2010-11	861591	788355	73236	-8.5%	122287	110256	-12031	-9.8
2011-12	937199	857886	79313	-8.5%	130006	116191	-13815	-10.6
2012-13	995557	908652	86905	-8.7%	135453	123294	-12159	-9.0
2013-14	1002257	959829	42428	-4.2%	135918	129815	-6103	-4.5
2014-15	1068923	1030785	38138	-3.6%	148166	141160	-7006	-4.7
2015-16	1114408	1090850	23558	-2.1%	153366	148463	-4903	-3.2
2016-17	1142929	1135334	-7595	-0.7%	159542	156934	2608	-1.6
2017-18	1212134	1203567	-8567	-0.7%	164066	160752	-3314	-2.0
2018-19	1274595	1267526	-7070	-0.6%	177022	175528	-1494	-0.8
2019-20	1290247	1283690	-6557	-0.5%	183804	182533	-1271	-0.7

Source- Government of India (GOI), Ministry of Power (MOP) published data and website [1], [7],[8] Under the above background, where India is facing energy and peak power shortages, the falling Utilization Factors (PLF) of existing generating assets presents a unique dichotomy. This is one of the reasons that make this research very relevant. [7], [8]

1.6 THE BUSINESS PROBLEM AND MOTIVATION FOR RESEARCH

A phenomenon called Un- Requisitioned Surplus (URS) reveals and explains the business problem vividly. When the bulk power procuring entity (usually a Distribution company, Discom) does not requisition power that it had originally contracted to procure from a generating station - it results in the plant running on low PLF thus resulting in unsold electricity for the generator which is termed as Un-Requisitioned Surplus (URS). This is the electricity; the power producer was ready to generate but could not generate because the buyer did not requisition it. In 2019-20, in one year alone, the largest power producer of the country NTPC could not generate and sell more than 74000 MUs (URS) [14] of electricity whereas in the same year 0.5 % peak energy deficit and -0.7 % peak deficit was reported at the national level [1]. (*Demand and supply data as depicted above, clearly shows that India has always remained a power deficit nation. There exists, also, another substantial demand which is not yet accounted in the deficit calculation – demand where electricity has not reached the consumers like un-electrified households, un-electrified farms, and un-electrified remote rural areas. Such demand obviously remains out of this estimation.)*

This situation shows a clear paradox here – On one hand, there is Un-Requisitioned Surplus Electricity (Remaining unsold by the power producer), and on the other hand, electricity deficit persists in the country.

In the above backdrop, many new, modern technology, high efficiency, supercritical thermal power plants are either running at very low Utilization Factor (PLF) or are kept under Reserve Shut Down (RSD). To understand the problem in a better perspective, the example of Capacity Utilization (PLF) and Declared Capacity (DC) of plants (Coal cased) of NTPC, a Govt. of India company, which is the largest power producer in India is depicted below. The table shows the difference between PLF and DC of NTPC plants.

The Declared Capacity (DC) of a power plant is the capacity in percentage terms at which the plant is ready to generate power. DC is declared by the power-producing plant so that the power purchaser can send its requisition accordingly. Such requisition is called the Schedule. If the purchaser does not buy the full Declared Capacity (DC) of the plant it will result in the plant running at lower than the Declared Capacity (DC), hence the Utilization Factor (PLF) shall be lower than the DC. This difference creates the Un-Requisitioned Surplus (URS). The table below, shows clearly that NTPC plants were scheduled much below their Declared Capacity and PLF was below DC.[7], [8]

Table 1.5 : NTPC PLF and Declared Capacity

Year	PLF (%) (Coal Stations)	Declared Capacity (DC) (%)	Difference (DC-PLF)- %
2005-06	87.52	89.74	2.22
2006-07	89.43	91.12	1.69
2007-08	92.24	93.86	1.62
2008-09	91.14	92.23	1.09
2009-10	90.81	91.41	0.6
2010-11	88.29	91.67	3.38
2011-12	85.00	88.35	3.35
2012-13	83.08	87.62	4.54
2013-14	81.50	91.79	10.29
2014-15	80.23	88.69	8.46
2015-16	78.61	92.29	13.68
2016-17	78.59	92.88	14.29
2017-18	78.99	87.88	8.89
2018-19	76.81	87.63	10.82
2019-20	68.20	89.36	21.16

Source – NTPC Performance Data [7], [8], [14]

As can be noticed above, the difference between Declared Capacity and PLF for NTPC has increased from 2.22 % in the year 2005-06 to 21.16 % in the year 2019-20. This is a staggering increase and is worrisome. This means that that a significant portion of available coal based power was not sold/purchased, which created Unrequisitioned Surplus (URS) of power. This URS is a clear indicator of low-capacity utilization (PLF) of power plants.

This is the situation faced by country's largest and premier thermal power generator which runs power plants at high efficiency, adheres to all environmental norms, and produces relatively affordable power. The company's average cost of power was around Rs 3.38 per unit (about 4.5 Cents/Kwhr) in year 2018-19 [15]. Still, even with all these inherent strengths, in the year 2019-20, NTPC could not generate and sell about 74000 MUs (URS) of electricity. Other companies are facing even graver situation. [8]

The lower capacity utilization not only affects the top line (due to less units of electricity sold) it also hurts the bottom line of thermal generators. The price at which the generator sells power is regulated in India through two-part tariff (Fixed Charges + Energy Charges) [16]. The Energy Charges that a thermal power generator gets through tariff is based on presumption that it will operate at certain benchmark parameters (called the normative parameters), which are fixed by the regulator. Low utilisation (PLF) means that plant is operating at a suboptimal level with operating efficiency parameters lower or worse than the benchmark/normative limits. This will cause loss to the generator. [8]

For example, the regulator fixes the normative Heat Rate (which is a measure of efficiency of the plant) for each power plant. The Energy Charges that the thermal power generator will get reimbursed through tariff is based on the presumption that the power plant would be operating at the specified normative Heat Rate and Aux Power. If a power plant has to run at low PLF, it's efficiency will get reduced and there is strong possibility that the plant will run at an efficiency level which is worse than the normative value. This will result in losses for the power producer in terms of energy charges. The power producer will spend more on fuel per unit of electricity produced but will get less remuneration through energy charge as per tariff. Every unit sold in this situation will be at loss. [8]

Realising this difficulty, at the representation of thermal power generators, the regulator has permitted some allowance in the Heat Rate (normative) and other parameters so as to compensate the generators for such loss caused by low load operations. However, the allowances are still not adequate as the PLF is going down day by day.[8]

In this scenario, the thermal generators have been hit hard and there is seemingly no respite coming up on the horizon. Predictions at [2], [3] show that by 2022, the national average PLF might slip below 48%. This could create major financial difficulties for the thermal power plants. Most of the thermal power plants are built through debt equity ratio of 70:30. That means there is heavy exposure of banks and lending institutions (upto 70 -80 %) in these assets. If the PLFs keep on falling and thermal power produces fall in red, it can have disastrous consequences for the developers, lenders, employees, contractors and eventually the consumers. [8]

Under above backdrop of low utilisation of existing plants, additional coal-based power plants of nearly 62000 MW total capacity are in the pipeline in different stages [4],[5] (as on June 2021). Moreover, renewable energy sources (RES) capacity is also being added at a very fast rate in India.

The Renewable Energy Sources (RES), which get policy support and preference in energy dispatch (being environment friendly), are likely to push thermal generators PLF to even lower values. There is an imminent danger for thermal power sector.

The situation warrants that we identify the factors behind falling PLF of thermal power plants (which are valuable assets and essential for grid operation), and chart out remedial measures so that the power plant developers, policy making bodies, distribution companies, banks, consultants and other key stakeholders can take appropriate actions to manage the situation optimally. In this paper we explore various factors responsible for such situation, their future outlook and remedial action. [7], [8]

1.7 OUTLINE OF THESIS CHAPTERS

The thesis contains 09 Chapters.

Chapter 1 Deals with the context of the research, background information, the business problem and motivation for research.

Chapter 2 - Contains literature review, sub themes, detailed literature review, research gap and theoretical underpinning

Chapter 3 - Covers the research design, research objectives, research methodology, validity and reliability aspects.

Chapter 4 - Contains results of Objective I & II and discussion over the same.

Chapter 5 - Covers the technical and financial impact of falling PLF (Objective II)

Chapter 6 - Deals with global outlook of the thermal (coal based) power in countries like Australia, Germany, Indonesia, USA, Japan and China (Objective - III).

Chapter 7 - Contains development of recommendations/ remedial actions and their validation using Delphi Technique

Chapter 8 - Contains key findings, conclusions, final recommendations/ remedial actions.

Chapter 9 - Contains contribution to literature, limitation of this research and scope for further work.

References and Annexures follow thereafter.

1.8 CHAPTER SUMMARY

This chapter (Chapter 1) brings out how the national average PLF of coal based (thermal) plants is going down and why it is very important to look into this aspect. The chapter sets the context why we need to find out the reasons behind (factors) the falling Utilization Factor (PLF) and then find remedial measures so that policymakers, power plant developers, distribution companies, consultants, bankers and other key stakeholders can take appropriate action to manage the situation optimally.

2 CHAPTER 2- LITERATURE REVIEW, RESEARCH GAP AND THEORETICAL UNDERPINNING OF THIS REASERCH

2.1 CHAPTER OVERVIEW

This chapter presents the detailed literature review, sub themes, discussion on important work already done, the research gap and theoretical underpinning. The chapter explores in detail the relevant work already done in this arena and finds what more can be done. This chapter also identifies the theoretical underpinnings that will support this research. The chapter thus lays the foundation of this research.

2.2 LITERATURE REVIEW (SCOPE AND OVERVIEW)

Literature review consisted of study of published scholarly papers, papers published in reputed journals. Govt. policy documents, websites of Central Electricity Authority (CEA), Ministry of Power(MOP), NTPC, National Electricity Policy (NEP), Websites and publications of Regional Load Dispatch Centres, Govt of India (GOI)-Ministry of New and Renewable Energy(GOI, MNRE), Major conference proceedings, research papers, reports and articles from credible newspapers etc. ProQuest was used to access some scholarly articles and papers. Reference has also been taken own published works. [7], [8], [9]

Review of the literature reveals that substantial work has been carried out in the field of renewable energy and its integration in the grid. Some papers have covered the effect on thermal power particularly from the viewpoint of flexibilization caused due to integration of renewable energy.

Most papers have dealt with the merits of renewable energy and have looked into how these could be integrated into the grid and how this integration will impact coal-based plants. Some papers have also dealt with isolated factors responsible for falling PLF of thermal power.

Some reports and articles have indicated what factors could possibly be affecting thermal power Capacity Utilization Factor (PLF). For example, some reports suggest fuel (coal) availability may be a factor, whereas some say transmission constraint can be an issue, some say renewable energy is a factor, some point towards poor financial health of the distribution companies, while few indicate that improper demand forecasting has caused overcapacity of thermal power which might be affecting capacity utilization. These papers and reports helped in creating a shortlist of the factors on which we did focus group discussions. Based on the focus group discussions, we further created a well identified, comprehensive list of factors which might be affecting PLF of thermal power plants, particularly in Indian context. Further on, our research here has brought out as to which factors, among those shortlisted, are the major factors.

However, to the best of the knowledge of the researcher, any comprehensive scholarly work has not dealt with the subject matter in holistically as to which are the Major Factors which can affect the PLF of coal-based power plants in India, and what could be future scenario with suggestive remedial measures.

There are many newspaper reports predicting that PLFs of thermal power plants in India will fall substantially from the current levels of about 60%. [2], [3] predict that all the coal based thermal power plants need to get ready to witness a drastic drop in PLF to a level of nearly 48% by the year 2022. However, it is found that there is no scholarly work or systematic research to predict the PLFs in next five years.

Review of the literature about the global experience with respect to thermal power has been very useful in terms of formulating remedial action because India is going to face the situation that other countries are facing already. The entire Literature Review was divided into *Sub Themes* for better understanding and clarity. In the following section, the sub-themes-wise details of the literature review are presented. [8], [9]

2.3 SUB THEMES

Based on the domain of coverage, the papers were segregated in six sub themes.[7], [8],[9]

2.3.1 THEMATIC DIMENSIONS OF LITERATURE REVIEW

Following is the illustration and brief description of the six sub themes that emerged out.

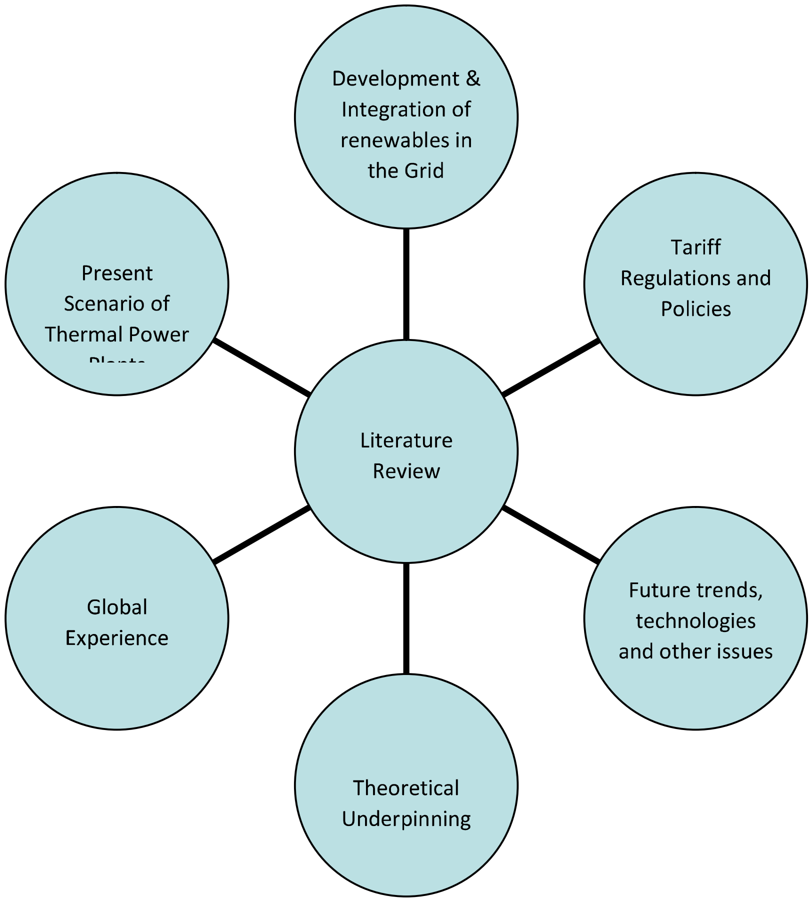


Chart C2.1- Graphical representation of sub themes of Literature Review
Source- Sub grouping the themes of Literature Review carried out in this research.

Sub Theme – 1 : Development & Integration of renewables- This theme gave a strong indication that Renewable Energy is being added in substantial quantity and at a fast pace and integration of renewables is affecting thermal power generation PLF in a major way.

Sub Theme - 2 : Tariff, Regulations and Policies- This sub-theme gave an understanding how new policies like Renewable Purchase Obligation (RPO), Ramp Rate etc are affecting thermal power generation.

Sub Theme - 3 : The present scenario of Thermal Power- This sub sub-theme gave clarity on how the PLF of thermal power is coming down in India, what issues the thermal power plants are facing, what is the present situation of PLF and what could be factors responsible for the same.

Sub Theme - 4 : The future trends, technologies and other issues affecting coal based Thermal Power Plants- This sub theme gives direction about what future has in store for thermal power plants, what can we expect in terms of PLF performance, what technologies will be required to keep the thermal power improve their performance.

Sub Theme - 5 : Global experience – Germany, China, Australia, South Africa, Indonesia, USA- This sub-theme gives valuable information about what is happening to PLF of coal based power plants in these countries, what are the strategies different countries are adopting to support thermal power, and if a decommission decision is taken how decommissioning of thermal is being done by different countries.

Sub Theme - 6 : Theoretical Underpinning- This sub theme gives valuable guidance about the sound theories and concepts that would underpin this research. At least five important theories give guiding light on this research which have discussed in detail in this research.

The study of literature divided in above **six sub themes** have helped immensely in the following –

1) Finding out the short list of probable factors affecting thermal power plants (coal based) in India. These factors formed inputs to our focus group discussions for identifying well defined variables for research questionnaire

2) Methodologies used for research by different researchers in similar research

3) Formulating Recommendations/Remedial Actions

4) Helped in confirming reliability and validity of this research

5) Giving strong theoretical underpinning for the research

Details of the Literature Review and Theoretical Underpinning have been covered in the next sections of this chapter.

2.4 SUB-THEME WISE LITERATURE REVIEW (A SELECTIVE PRESENTATION ONLY. TOTAL 125 PAPERS AND ARTICLES WERE REVIEWED, HERE ONLY SELECTED ARE PRESENTED)

Table 2.1: Table showing sub theme wise objective, coverage and gap of some selected papers/articles under Literature Review.[7], [8], [9]

Sub Theme - 1. Development & Integration of renewables in the grid					
Sl No	Short Title, Author & Publication	Month / Year	Objective	Coverage/Guidance	Gap
1.	Technical Report - Integrating Variable Renewable Energy:	Sept 2013	To find out how to integrate renewable energy in the Grid	How the fluctuations in energy supply can happen due to renewable energy- mainly due to Wind and Solar and how	Although it identifies renewable as a source of flexible operation requirement for

	Challenges and Solutions- Bird et al, NREL/TP-6A20-6045			additional flexibility will have to be imposed on other generators like thermal power	thermal, thus affecting PLF, the paper does not holistically cover what other factors could be affecting PLF of thermal power plants.
2.	Research Paper- Effect-of increased renewables. Eser et al, Elsevier, Applied Energy, Vol 164/15 Feb 2016, Pages 723-732	Feb 2016	To find out effect of renewable energy on thermal power	The paper says that the high quantum of renewables will cause an increase of 4–23% in the number of start- stops of thermal power units. The number of ramp up ramp down is also likely to increase by 63–181%. This is a valuable guide for our research.	While effects on thermal power ramp rates and start-ups/shutdowns have been studied, the effect on Utilization Factor is not studied.
3.	Technical Report – Back ground Paper on Distributed-Renewable-Energy-Generation (DREG) and Integration	Feb 2015	To bring out what can be learnt from the recent experiences in DREG installation and	It covers all the barriers (technical, economic, political and social) that involve the use of DREG. The paper discusses policy issues and options. Authors have mainly suggested policy and	Paper does not address effect of renewable energy on thermal power PLF.

	By Komor et al, TEC, UNFCCC, Bonn, Germany		integration.	other measures to promote Renewable Energy. Its effect on thermal power has also been mentioned but not in detail.	
4.	Technical Report - Flexible opn. of thermal power plants for integration of renewable generation- GOI, MOP, CEA Report	Jan 2019	To find out flexibilization requirements on thermal power plants due to addition of renewable energy	Effect on various modes of generation including coal based thermal plants, their scheduling , start up and shutdown requirements seasonal variations have been studied in detail.	This is a comprehensive work by CEA, Govt of India, covering details of ramp rate, start ups and shut down requirements. It has found that with BAU situation, coal-fired units will be under tremendous stress and may have to lower the generation level to the level of 26%, for which they are obviously not capable. Also, a 0.96% reduction in rate of addition of renewable energy can

					improve the Minimum Technical Load of coal-fired units from a low level of 25.73% to 45% on annual basis. This study is of major significance to our research here. However, effect on PLF have not been predicted.
5.	Research Paper- RE and its impact on thermal generation- , Claudio Marcantonini - Energy-Economics, Elsevier, Science Direct, Vol-66, Pg 421-430	Aug 2017	To find out effect on emissions of thermal power plants because of addition of renewable energy	The paper studies Italian power sector. It is mainly focussed on the effect on emissions of thermal power plants due to addition of renewables. They show that a 10% increase in solar and wind power in the grid has resulted in reduced CO2 emissions by about 2% compared to a thermal installation.	The paper is mainly focussed on the effect of renewables on thermal plants from the point of view of CO2 emissions.

6.	Research Paper- A Generalized Overview of Distributed Generation by Sweta & Mohamed Samir, International Journal of Emerging Research in Management & Technology	Dec 2013	To focus on the benefits of distributed generation for attaining sustainable development in approaching future	It focuses on the point that in future Distributed Generation will play an important role. The authors feel that the fuel availability is quite tough in developing countries like India, so renewable energy resources are more justifiable. The paper also predicts that thermal power will be less favoured in future.	It focuses mainly on the merits of renewables and the fact that fossil fuels are unsustainable. Paper does not address effect of renewable energy on thermal power.
7.	Research Paper- Distributed generation- a new approach by Kamal Kant Sharma, Dr Balwinder Singh, International Journal of Advanced Research in Computer	Oct 2012	To review Distributed Generation (DG) and its associated technologies, impacts of DG on various critical issues which are responsible for	This paper concludes that the integration of Distributed Generation impacts the power flows significantly and this new reality will require fresh and extensive load flow analysis.	The paper mainly focusses on technical challenges arising out of changed power flow patterns caused by renewable energy. Paper does not address effect of renewable energy on thermal power PLF.

	Engineering & Technology (IJARCET)		maintaining reliability and cost effectiveness.		
8.	Article- Decentralised distributed generation: An ideal mode for rural electrification by Anil Sardana, Coal Insights	Mar 2013	To emphasis on advantages of decentralised distributed generation	The paper discusses how Distributed Generation in India can be effectively used on stand-alone grid systems in rural and remote areas where grid connections are not possible or expensive. The paper also covers the challenges the DG puts on the thermal power plants.	The paper mainly discusses about mini grids. Does not address effect of renewable energy on thermal power PLF.
9.	Research paper – Issues-Challenges-Causes-Impacts and Utilization of RE Sources - by Sandhu et al Int. Journal of Enggg	Mar 2014	To present some issues and impacts related to grid integration of RES and their utilization.	It covers the role of consumer (load end) appliances for power quality and also covers energy storage for reducing the power fluctuations in PV systems. The paper does not touch upon effect on thermal	Paper covers the methods to reduce the fluctuation in grid due to renewable energy. However, the impact on thermal power is not covered.

	Research and Applications			power	
10.	Technical Report – Micro Gid Systems- Current Status & Challenges by Carpio et al, Univ of Sao Paulo & Control Engg ltd.	Not Men-tioned	To bring out the present status and of micro grid systems and the barriers in their integration to the network.	This paper covers the progress of the microgrid system supported by the regulations and standards available in India. The authors find that public utilities are apprehensive to integrate large scale renewable into the network until this becomes unavoidable.	This paper is mainly focussed on the problems faced in proliferation of renewable energy in the grid. Paper does not address the what will be impact on the PLF of thermal plants.
11.	Research Paper - Impact of Distributed Generation (DG) on Reliability of Distribution - System by Das et al, IOSR Journal of Electrical	Nov-Dec 2013	This paper focuses on the effect of REDG on reliability of distribution networks.	It covers the important role of and application of Distributed Generation. It also shows how the reliability of the distribution system can be improved.	This paper is more oriented on the impact of DG on the distribution system, does not discuss impact on thermal power

	and Electronics Engineering (IOSR-JEEE)				
12.	Research Paper - Assessment of DG in a deregulated power market scenario by Chanda et al, International Journal of Emerging - Technology and Advanced Engineering	Feb 2013	The authors have evaluated the future scope of DG and have studied its impact on the present electricity market scenario.	It presents a detailed analysis of the effect of advent of Distributed Generation in the existing power market mechanism. The authors have depicted this effect with the help of an index called Herfindahl-Hirschman-Index.	This paper does not address the effect of distributed generation or renewable energy on thermal power PLF because the main aim is to discuss DG and RE.
13.	Research Paper-Integrating DG into electric power systems, by Lopes et al, EPSR, Vol - 7, Issue-9,	July 2007	To present the issues related to integration of DG into electric power systems.	This paper, in particular, addresses the change in network planning and operational codes from the present plug-in-and-forget approach to integrated power systems approach.	Effect of renewable energy on thermal power has not been touched upon.

	Elsivier			Schemes like flexibilization of thermal power plants may be used to support integration and that is how the greater involvement of the DG in energy systems can be made possible.	
14.	Research Paper - Rural Electrification in India using Distributed Generation: Current Scenario, Government Initiatives, Regulatory & Technical Issues by Apoorva Saxena, Subhash Chandra, American Intl. Journal of Research	May 2013	To adopt a systematic approach to present the Government of India initiatives so far regarding rural electrification	The paper examines the efforts of Government of India in providing electricity to rural areas in last four decades. Having recognized the limitations of centralized energy supply systems, the paper talks about distributed generation as a viable alternative.	This paper does not address the effect of renewable energy on thermal power

	in Science, Technology, Engineering & Mathematics				
15.	Research Paper - RE resources and DG in India by Pandey et al, Intl. Journal of Advanced Research in Elect, Electronics and Instrumnt. Engg.	Dec 2013	To discuss the scenario for distributed generation with progress and achieveme nt so far in India	The paper finds that India is progressing well to pursue development of Distributed Generation along with unbundling of power sector. The country is also giving thrust on harnessing various forms of new and renewable energy.	An all-out increase in Distributed Generation has been advocated in this paper in complete disregard to effect on thermal power.
16.	Conference Paper- RE dev. in Indian Deregulated Power Mkt: Future-Aspects, by Y R Sood, and N K Sharma,	May 2014	To present the status, future plans, environme ntal footprints, supportive policies and strategies	The paper states that for the development of renewable energy in India, the renewable energy strategy must be integrated with the liberalization of the energy market. The authors advocate that in	This paper advocates liberalisation of markets and advocates free market competition in the power sector. However, power being a complex issue hands off

	2nd International Conf on Emerging Trends in Engg. and Technology		of renewable energy addition in India	order to effectively promote renewable energy, it is necessary to develop a market-based energy policy that provides a competitive environment while considering important factors in terms of energy security, environmental protection, and economic efficiency.	approach may not work.
17.	Article- Delhi's power Distribution Companies penalised by Delhi Electric Regulatory Commission -The Economic Times (ET), India	Oct 2019	To report how courts are penalising the purchasing entities for not meeting the obligations of RPO (Renewable Purchase Obligation)	The report informs Delhi Electric Regulatory Commission has slapped a penalty of Rs 1.71 Crores on the Distribution Company- Tata Power Delhi Distribution Limited (TPDDL) and Rs 2.88 Crores on both BSES Yamuna Power Limited (BYPL) and BSES Rajdhani Power Limited (BRPL) for not fulfilling the RPO	The report clearly brings out how regulatory and enforcement authorities are very strict on RPO. Such stringent provisions have significant impact on the future of Thermal Plants. However, the report does not touch the implications on Thermal Power.

				quota for three consecutive FYs.	

Sub Theme- 2. Tariff, Regulations and Policies					
Sl No	Short Title, Author & Publication	Month / Year	Objective	Coverage	Gap
1.	Technical Publication- CERC, New Delhi, (T&C of RE Tariff) CERC Regulations, 2012	Feb 2012	It contains the salient regulatory information on RE Tariff.	It covers technology specific parameters for renewable energy.	This paper does not address the effect of renewable energy on thermal power. It only covers the salient points of CERC Tariff determination RE Sources and .
2.	Technical Publication- CERC New Delhi, Ref- L-1/12/2010-CERC, Alok Kumar, CERC	Jan 2010	This document highlights the Terms and Conditions of CERC for Tariff of Renewable Energy Sources	It covers regulations for the development of market for Non-Conventional Energy Sources.	This paper from the regulator delas with renewable energy. However it does not address issues of thermal power. Sine all the sources are connected in the grid, regulation on one affects the other. The regulations meant

					to deal with renewable energy seem to completely other sources as to how they will be impacted.
3.	Technical Report- Decentralised Distributed Generation (DG), Iyer et al, India Infra Report	2010	To highlight renewable energy-based DDG programs.	It covers the Framework for DDG System Implementation. The paper mainly covers Implementation of Policy, Regulatory Frameworks and proposes a solution for management of DDG system Etc.	While suggesting the framework the paper does not touch upon effect of such changes on thermal power. The focus is mainly on DG.
4.	Technical Report- Guidelines for a Model RE Policy, Basu et al, Climate Parliament	Nov 2014	To present model for the states to formulate their RE policies.	It covers objective of the policy i.e.it should be clearly pointed out the specific aspects that the policy would like to focus on for the next five years in order to reach the target.it covers scope of the policy. Role of state nodal agency, target and goals of the policy and	This paper presents a policy model to promote renewable energy. It does not address issues of thermal power plants.

				technology, special focus on supply of rural energy.	
5.	Research Paper- Marginal Cost-Based Electricity Tariffs, Mark W. Gellerson, Deptt. of Economics, DSE, Univ. of Delhi, JSTOR.	Aug 2016	To highlight the Marginal Cost-Based Electricity Tariffs in India	It covers methods of calculating marginal cost and its comparison with existing tariffs etc.	This paper only talks about marginal costs in isolation, does not address how the costs might be affected due to interaction between different sources.
6.	Research Paper - Rural Electrification (RE) in India, Cust et al , SSRN, Electronic Journal.	Dec 2007	To find out how much demand exists for rural electricity services and what options are available and	It covers that in rural areas, access to electricity is insufficient. Authors find that there willingness to pay higher for better electricity supply. They further highlight few new initiatives to expand	The paper mainly espouses the case of Distributed Generation (DG). It does not address the effect of DG on thermal power.

			suitable for the same.	access. They point out that RE based DDG projects can help in significant reduction in load shedding and also the reduce and need for costly grid extension.	
7.	Govt Notification - Norms for installation of Flue Gas Desulphurisation (FGD) – Central Electricity Authority (CEA) publications	Dec 2015	Norms for pollution control in thermal power plants	New Norms for Emissions from thermal power plants	This paper talks about thermal power plants and how they will be impacted by emerging norms for environment like FGD. But it has not looked into how the norms will affect the capacity utilization and financial condition of thermal power plants
8.	Govt of India Paper- India's NDCs- Govt of India- UNFCCC	Sept 2015	To present the preface and details of India's Intended Nationally Determined	This is the commitment document of Govt of India(GOI) to UNFCCC about mitigation measures towards climate	This commitment of the country has major fallout for thermal power. This INDC is at the heart of energy transition happening in

			Contribution	change.	India.
09.	Regulator Notification - CERC Tariff Regulations 2014-19 & 1019-24	March 2019	To issue guidelines for Tariff for the period 2014-19 and 2019-2024	This are detailed guidelines from CERC for the Tariff of Thermal Power Plants	This is a detailed order on Tariff of Thermal Power. New provisions of Ramp up and Ramp down have been rate and related incentive/disincentive have been brought out in this regulation. The regulation does recognise that there will effect on thermal power in terms of load ramp up and ramp down but does not give any figures for future PLF levels.
10.	Technical Article- Government will advise utilities to close-down power-plants - Koundal et al, ET	Feb 2020	To bring about Govt's policy to close old thermal plants who are violating	The article describes the announcement made by Hon'ble Finance Minister in her budget speech about closure of old thermal power plants	This article gives a pointer towards Govt's intension to shut down old power plants. However, it does not address effect on PLF, Financials or any other

	Energy World		the clean air norms		parameters.
11.	Govt Notification - Guidelines for RPO - Ministry of Power- Govt of India	June 2018	To specify policy targets for purchasing of renewable power by the Distribution Companies in India	The target set for Renewable Purchase Obligation (RPO) is 21% by the year 2022. This target is further divided between solar and other than solar equally (i.e. 10.5 % + 10.5%).	This is an important regulation which will have heavy impact on PLF of thermal power plants. However, the Policy does not talk about impact on thermal power.
12	Regulator Notification - IEGC- CERC Notification Ref. L-1/18/2010	Main notification in 2010, and then amendments 2012, 2014, 2015 & 2016	To bring out Standard Operating Procedure as to how the grid constituents will operate	This is a comprehensive code which guides the operation of power systems in India. It covers in details various parameters, normative values for safe and efficient operation of power plant.	This code does acknowledge that the thermal power plants will get impacted due to renewable energy and gives certain margins in Heat Rate, APC and Start Up Cots in case of low loading factors and reserve shutdowns.

Sub Theme - 3. Present scenario of thermal power					
S. N	Short Title, Author & Publication	Month/ Year	Objective	Coverage	Gap
1.	Technical Article 35% of total thermal power capacity lying unused - Debjoy Sengupta, Technical Report- The Economic Times	Aug 2016	An overview on consumption of thermal power capacity in India.	It presents the average data of production and PLF of thermal power in India. The paper says that nearly 35% of the installed capacity i.e nearly 1,04,000MW, is lying idle at present. On top of it, the country added about 24,000 MW of fresh conventional capacity whereas 86000 MW is planned to be added by 2022. Under this backdrop, a total of 100000 MW of solar power is to be built by 2022. This will add to the woes of thermal and other power producers.	This paper support the work being done in this research. According to the report more than a third of India's thermal power capacity is lying unused while the rest is running at a slightly above 55% Utilization Factor mainly because of the lesser than expected demand. This report mentions that falling capacity utilization leads to losses and consequently the new power plants may find it difficult to service debt, which ultimately leads

					to such assets being non-performing assets at banks. This a paper which helps this research by giving valuable inputs. However, it does not bring out all the possible factors that might be resulting in low utilization of thermal power, (except low demand)
2.	Research Paper- Changing Role of Coal-Fired Power Plants- N K Gupta, International Research Journal of Engineering and Technology (IRJET)	Mar 2017	To bring out the impact of flexible operation on the performance and reliability of coal-fired units.	This paper addresses the concerns of thermal power plants. It covers the need to usher into flexible operation regime and introduce better preventive maintenance practices. It argues that coal-fired power plants need to adopt best operation practices. It also says that new plants	This paper brings out merits of thermal power plants with respect to reliability and robustness as compared to RE sources coal-fired power plants. The paper partly covers the effect of renewables on thermal power (technical area). However, it does

				should be designed better flexibilization capabilities.	not give future strategic roadmap for thermal power generators.
3.	Technical Paper - Disruptive Challenges: - Changing Retail Electric Business, Peter Kind Energy Infrastructure Advocates, Prepared for: Edison Electric Institute	Jan 2013	To discuss how the federal and state policies are not in sync with the needs of investors, customers, power producers and other stakeholders particularly with reference to last mile distribution level tariff structures.	It covers Strategic Considerations, Corporate Finance structures, Financial Market Realities and Financial Implications of Disruptive Forces and presents some industrial examples.	Paper looks at the beginning of customer disruption in the electricity industry and stresses the need of proactive approach It argues that all stakeholders have to accept and adopt the changes in technology and business models in so that the utility industry remains viable. The paper, in a way, supports the view that thermal power should also be taken care for their survival because they form an important part of the energy infrastructure.

4.	Research Paper- Performance of Coal Based Thermal Power Plants - Umrao et al Global Journal of Technology & Optimization	Jan 2017	The paper analyses the performance of a 210 MW power plant at various loads The paper then brings put how the deviations in terms of actual values of boiler efficiency, specific Coal Heat Rate and overall Efficiency are compared to design values.	The paper brings out effect on coal consumption because of deterioration in efficiency of thermal power units caused by lowering of load. About 2681 MT of additional coal is burnt additionally resulting in additional Rs 67 Lacs of additional costs, which is caused by deterioration in boiler efficiency if plant runs at part load.	This paper mainly lays emphasis at performance of coal based thermal power plant on part load operations. It covers an important aspect of deterioration of efficiency parameters due to part load. It does not cover other effects on thermal power.
5.	Technical Report - Dispelling Myths: Coal cannot be	Sep 2016	To highlight threats posed by RE for	The paper covers that coal plants can provide sufficient flexibility to integrate renewables. The	This paper discusses the current threat posed by renewables on

	cycled– Technical Report, Shakti Sustainable Energy Foundation		thermal power	authors are of the opinion that the flexibility of thermal power plants is not fully utilised and it can be exploited more.	thermal power mainly from the point of view of variability of the load pattern. However, it does not address what thermal power generators should do in future.
6.	Technical Article- Renewable push may hit thermal power plants: Experts - Sarita Singh, The Economic Times	Sep 2016	To highlight the data of impact of renewable energy on thermal power plant.	The article underlines the fear that addition of RE in large quantities will further erode the profit margins of thermal power projects. As per CEA projections, the average PLF may drop below 50% by 2021-22 if RE addition plans go as per target and the 50,000 MW of thermal power capacity which is in pipeline, comes on stream.	This report discusses the impact of adding renewable energy on thermal power and says that renewable energy is causing lower capacity utilization of thermal power. From this point of view, it is a very useful report. However, it, does not cover what thermal power generators should do in future.
7.	Technical Report - The disruptive	Apr 2014	To highlight the	It covers the economic aspects of RE addition like -	The paper covers broader management

	potential of solar power - David Frankel, Kenneth Ostrowski, and Dickon Pinner, McKinsey		economics of solar power	economic fundamentals, consumption and investment coming up in renewable sector.	implications and economics of solar generation. It says that as solar becomes cheaper with passage of time, it can pose greater threat to thermal power. However, this work does not explain the effect of solar power over thermal power plants, utility of thermal power and future trend.
8.	The future role for thermal generation, Power, Niina Honkasalo, Engineering International (EI)	May 2015	To highlight the need of thermal power plant in spite of massive addition of renewable energy	It advocates the need of thermal power plant. As per the authors thermal power has a key role in maintaining system stability. Particularly during sudden and unexpected generation loss or network fault, stability of the grid comes in danger. In such conditions,	It advocates need of thermal power plants for system reliability. However, it does not explain the effect on thermal power plant PLF. This is a helpful paper and gives direction for recommendations.

				thermal generation plays crucial role because: it provide support inertial response or fast frequency power recovery. In this fashion thermal power can help stabilize the power network. The paper also says that thermal power generation has entered an era of major change wherein it has to adjust to the "new rules of the game" by providing new kinds of services, and at the same time improving on various fronts like efficiency, flexibility, environment, and competitiveness.	
9.	Technical Article- Are India's Thermal - Power - Plants Running	July 2017	To highlight the challenges being faced by thermal power	The article opines that over-capacity of generation and less demand has resulted in this situation where thermal power plants are facing	It takes a partial view of effect of high supply and low demand of power affecting thermal power stations. However,

	Out- of-Steam? Business World		plants.	difficulty.	as part of exploratory research, this article helps in identifying some factors affecting PLF of thermal plants (Overcapacity, Low Demand)
10.	Technical Article- Power: Low PLF, high demand- Financial Express	June 16, 2015	To highlight the growth and decline of thermal power generation.	It reports how the PLF of thermal units - coal and gas- have come down in in the FY15 reaching the lowest level in 15 years.	The reason attributed for drop in PLF is the slowdown in Indian economy which has impacted the demand growth. The paper brings out one important factor- Slower demand growth than expected, which could be responsible for falling PLF of thermal plants. However, it does not cover other aspects affecting thermal power and no roadmap for

					future is indicated in the paper.
11.	Technical Article- What's killing India's giant coal power plants? Devjyot Ghoshal Quartz Publication	May 04, 2017	To highlight the reason for decline of India's giant coal power plants.	It covers how the slow economic growth and steep drop in the prices of renewable energy, are causing huge hit to coal-based power generation etc.	Looks at two aspects (i) Sluggish demand (ii) Drop in prices of Renewable Energy. Does not cover other aspects and there is no roadmap for future.
12	Govt Notification - National Electricity Plan (Draft)-CEA	Dec 2016	To highlight the report of CEA on coal fired power plant.	CEA has done demand and supply projections for 2022 and has tried to cover some of the key aspects of effect on thermal power and its future planning	This report stresses that new thermal (coal) power plants addition should be halted for the period on 2017-22. This study has done projections and sensitivity analysis for renewable and thermal power. This is a very valuable work for this research. However, this work has also missed some of

					the factors like coal availability, health of Discoms, global experience etc.
13.	Research Project - Greening the Grid- USAID and MOP, Govt of India	June 2017	Pathways to integrate 175 of Renewable by 2022	This is a comprehensive work on integration of renewable energy covering the policy aspects, operational aspects, costs aspects, technological issues etc for renewable energy. This work uses modern power system planning tools.	This work has served as a major guide for this research work. It is a joint and substantial project of USAID, Ministry of Power, and Govt of India. It contains several scenarios and discusses in detail what could be the alternatives for future capacity addition in India. This paper is helpful in this research as it gives a roadmap for future for the optimum capacity mix which gives support to this work. However, this work is also

					primarily looking at integration of renewable energy and bears a renewable energy promotion perspective. Like most of the scholarly works and projects in this area, this work also looks at Greening the grid through renewable energy rather than looking at the thermal power perspective.

14.	Technical Report - Low Demand and Financial Health of State DISCOM Forces MAHAGENCO Shut Down Power Projects – Solar Not Affected, Mercom India	Sep 2016	To highlight the plight of thermal power plants in Maharashtra	The article says that falling price of solar, remote location of thermal plants, difficulty and fuel transportation are causing thermal power to shut down.	The article says that poor financial health of Discoms is one of the factors why thermal power plants are getting shut down. The article helps in identification of two factors that might be affecting PLF of thermal power plants (Low demand and poor health of state Discoms)
15.	Technical Article - Lack of Trans. Cap. is hampering the growth of India's elect. mkt- Live mint	Jan 2016	To highlight the effect of power evacuation constraints on electricity market	This article argues that the growth of India's electricity market is getting affected due to limitations of transmission capacities. The report brings out that an estimated 5,591 MUs of electricity could not be cleared by the country's energy exchanges due to the	The article identifies that lack of sufficient evacuation capacities is one of the reasons for lower utilization of capacity. But it does not talk about other factors.

				lack of a transmission network	
16.	Technical Report - Understanding India's Power Capacity- Surplus or not? Tabish et al- Brookings	Aug 2019	To analyse the current situation of demand and supply of power in India	The report says that India has reached a stage where it has excess capacity. The minor shortages are actually because of technical reasons and high T& Losses	The report gives good insight into the demand supply situation and indicates some of the factors responsible for loss/surplus. However, the projections for future have not been made.
17.	Technical Article- India's-coal-sector-output-is-back-in-the-black, Ankit Saproo- ET- Economic Times	Jan 2020	To report t About the signs of recovery in the coal sector.	This article describes how coal sector is showing signs of recovery. It also describes how the coal sector has been opened up and how it is going to benefit the production capacity.	The article shows that coal sector is improving. This work is helpful in our research because it helps in discussion on the availability of coal which is one of the factors affecting thermal PLF as identified during exploratory research. However, the fact remains that only the coal availability does

					not determine how the thermal power sector will behave.
18.	Technical Article- How the economic slow down- has dented India's-power-sector- Adi et al, ET, Energy World	Jan 2020	To point out how the country's economic woes are affecting the power sector	How the lower rate of GDP growth affecting demand and how it is affecting power demand also	This article shows the impact on demand which is a major driver for PLF of thermal power plants.
19.	Research Paper- Financial sustainability of Indian power sector. - Bhardwaj, et al Integrative-Business and Economics-Research	2020	To bring about the financial condition of distribution companies (Discoms) in India	The paper deals with staggering losses, high debt and financial woes of the Discoms	The financial condition of Discoms is a factor affecting thermal power plants because the Discoms are basically the "customers" for the thermal power. This paper helps in identifying one of the factors as part of exploratory research.

20.	Research Paper- Measuring productivity change in Indian coal-fired Elect. Gen.- Singh, et al. International Journal of Energy Sector Management ISSN: 1750-6220	April 2013	To find out how the Indian coal-based electricity generation is doing in terms of capacity utilization	This paper presents the changes in productivity levels of 25 public sector coal-based power plants in India, between 2003 to 2010. Authors have recommended policies to increase the productivity of power plants. DEA-based MPI model has been used in the study.	As per this paper- ageing of plants and lack of R&M could be a factor responsible for low PLF. However, a comprehensive view of all the factors responsible is not presented in the paper.
21.	Research Paper - Generalised congestion of power systems - Xue, et al *Journal of Modern Power Systems and Clean Energy*	2013	To bring about the vulnerabilities of evacuation system in Indian grid	The paper deals with transmission constraints and consequent dangers of black out	This paper brings out evacuation constraint as one of the reasons of low utilization factor of thermal units. However, a comprehensive view of all the factors responsible are not covered in this work.

22.	Article- Thermal power plants hit by Coal Shortage, Twesh Mishra, The Hindu Business line (2018, January 09)	Jan 2018	To point out the coal shortage affecting PLF of thermal power plants	The article talks about 'supply constraints' affecting thermal power plants. It points out how several plants had faced major coal shortages.	It clearly brings out coal shortage as one factor which affects coal power plants. However, as with other papers and articles, the article is limited to one factor.
23.	Article- Power Pipeline: - Over 20,000 MW of projects face an uncertain fut ure. Anupam Chatterjee, The Financial Express.	Feb 2018	To point out about low growth in demand and overcapacit y in thermal power	The paper brings out how the sluggish growth in demand for power and overcapacity of thermal power, has resulted into a situation wherein the fate of more than 20,000 MW of upcoming coal-based projects seems uncertain.	The article points about two factors- low growth in demand and overcapacity of thermal power. These were used in this research for finding out if these are really among Major Factors affecting thermal power PLF.

24.	Article- Thermal power sector starts seeing gains, R Sree Ram, The Mint.	Jun 2018	To report recovery in thermal power PLF due to improved coal availability	The article says that if demand rises and coal stock improves, the PLFs will recover	The article gives guidance for this research by pointing out two factors- Power Demand and Coal Availability
25.	Article- Power plant load slips, Ruchita Prasad, The Economic Times	Jul 2015	To illustrate how power demand is important for PLF	The article shows how the aggressive capacity addition has aggravated problems for the IPPs and subdued demand has caused low PLF of thermal power plants.	It is an important article for this research because it points out two specific factor affecting thermal power PLF (Overcapacity and low demand growth)
26.	Research Paper- A novel approach for UI charge reduction, Journal of Electrical System and Information Technology Science Direct, Pujara et al,	Sept 2017	Use of advanced techno commercial software in power plants	This paper presents a new model for frequency control. A new type of circuit is presented in the paper which considers prioritization of loads depending on their importance. This circuit uses Advanced Metering Infrastructure (AMI).	It shows how power plants are adopting modern techno commercial software

	Volume 4, Issue 2, Pages 338-346				
27.	Article- India's 269 thermal power plants aren't just polluting air- Rishika Pardikar, IndiaSpend.com.	Sep 2019	Water scarcity caused by thermal power plants	Huge amount of water consumption by thermal power is causing water-stress, for households, agriculture and industries. In some cases scarcity of water results in shutting-down of the thermal plants. The paper further says that nearly 40% of thermal plants in India are located in areas that are facing water shortages.	This article helps in identifying problems being faced/created by thermal power plants. Water consumption being one such big problem. It helps in identifying one of the possible factors (Water scarcity) affecting PLF of thermal power plants.
28.	Article- Over-capacity, water shortage and renewable power exerts pressure on thermal power plants- ET	Sep 2019	Problems being faced by thermal power	The paper brings out three factors that might be responsible for low PLF of thermal plants – (i) Over-capacity, (ii) water scarcity and (iii) addition of RE.	The article gives guidance about three probable factors (Over-capacity, (ii) water scarcity and (iii) addition of RE). affecting thermal power plants. However, it does not throw any

	Bureau - D. Sengupta				light on other factors.
29.	Article- Digitization and Analytics in Power Plants - Power Magazine	Feb 2019	Impact of digitisation on utility earnings.	Advanced software and digitisation could help in achieving better PLF by predictive analytics, monitoring, and integrating key data into plans.	The article points out towards techno commercial software usage. It does not however holistically cover problems faced by thermal power plants.
Sub Theme- 4. The future trends, technologies and other issues affecting coal based thermal power plants					
S. N.	Short Title, Author & Publication	Month/ Year	Objective	Coverage	Gap
1.	Research Article- The Future of Coal, Ansolabehere et al, MIT, USA	2007	To examine how the world uses coal and how it faces significant issues like CO 2 and other GHG emissions.	It covers the role of Coal based generation in installed capacity growth and greenhouse emissions, Carbon Sequestration and Coal Consumption in India and China. It also points out towards society's attitudes toward	It discusses the harmful effects of coal and related emissions. Does not say what we should do for future in terms of thermal power, particularly in Indian situation.

				Global Warming, and Carbon Taxes etc.	
2.	Policy document- Cost and United States public policy for new coal power plants Hamilton et al, Science Direct	Feb 2009	To present a financial analysis of supercritical plants that are provided with Carbon Capture and Sequestrati on (CCS).	It presents financial calculations regarding carbon capture technologies to be provided for supercritical technology based coal plants and compares the differences between a plant with carbon capture technologies and another one without it.	Talks about the cost of emerging technologies like Capturing the Carbon and its Sequestration (CCS). However, the paper does not give any roadmap as to how it will affect future of thermal power plants.
3.	Research Article- Dark future for coal-based plants – The independentb d.com, Panorama, N Sai Siddhartha	Jan 2016	To highlight serious concerns over the viability of coal-fired plants	It covers how, over the past two plan periods (between 2002 and 2012), India's coal-based power plants have increased (almost doubled in capacity) and currently stand at 160 gigawatt or GW (60 per cent of total). It Highlights the environmental concerns due to	Paper says that growing environmental concerns show a dark future for coal-based power plants. However the paper does not look at other critical aspects affecting the coal power plants and also does not not suggest any road

				thermal power, concern over water consumption, impacts of fly ash disposal etc. on the environment	map.
4	Article- Future of India's Green Fund - ET Editorials, The Economic Times.	Dec 2019	How the coal cess will be used for transition to renewable energy	It says that coal will be taxed (cess will be levied) and the cess will be used for supporting renewable energy	How this will affect thermal power has not been discussed
5.	Article- Coal going from winner to loser, Reuters, ET Energy World.	Feb 2019	To assess the competitive ness of coal-based generation Vis a Vis renewables	It says that coal is losing the battle because coal based electricity is being costlier, even costlier than renewable energy	It depicts a difficult future for coal but does not give projections or roadmap.
6.	Article- The last coal power plant in India can be closed by 2050- Down to Earth, Energy, Chandra	Oct 2017	To predict about future of thermal power plants in India	The paper suggests that there will be major changes in the manner world produces and consumes energy. There is a strong possibility that the conventional energy	The paper predicts the closure of thermal power plants by 2050. It does give indicators for future of thermal power plants. However, it does

	Bhushan			plants being erected now would be have to be abandoned even before their economic life is over. China is already experiencing this.	not cover the factors responsible and the effect on PLF.
7.	Article- New coal-fired power plants in India IEEFA- ET Energy World, Aarushi Kaundal	June 2021	What is the fate of new power plants in India.	The article says that as per IEEFA projections, about 33000 MW of coal-plants currently under construction and additional 29000 in the planning stage are likely to go stranded because of competition from renewables.	The article supports this work in the sense that it gives one strong reason why thermal power utilization will get affected.
8.	Research Paper- Cost analysis of a coal-fired power plant, Kumar et al (2015), Jour nal of Indl. Engg.	June 2015	A detailed cost modeling on the effect of PLF.	This is a comprehensive work, which analyses the effect of low PLF on the operating costs, revenues and equipment life. Authors find that PLF has a direct bearing on earnings and hence on its Net Present Value.	This study supports the work being done in this research because it shows how PLF affects the NPV.

9.	Research Report- The Western Wind and Solar Integration Lew et al (Technical Report, NREL.	Sept 2013	To study the costs of flexibilization	The paper shows that flexibilization costs of thermal power plants include costs due to incremental fuel requirements and enhanced O&M costs caused by additional wear and tear of the machines.	This paper brings out costs involved due to flexibilization and thus supports the work being done in this research.

10	Research Paper- Cost-Benefit Analysis of Flexibility Retrofits for Coal and Gas-Fuelled Power Plants. Venkataraman et al , U.S. Department of Energy Office of Scientific and Tech Information.	Dec 2013	The paper presents how investments in flexibilizati-on technologies benefit the thermal power plants.	The authors bring about the cost benefit analysis of flexibilization retrofits. The cost-benefit analysis has been performed by running Plexos software with and without the retrofits on selected power plants.	This paper brings out costs involved in retrofits for flexibilization and thus supports the work being done in this research.

11	Research Paper- Lit. Rev. Cycling- Cost in a Power System, Wu et al, Science Direct Books and Journals, Energy Procedia.	Jan 2019	To bring out parameters that get affected due to flexibilization of the plants.	They opine that coal-fired units are originally designed for baseload operations and may suffer great losses as their operation mode changes. Losses happen in terms of Variable Operations & Maintenance Cost.	This work helps in the current research from the view point that it shows how O&M costs get affected.

	Sub Theme -5. Global experience – Germany, China, Australia, South Africa, Indonesia, USA				
S. N.	Short Title, Author & Publication	Month / Year	Objective	Coverage	Gap

1.	Report- Government has no plans to build coal-fired power station, says Josh Frydenberg Energy Minister of Australia- **Australia**	NA	It covers the government decisions to support coal-fired plants.	It covers what the Energy Minister has to say for not supporting coal fired power systems and it covers that coal fired plants should be judged on its merit. Shows a hands off approach of Govt.	Australia is looking at reducing investment in thermal power because renewable energy is being promoted in big way. It does not give a roadmap, particularly for Indian situation.
2.	Report- Building new coal-fired power stations should be market's decision says, Malcolm Turnbull- **Australia.**	NA	This article It covers the government decisions to support coal-fired plants	It covers what pm says for not supporting coal fired power systems and it also covers the market agenda in no planning of coal fired plants.	This article draws attention about problems being faced by thermal energy
3.	Report - Beijing shuts last coal power plant, Phys Org- **China**	Mar 2017	To highlight the steps taken by Beijing government to make their skies	It reports how Beijing has realised its five-year clean air action plan prepared in 2013 and how it has become the country's first city where all the power plants are fired	In this particular paper the pollution arising out coal plants has been discussed. It says that Beijing is closing down thermal plants due to environmental

			blue	by natural gas.	concerns
4.	Report- China's war on coal continues — the country just cancelled 104 new coal plants- Brad Plumer, **China**	Jan 2017	It highlights how clean energy movement in China is hindering setting up of new thermal power plants.	Report mainly emphasis on China's efforts towards global warming. The country has been making heavy investments in green energy. China is planning to add 130 GW of wind and solar by 2020. It has also announced cancellation of 104 new thermal power plants.	It says that China is cancelling new power plants due to **pollution concerns.** It helps in identifying one of the factors responsible for drop in PLF.
5.	Report- If China is so committed to RE, why are so many new Coal Plants are being built? By Shepard W, Forbes Contributors **China**	July 2016	To highlight the issues of building new coal plants in China.	It covers the situation in China. The report says that coal plants still have a strong position even when substantial amount of renewable energy is being added in the country.	It covers efforts to make skies pollution free and development of new renewable sources. But it does not highlight issues arising for thermal power generators.

6.	Report- Powering your world, Integrated report, Eskom, - **South Africa**	Mar 2016	To highlight integrated report on powering in the world	It covers the aspects like Plant performance and sustainability from different angles like (i) Economical sustainability (ii) Customer sustainability (iii) Operational Sustainability (iv) Environmental and climate change sustainability and (v) Social sustainability etc.	It is a comprehensive work concerning sustainability and advocated energy mix based on the sustainability concepts. This report does not address the connection between renewable energy and thermal power.
7.	Research Report- Flexibility Concepts, Leopoldina Acatech, Union **Germany**	Feb 2016	To describe and compare different ways of ensuring a stable power supply in the age of renewable energies	This paper covers futuristic flexibility options, different scenarios an overview of Flexibility technologies for The power supply in 2050. etc	The papers says that renewable energy will result in ramping up and ramping down of load in thermal power plants. It supports our research by providing one important factor (RE) that affects thermal power plant's PLF. However, the paper is only

					focused on flexibilization option and does not cover other aspects.
8.	German utilities and the Energiewende by Appunn et al, Clean Energy Wire CLEW- **Germany**	Jan 2015	To highlight all the aspect of power production and policy draw- back in Germany	It covers the data of four big suppliers regarding renewable development in Germany. These four big producers are - EnBW, RWE, E.ON and Vattenfall –	Criticises some policy drawbacks creating difficulties in Germany. However, it does not explain effect on future and Utilization Factor of thermal power stations.
9.	Research Report- Energy Transition by Morris et al, Heinrich Böll Foundation- **Germany**	Jan 2014	To highlight the need of transition to renewable energy in Germany	It covers the reasons for transition, technology adoption for consumption of renewable energy like wind power, biomass etc	It does not explain effect of renewable energy on future and PLF of thermal power stations

10.	Article- Coal-Fired Power-Plants: Important in United States Future by The Associated Press **USA**	June 2017	To highlight that coal plants, have an important role to play in energy supply in USA	The report is based on a statement from the Energy Secretary of USA, about how the coal-based power plants are important for the future of the country.	This report says that coal plants have an important role to play and must be kept on stream to spark demand and growth. This is a valuable input for this research work.
11.	Research Report- Reducing emissions - Burnard et al IEA- **Indonesia**	2016	Reducing the coal fired generation emission	The paper talks about generation mix planning and maintains that coal has a dominant presence	Paper speaks about enhancing thermal power generation with pollution control should be the strategy for future. However it does not cover aspects like effect of renewables, low demand etc.
12.	Research Paper- Scenario analysis in the electric power industry in China, Wang	2019	To project various scenarios in the electricity sector in China under	Authors have done scenario planning in China against various projected assumptions	This is a relevant work for guidance of this research but the findings are very specific to China

	et al Energies- **China**		market reforms backdrop		
13.	Research Paper- The environmental effect of capacity utilization, Wang et al, Env. Science and Pollution Research International, **China**	2019	To bring about the impact of capacity utilization on pollution created thermal power	Authors have presented the effect of changes capacity utilization of thermal power plant on the emissions	This is a very relevant research from China. However it concentrates only on the environmental factor which not included in the objectives of the current research.
14.	Research paper- Analysis of hourly generation patterns at large coal-fired units USA- Robert, K. S. - Journal of Modern Power Systems and Clean Energy **USA**	2019	To bring about how the coal - fired thermal units are being affected because of the renewable energy in the USA	The article describes how the thermal power are becoming a load following station from base load stations	This paper brings out the affect on thermal power and they are undergoing cyclic operation. This research pertains to USA. Research needs to be done in Indian context.

15.	Research paper- Demand for flexibility improvement of thermal power plant, Luo et al, Env. Sc. and Pollution Research International- **China.**	2019	To bring out the effect of Wind Power on flexibility requirements in the Grid.	This paper studies how the wind energy affects thermal power and what will be scenario when proportion of renewable energy increases in the Grid.	The study looks at mainly the effect of wind energy on the power system and consequent effect on remaining sources of generation. The study mainly focuses on wind power.
16.	Research paper- Modelling and optimisation of thermal power- Liao et al, Energies- **China**	2015	To bring out the issues in optimum utilization of thermal power in the medium term.	Howe the thermal power can be utilised in the medium term in view of large-scale integration if renewables	This paper looks at the utilization of thermal power at the medium-term perspective. Authors have suggested a novel scheme by the name MOCTU. The model suggests ways to reduce start-up and close-down times of thermal units. This paper suggests that flexible operation regime is imperative for coal

					based conventional units.
17.	Article- The Demise of Coal- M. Narayan, Energy Networks Australia, Energy Insider, **Australia**	Jul 2019	To study how Australia plans the closure of thermal power plants.	The paper brings out how, in the year 2018, phasing out of coal plants has happened at a fast rate pace across the globe. The year 2018 saw third highest quantum of decommissioning.	The paper suggests that closure of thermal plants will be inevitable as ageing plants become less and less efficient and more and more polluting
18.	Article- Future of US Coal based power will be one of small, technology-driven units- Andrew Fawthrop-N S Energy **USA**	Mar 2020	To study the future trends of thermal power plants in USA.	Government is funding research and development of small capacity, flexible, cleaner power plants that will characterise the future of the industry.	The report gives a good guidance about what kind of plants can come up in future. However, it does not address as to what will happen to existing plants.
19.	Article- A week after shutting its coal-fired plants Germany	April 2021	To bring out what can happen if thermal power plants are	Paper shows that 11 power plants totalling a capacity 4700 MW were decommissioned on January 1, 2021 in	The article clearly brings out the perils of shutting down thermal power plants too early without

	forced to reopen them- Peter Rudling, Energy Education- **Germany**		shut down without proper substitute generation.	Germany. However, this phasing out created emergency within 8 days, following which many thermal power plants were required to be put back into service to sustain the grid.	developing a proper substitute. This article supports the work being done in this research.

Sub Theme 6 - Literature Review on Theoretical Underpinning					
S. N.	Short Title, Author & Publication	Month / Year	Objective	Coverage	Gap
1.	Article- What is disruptive innovation- Harvard Business Review- Catharine Cote	Sept 2020	Explain the phenomena of Disruptive Innovation	Disruptive innovations originate in two types of markets that that established players may overlook. Established players put attention on customers from where most of the profits come. They tend to better their products and services for such segments. In the process, they may	There is already enough confusion about what a disruptive innovation is. The applicability of this theory for situation like emergence of Renewable Power against Thermal Power cannot be established within or outside the definition of Disruptive

				forget about other customer segments. A new company might do exactly that. It may come up with solutions for other customers who are less demanding and less profitable, a so called low end customer. A low-end customer is thus presented with a "good" product that becomes a success and later challenges the established companies.	Innovation
2.	Article- How Useful Is Christensen's Theory of Disruptive Innovation?- Steve Denning, Forbes	Oct 2015	To discuss usefulness of theory of disruptive innovation	The article presents a comprehensive explanation of Clayton Christensen's theory of disruption.	The paper does not address whether a situation like Renewal Vs Thermal falls under the theory, supports or negates it.
3.	Research Article- Debating	Mar 2016	To critically examine	The article critically examines the validity and use of Theory of	The article explains the way in which disruptive

	Disruptive Innovation Juan Pablo Vázquez Sampere, Martin J. Bienenstock, and Ezra W. Zuckerman, MIT Sloan		Disruptive Innovation	Disruptive Innovation.	innovations emerge- When a seemingly low end customer is presented with a "just good" product that is cheaper, fulfils a need and can challenge the established companies.
4.	Article- Why Porter Model no longer works	Feb 2012	To critically examine the applicability of Porters various management models.	Covers contrarian views on most of the Porters theories including Value Chain, Generic Vs Differentiated positioning model	The fitment of the our situation of electricity generation either through cost leadership or through differentiation needs discussion

5.	Research Article- A critique of porter's strategies Y. Datta, Ph.D., State University of New York at Buffalo, USA	2009	To critically examine the applicability of Michael Porter's Cost Leadership and Differentiation Strategy	The authors argue that lower-cost and differentiated can both coexist, they are not necessarily be either or strategies.	The articles opens up a question relevant to our research- Whether differentiation strategy can work in product like electricity? Or Cost leadership is the only option ?
6.	Research Article- What is Strategy Michael Porter, HBR	Dec 1996	To bring forth the key concepts of Competitive Advantage	Several profound, path breaking concepts in Strategy are covered in this famous article of Porter	There are products like Automobile where differentiation can work, then there are products like cement where cost leadership can work. But what about product like electricity?
7.	Research Article- The Resource-based theory of competitive advantage: implications	1995	To explore sources of competitive advantage	Link between Strategy and Internal Resources	Whether superior resources will always remain source of competitive advantage?

	for strategy formulation Grant Robert M., California Management Review				
8.	Report- Capacity and Capacity Utilization- FAO, Washington, DC 20037, USA	Not menti oned	To find out the definitions and concepts related to capacity utilization.	Defines the technical and economic view of capacity utilization and how capacity utilization can affect investment.	The definition is helpful as theoretical underpinning.
9.	Research Article- Capacity utilization, Berndt et al, The American Economic Review.	May 1981	To discuss how capacity utilisation can affect investments	Investment in a particular technology may get affected due to low-capacity utilizations.	This is a helpful theory and forms theoretical underpinning for our research
10 .	Policy Paper- Policy Analysis: Concepts and Practice, p. 13- David l.	Book	When governmen ts intervene in the markets	The book says that when private interests fail in efficient distribution of goods, govt intervenes	This work is related to the current research where we find unequitable distribution of energy sources and

	Weimar and Aidan R. Vining				recommend that Govt/Policy makers should intervene to see that capacity utilization of thermal power stations remains at sustainable level.
11.	Research Article- Theory of Public Expenditure, Paul A Samuelson	Nov 1954 & Nov 1955	To explore how markets behave in terms of public expenditure	This work extensively discusses about the factors that might cause Market Failure	It is a useful theory and helps as underpinning of research. We find that some elements, which Samuelson brought out are present in electricity market in India and which might cause market failure. We find that information asymmetry and negative public perception are present in electricity market and we further recommend that holistic intervention of Govt is needed.
12	Research	Dec	Efficiency	Energy markets are	This work also

.	Paper- Testing the Efficiency of Electricity Markets, Energies, George P. Papaioannou et al.	2018	of Energy Markets	inherently inefficient	helps in theoretical underpinning of this work because we look at the symptoms of inefficient market behaviour particularly in the power sector.
13.	Book- The Innovator's Dilemma - Clayton Christensen	(1997) Book	How innovation happens	The concept of disruptive innovation	This is also a useful work that forms theoretical underpinning of this work because we find that renewable energy is acting as disruptive innovation for thermal power.
14.	Research Article- - The resource-based theory, Grant Robert M, California Management Review	1991	Resource Based Strategy	How resources can be source of competitive advantage	This theory is one of the theoretical concepts which my research is likely to be either enriched or challenged because the large thermal power plants, which were considered as source of competitive advantage are

					proving to be source of competitive disadvantage.
15.	Research Article, Competitive Advantage, Porter M, The Free Press, NY, USA	1985	How firms can get Competitive Advantage and resources are important	The famous article by Porter explains the Generic strategies to gain leadership in competitive markets – Leading with low costs or creating differentiated products and services.	This work of Michael Porter is a relevant theoretical underpinning of this research work. We explore whether coal based thermal power plants can sustain their current strategy of cost leadership.

Source – Literature review of various papers and articles carried out for this research [7], [8], [9]

2.5 SALIENT HIGHLIGHTS OF LITERATURE REVIEW

Substantial work has been in the area of renewable energy integration in the grid and its consequent effect on thermal power. Papers in this arena have dealt mainly with merits of green and renewable energy and have looked into how these could be integrated into the grid. Some papers have delt with how this integration will impact coal plants in terms of capacity utilisation. [7], [8]

One of the relevant works in this field comes from Wang P et al [17]. They have done analysis of various scenarios in the power industry in China under the backdrop of the electricity market reforms and a carbon policy in the country. They have modelled four factors (i) Power demand; (ii) Selling process; (iii) Capacity (fixed) changes of thermal power units; and (iv) Taxes imposed on Co2 emission. Impact of these factors on the generation mix, electricity prices, Capacity Utilization Factors, Green House Gas emissions, etc, have been found out through a modelling process. Using the four factors, two scenarios have been drawn by the researchers- The Business-As-Usual (BAU) scenario and Aggressive Demand Response (ADR) scenario. The model suggests that the new the electricity market reforms have helped renewable energy, and has put pressure on thermal power. In The Business-as-Usual case, Utilization Factor (PLF) of thermal power shall drop considerably from **42 % in 2020 to 28 % in 2035**. They further predict that thermal power capacity addition will have **negative growth of 0.004 %** during 2030-35. This paper has considered four factors **-**(i) Power demand; (ii) Selling process; (iii) Capacity (fixed) changes of thermal power units; and (iv) Taxes on Co2 emission. However, it has not established how these factors were arrived at. Moreover, the study is based on situation in China, which has large difference with India with respect to tariff, capacity mix, fuel availability etc. A comprehensive study encompassing major factors affecting PLF, in Indian context is needed. However, this work gives direction to this research because the path followed in this research is similar to one used here.

The research work by Wang Y et al [18] has addressed the issue of continuous reduction in utilization of thermal power generating capacity in China. They have studied the interaction between installed capacity and PLF of power plants of China's provinces for the period between 1991 to 2015, using a dynamic spatial Durbin Model. They have also estimated the impact on GHG emissions from the power sector. The results demonstrate that installed capacity and utilization factor both have incremental effect on carbon dioxide emissions. Authors suggest that reducing the overcapacity of thermal power capacity will help in reduction of carbon emission. They add that instead of adding new coal-fired power plants, investments should be made in adding clean power technologies in the existing plants. This paper studies the impact of capacity utilisation of thermal power plants vis a vis GHG emissions. It is therefore a study limited in scope wherein optimisation of capacity utilisation with respect to GHG emission is the primary focus. Other factors- like demand, integration with other sources of generation like renewables, fuel supply etc have not been considered. The paper also dos not address financial impact on the thermal power generated due to lowering of PLF. A more comprehensive study is therefore required.

In the research work by Bhardwaj N et al [19], the authors have analysed the sustainability of the power sector, particularly in the backdrop of poor financial health of the electricity distribution companies in India. They have discussed the poor financial condition of the distribution companies coupled with mounting losses that these entities are suffering. Further, they state that distribution sector is the vital revenue earning link and it is imperative to bring these entities into profit zone so that the whole power production-to-consumption chain can survive. The paper indicates that this poor financial condition of distribution companies might be affecting the performance and PLF of thermal generating companies also. This paper brings forth one very important factor - *poor financial condition of the distribution companies* (distribution companies, DISCOMs, are customers of generating companies), which might be responsible for the falling PLF of thermal power plants. To this extent, the paper is useful for identifying one of the factors responsible for falling capacity utilisation of thermal power, which helps in exploratory research for the current thesis. However, the scope is limited to identifying and studying just one factor. Need for a more holistic study remains.

In the paper by Singh S et al [20], the authors have studied the productivity of 25 coal-based power plants in India. This study brings out some policies that can be implemented to enhance the PLF of thermal power plants. In this paper, the authors have used Data Envelopment Analysis (DEA) based Malmquist Productivity Index (MPI) approach, to measure the change in productivity. This study finds that ageing and lack of renovation and modernisation could be a factor responsible for low PLF of plants. This paper again brings forth another factor –

poor maintenance, renovation and modernisation of thermal power plants, which might be responsible for the falling PLF of thermal power plants. Here again, the paper is useful for identifying one of the factors responsible for falling capacity utilisation of thermal power. However, the scope here again, is limited to identifying and studying just one factor. A comprehensive study in this area is a gap that needs to be filled.

Credible newspaper reports in papers like Economics Times and Energy Monitor [2], [3] predict a fall in PLF to as a dismally low level of 48% by 2022, as more and more renewable capacities get integrated into the grid. It warns that at that at such low level of PLF, they may find it technically unviable top operate and might find very difficult situation to service debts. There is an imminent danger of such assets turning into non-preforming assets. This report confirms researchers concern and business problem. It creates a need for a comprehensive study as to why PLF of thermal power could drop to the levels of 48 %, what could be factors responsible and what should be done.

Another important work comes from the USA by Robert KS et al [21] where the author has analysed the generation patterns of large coal-fired units. They have studied the implications of migrating from the status of baseload generation to load-following flexible-generation regime. The paper states that many factors are responsible for fall of PLF of coal-based plants. One of the factors is the high rate of growth of wind and solar generation in coming years, thereby further impacting the thermal generation. This is an important reference for the current research. As part of exploratory research, we picked up this factor as one of the probable factors affecting PLF of thermal power plants. This factor (renewable energy addition), in fact, has emerged as one of the most prominent factors affecting PLF of thermal power plants in our research also.

Research by Luo G et al [22] has brought out how thermal power generation is being affected by renewable energy. They have also analysed how there is demand for flexibility improvement of thermal power units for integrating wind power in the grid.

In the research work by Patrick et al, referred to at [23], the authors have studied how increased renewables generation have affected operation of thermal power plants in Europe. They found out that the increased proportion of RE, will cause a 04 -23% increase in the number of start-ups and shutdowns of conventional plants. The number of load ramps will also significantly increase by 63–181%. This is valuable guide paper for our research.

In a very relevant work related to this research, The Central Electricity Authority report Govt of India [24] has brought out a detailed report on flexibilization of coal-based power plants for integrating renewable energy. In the report there is extensive analysis of how thermal power will get affected by changes in renewable energy. The report finds that in business-as-usual case, coal-based plants may have to reduce the PLF to the unsustainable level of 26%. The report also indicates that even a small 0.96% curtailment of renewable energy can boost the Minimum Technical Load from 25.73% to 45% for the coal-based units. This study is of major significance to our research here.

In a significant work done in China [25] where the researchers Liao et al have used models to optimise the dispatch of electricity from the coal-based plants. The model is nick named as MOCTU. This model aims at smoothening the generation from thermal power while minimising light up, synchronisation, and shut- down times. This paper deals with how thermal power should embrace the flexible operation regime.

There are also many articles from prestigious news publications in India which have cited that the Utilization Factor (PLF) of coal-based power plants in India is going down and likely to drop further. They have also brought out some of the factors behind such drop in Utilization Factor. The Hindu Business Line Mishra et al [26] reports that the coal 'supply constraint' is one the prominent reasons affecting utilisation of thermal power plants. This work helped us in our exploratory research as we have picked fuel supply constraint as one of the probable factors responsible for falling PLF.

Sengupta D, The Economic Times [2] predict that thermal power plants' Capacity Utilization in India will drop to 48% by 2022. The report further adds that coal-based thermal power plants should be ready to endure major fall in PLF, as more and more RE capacities get added. The paper further adds that due to very low PLF, the plants may find it difficult to repay loans and there is a possibility of these plants becoming non-performing assets.

The Mint [27] another prestigious newspaper dedicated to economic news, reports that Renewable Energy might be responsible for falling Utilization Factor of thermal power plants.

Prasad, Economic Times [28] points out that addition of new capacities in the thermal power sector, shortage fuel on one hand and low demand on the other hand, has forced thermal power generators to run below optimal capacity.

Nirbhay, Business Today [29] quotes Honourable Union Minister for Power, New and Renewable Energy, Govt of India, saying that the India is already surplus in power and renewable capacity addition that has been added is behind dropping PLF of thermal plants.

Xue, Y et al [30] point out towards generalized congestion of power systems of India which affects the adequacy and security. The researchers bring in term as generalized congestion. This generalised congestion might a constraint in effective and efficient utilization of generation assets.

Another important work has come from South Korea. Geem et al [31] have presented a model for attaining better agility in the grid operations and better overall environment footprint. This optimization model aims at minimisation of costs related to erection, O&M and fuel and control of emissions. Authors have suggested a energy mix transition from 2012 to 2030. Authors feel that this model can be useful for energy mix decisions across the world. Interestingly, this model predicts energy mix shift between 2011 to 2030 as follows – Gas 32 % to 27 %, Coal 37 % to 21 %, nuclear 29 % to 39 % and renewables 2 % to 13 %, respectively.

There are two very important reference works relevant for this research coming from the advisory bodies/agencies related to Govt of India. One is the Draft National Electricity Plan 2016, Volume I ; Central Electricity Authority, (CEA) [32] and the other one is Greening the Grid : a combined study by USAID and MOP, GOI [33]

The Draft National Electricity Plan (NEP) of Central Electricity Authority (CEA, a Govt of India policy body, vested with planning in the Power Sector) discusses the issue of PLF of thermal power plants in India. It predicts that by the year 2022 several plants will get partial or no schedule (for generating power) at all. This means that many plants may have to be kept under shutdown because of lack of demand. Technical viability of thermal plants becomes dicey if they have to run below 55% level of capacity. [7], [8]

Greening The Grid (GTG), which is a collaborative endeavour of USAID and MOP, GOI, is an extensive dealing with operational as well as overall cost reduction opportunities for renewable energy. This paper discusses in detail the integration of renewable and also discusses flexibilization requirement of thermal power plants in India.[7], [8] In another very significant and extensive work Central Electricity Authority (CEA) vide their report (Draft) [6], have projected on optimum capacity mix till the period 2029-2030. In the report, CEA has suggested the most appropriate energy mix for India for next 10 years based on many important considerations like demand growth, emission, RE integration, flexibilization. In our current research, the optimum generation mix suggested by CEA in their report has been taken as one of the possible scenarios of PLF projection for future.

Kumar et al, [34] have done a detailed cost modelling on the effect of Capacity Utilization Factor (PLF) on profitability and returns of the power plants. They have brought out the impact of PLF on repair and maintenance, fuel cost, revenue and the consequent impact on NPV. The calculations have been projected over life-cycle of plant. The study pertains to a typical 210 MW coal-based plant. They found that PLF has a direct bearing on earnings and NPV. For the plant considered in the study, annual revenue increased from INR 7537.3 Crores (US$ 1011 Million) to INR 9915.2 Crores (US$ 1330 Million) due to increase in the average annual plant load from 168 to 221 MW. This work has helped in current research by providing a base framework for cost implications of fall in PLF.

Lew et al, [35] show that flexibilization costs of thermal power plants include costs due to additional fuel requirements and increased O&M costs caused by additional wear and tear of machinery. In addition, various scenarios have been projected to assess the possible fallout of enhancing Variable Renewable Energy (VRE) on scheduling and flexibilization requirements of coal fired plants, particularly with reference to the US Western Interconnection.

Venkataraman et al,[36] bring about the benefit analysis of spending on flexibilization technologies vis a vis returns. The cost-benefit analysis has been done using Plexos simulations with and without the flexibility augmentation retrofits on the power plants under study. The changes in production costs and revenues (i.e., the benefits), have been determined.

Kang et al, [37] have studied what factors get affected due to flexibilization of the plants. They opine that coal-based power plants are originally designed for baseload operations and may suffer great losses as their operation mode changes. Losses happen in terms of Variable Operations & Maintenance Cost, Load Following and Ramping Cost, Auxiliary Power Consumption, Heat Rate, Forced Outage Rates etc.

Keatley et al, [38], bring out how large thermal power units, which were originally designed to operate as base load stations are forced to operate cyclically due to market liberalization and the substantial addition of variable renewable energy sources. This type of unplanned activity results in faster levels of health deterioration due to the fatigue-related injuries that these units were not designed to withstand.

Bergh et al, [39], find that cyclic operation of conventional thermal plants is an important source of operational agility in the grid. Cyclic operation alters the load output of normal units through load ramping up & down and frequent start-stops of the units. The authors find that, a wide variety of cost-related implications of such cycling is available in literature. Different studies have come up with different parameters to assess the cycling costs. This paper thus examines the impact of cycling parameters on a typical power production unit.

Hermans et al [40], find that cyclic operation of thermal plants is increasing alongwith the addition of the unpredictable output renewable energy sources (RES) such as wind and solar. However, coal plants have to incur costs to operate under such conditions. Costs of cycling include the costs of additional retrofits and additional costs on fuel which can be easily determined and calculated.

It is found that in terms of future of thermal power, most of the work already done revolves around ways to support grid level integration of renewables. Such works have dealt mostly with ways to integrate renewable in the grid and consequences of such integration on thermal power. Also, substantial work has been on cycling and flexible operation of thermal power plants. Some of the papers and reports have identified on one or two factors that affect Utilisation Factor (PLF) of coal based thermal power plants. *However, to the best of the knowledge of the researcher, there is no scholarly work available* ***from thermal power plant perspective*** *where comprehensive study has been made to find out the major factors affecting the PLF of coal based thermal power plants alongwith the projection of future PLF trends and suggested roadmap. [7], [8], [9]*

2.6 RESEARCH GAP

Relevant literature on the subject were examined in order to explore factors affecting thermal power generation. It is found that most work literature is focussed on renewable energy and looks at the issue from the renewable energy perspective. There is no work which comprehensively focuses on the thermal power story. Some articles and papers have identified one or two factors that affect the Capacity Utilization of thermal power plants.

Moreover, in terms of future projections, most of the available work is focussed on how to support and integrate renewables in the grid. In terms of technical fall out of such integration, the studies have focussed on the requirements of ramp up and ramp down (cyclic or flexible operation) of thermal units consequent.

In terms of cost implications, excellent work has also been done as to how cyclic operation (flexibilization) is affecting the costs of thermal power plants.

However, in most studies, the thermal power perspective is missing. To the best of the knowledge of the author, there is no scholarly and empirical study done to find out the major factors affecting Utilization Factor (PLF) of thermal power plants. Also, projection of Utilization Factor (PLF) for next 05 years could not be found in any published scholarly paper (although several newspaper reports have touched this issue). Financial impact of change in PLF has also not been studied in any scholarly paper. Also, there is no comprehensive roadmap suggested for thermal power plants in any scholarly work.

In essence – there is a need to do comprehensive work to (i) Identify Major factors affecting the Utilization Factors (PLF) of thermal power (ii) Projections of thermal power Utilization Factor (PLF) and it's consequent financial impact (iii) Finding out remedial action for future. This research addresses this gap.

2.7 THEORETICAL UNDERPINNING

Review of literature shows that prominent researchers have dealt with following five concepts and theories that underpin of this research. Following are the names and authors of the concepts / theories. How these concepts relate closely to this work is presented in detail in the next section.

(i) ***Capacity Utilization – (a)*** *E. R. Berndt and C. J. Morrison– Capacity Utilization Measures, FAO, USA- Capacity and Capacity Utilization- https://www.fao.org/3/X2250E/x2250e07* [41] ***(b)*** *E. R. Berndt and C. J. Morrison, The American Economic Review, Published By: American Economic Association, Papers and Proceedings of the 93rd Annual Meeting of the American Economic Association, Vol. 71, No. 2,pp. 48-52 (May, 1981), Capacity Utilization Measures – Underlying Economic Theory and Alternative Approach.* [42]

(ii) ***Inefficient utilization of resources and market failure*** *– P. A. Samuelson- The Pure Theory of Public Expenditure," Review of Economics and Statistics 36 (November 1954): 387-89; and, "A Diagrammatic Exposition of a Theory of Public Expenditure," Review of economics and Statistics, 37 (November 1955): 350-56.* [43]

(iii) ***The resource-based strategy- How the resources can be effective in competitive advantage*** *– R. M. Grant, 1991, The resource-based theory of competitive advantage, California Management Review 33 (3) pp.114-135, Berkeley, Calif.: University of California).* [44]

(iv) ***Disruptive Innovation - How the established business models can get disrupted due to disruptive innovation*** **-** *Clayton Christenson, 1997, The Innovator's Dilemma*. [45]

(v) ***Competitive Strategy*** **- C*ost Leadership or Differentiation-*** *Porter, Michael, Competitive Advantage, The Free Press, NY, 1985.* These major management theories underpin this research work. This work shall either substantiate, enrich or challenge these important theoretical concepts. [46]

How these theories relate to this work is explained in detail as below.

2.7.1 CAPACITY UTILIZATION

FAO, Washington [41] brings out two constructs of Capacity Utilization : (1) A technology-based construct, and (2) An economics-based construct. Both constructs basically define capacity utilisation as the ratio of actual output vs possible output as per the rated capacity or the possible output capacity which can be potentially obtained. The difference between the two constructs of capacity utilisation is based on how capacity is defined and calculated. From technology-oriented point of view, capacity is defined as the highest possible output which the technology permit. Capacity utilisation is therefore the ratio of the actual output vs the maximum possible output that the technology permits, expressed in terms of percentage. In this technology-based construct, the economic considerations of output are are not taken into considerations and only the technical ratio is considered. It looks at actual vs maximum output. This construct therefore looks at capacity utilization only from technical point of the view. For example, if a machine is running at 50 % capacity utilization, it means that it is technically able to produce only 50 % of what if could have produced, had it been technically fit and available. The economic construct, also takes into consideration the optimum output which should be or could have been produced with the available capital investment, available technology, inputs factor prices, output prices and demand.

This construct therefore looks at optimally utilising the factors of production to achieve maximum profit or minimum cost. The economic construct of capacity utilization therefore looks beyond the technical capability, and gives the economically optimum level of output, considering firm's costs, technology, revenues and profits.

Ernst R. Berndt and Catherine J. Morrison opine that [41] that the economic measures of capacity utilization have been used extensively to determine Net Present Value (NPV) and Internal Rate of Return (IRR) of the projects.

In thermal power sector in India, Capacity Utilization Factor (CUF) is denoted by special term (name) called Plant Load Factor (PLF). The term CUF is more prevalent in Solar Power. Bhagyashree Rath [47] states that determining the performance of a power plant is a complex topic, because several factors like availability of fuel, availability of water, rated capacity, ageing of the unit, planned outage etc, come into play. Understanding of Plant Load Factor (PLF) helps in assessing the performance of coal-based plants. Plant Load Factor (PLF) is a very popular index and is generally used to express Capacity Utilization Factor. Technically, Capacity Utilization or Plant Load Factor of Thermal Power is defined as "*Actual electricity generation of thermal power plant(s) X 100 / Full capacity of electricity generation of the thermal power plant(s)*". This is the definition, measure we have used in this research.

Although this research uses Capacity Utilization (PLF) in technical sense, it also finds out the how it will affect the economic performance of thermal power units.

2.7.2 INEFFICIENT UTILIZATION OF RESOURCES AND MARKET FAILURE

As the resources are scarce, it is desirable that they should be used most efficiently. This is a basic premise for economic theory. In this context, it is presumed that a competitive, free market will achieve the goal of optimum utilization of resources.

However, the concept of competitive markets is based on some major presumptions. First major presumption is that when the market trades freely, *players choose the best actions leading to the optimum benefit of all the parties*. This presumption, inter alia, also means that government regulations actually restrict the free choices of players and limit the benefits gained from in a free market, hence Govt intervention should not be there. [42], [43]

Second major presumption is that, competitive markets allocate resources efficiently. Prices reflect the demand supply situation and create the best producer-buyer combination. This assumption also stipulates that no policies or central planner interventions are required to deal with distortions, and demand supply interaction will take care of everything. It is also argued in favour of free market efficiency that firms in free markets satisfy the wants of consumers better than any alternative system would do. In Economics parlance, when competitive markets work at best efficiency, the situation is called Pareto Optimality (V Pareto, Manuale d'economia politico [48]. Pareto Optimality means that all resources are utilised in a manner which is economically most efficient.

However, Pareto Optimality does not mean that market has perfection, complete equality and fairness. In actual practice, market perfection is not feasible due to inefficient producers, irrational consumers, externalities, information asymmetry, societal concerns, and existence of public goods. In such cases *Market Failure* can happen. Since the concept of Market Failure is relevant for this research, it has been thought appropriate to briefly discuss the concept here.

The theory of market failure got elaborated during the mid of 20th century through the School of Keynesian Welfare. Prominent contributors to the development of the theory were Paul A. Samuelson, Arthur C. Pigou, Francis Bator and William Baumol. These economists studied and conceptualised the correlation between free market outcomes on output and profits and the social welfare consequences of free markets. The concept of *Market Failure* forms the basis of many economic policies that justify *intervention by government* in the markets. The market failure theory is generally attributed to the work of *Paul A Samuelson*. [43]

In a prominent work (published in book form) by David l. Weimar and Aidan R. Vining [49], which is also used as a textbook, the authors explore when the government intervention in markets could be considered justified. They say that such interventions are justified in situations of market failure— a situation where society's resources may not get efficiently utilised due to contradictory interests.

In this research we shall explore whether such situations exists in electricity markets, whether govt intervention is there in electricity markets, to what extent and whether it is sufficient.

Erik Bækkeskov [50] argues that in economics, the premise of "invisible hand," should be upheld and the market should be left to perform without government intervention, *which is a laissez-faire approach to market performance. This premise argues that the laissez-faire approach* brings *Pareto Optimality* in the market.

Pareto Optimality assumes that decisions of consumers and producers are rational and they respond perfectly to price signals. The decisions about buying or selling a good are taken by buyers and sellers on economic considerations. The market situation emerging due to such rational decisions by all players results in Pareto Optimality, which is a desirable situation in the market. However, economists looking at welfare state took this with a pinch of salt. They argued about the conditions under which such imaginations of Pareto Optimality could fail. Such situations could be when there is no intervention by Govt, (i.e. govt remains an invisible hand) but where optimal distribution in market could fail. Economists tried to describe such conditions. It is this very interest of economists in the conditions which could become exceptions to the invisible-hand approach, that led to the theory of market failure and resulted in exploration the underlying conditions which could lead to market failure.

The term "Market Failure" can be understood as the economic situation where the distribution of goods and services is done in an *inefficient fashion*. Some of the reasons why markets can fail are (1) information asymmetries, (2) monopoly market (3) externalities (4) public perception (5) environmental concerns, (6) public goods. In such situations, markets fail to allocate resources efficiently or fail to supply the socially optimal amount of the good or service. Prior to market failure, all the resources are not optimally utilised and the imbalance causes allocative inefficiency.

Literature review shows that the electricity markets are indeed *susceptible to Market Failure*. In fact, electricity markets, worldwide are found to be operating far from the Pareto Optimality. George P. Papaioannou et al [51] have concluded that all the electricity markets that they examined in their research were found inefficient.

This means that electricity markets are too complex and are prone to market failure owing to factors like externalities, information asymmetry and public perception etc. unless careful and consistent regulatory interventions are done. In this research we are going to see if these conditions exist.

2.7.3 THEORY OF DISRUPTIVE INNOVATIONS BY *CLAYTON CHRISTENSON*

Harvard Business School (HBS) *Professor Clayton Christensen* is the architect of the theory of disruptive innovation. This theory says that disruptive innovations can challenge the established business models. In the year 1997, *Professor Christensen* in his famous book - The Innovator's Dilemma coined the word Disruptive Innovation for the first time. The idea presented in this book is considered *as one of the most influential ideas of the 21st Century in the business world. [45]*

Disruptive Innovation is a situation in which a product or service emerges as a frugal and simple alternative to an established product- typically by being less expensive and more accessible, and then moves fast to capture a niche market, eventually displacing established competitors. When a new product is cheaper and easier to use, it can cause established companies to lose market share or even become irrelevant. Christensen says that it is not that established players do not innovate, but they get preoccupied with improving the existing products. Such incremental innovations can make products better but can-not become disruptive.

Christenson suggested that faced with disruptive innovation companies resort to some of the following:

i. They should start their own forays into the product or services that have brought out disruption into current model.

ii. Rather than using the current business models, they should come out with different business models for entering the business of the disruptive products and services.

iii. They should continuously monitor customer behaviour and see how they can harness the emerging needs.

iv. The established companies can leverage their financial soundness to harness cheaper financing.

v. They should draw a plan for exiting the current business if the disruptive innovation scales up, matures and becomes a major source of revenue.

The question here is, faced with disruptive innovation, what the companies should do? Our work will explore whether thermal power producers are facing disruptive innovation in the form of renewable energy sources and what options lie before them.

2.7.4 RESOURCE BASED APPROACH TO STRATEGY *BY ROBERT M GRANT*

Robert M Grant is a renowned thought leader, author and professor in the area of strategy. He has taught in many prestigious institutions in the US, UK and Canada. Presently, he teaches at Bocconi University in Milan.

His theory deals with competitive advantage based on resources [44] The theory says that resources of a company are a major source of competitive advantage.

Grant tries to look competitive strategy theory from a different perspective, than the Porter's "strategic positioning" through "cost leadership" and "differentiation". He says that a more fundamental way to look at strategic advantage is to look at the "resource position of the firm". For example, in order to become a cost leader, a firm would require resources like - having plants that can efficiently harness economies of scale, possession of superior intellectual capital, access to cheaper or better raw materials, or access to cheaper labour. *As per Grant, therefore, the "resources" are at the core of competitive advantage.*

Grant's theory stipulates that companies can compete and excel based on long term and difficult copy resources. Grant further states that sustained competitive advantage can happen if the company develops and nurtures such resources. We will explore how this theory applies to the thermal power business.

2.7.5 THEORY OF GENERIC COMPETITIVE ADVANTAGE BY *MICHAEL PORTER*

Michael Eugene Porter is an American author, professor and management thinker known for his theories on business strategy, economics and social causes. He is a Professor at the Harvard Business School.

His theory of generic competitive advantage [45] says that companies compete in two basic ways - Cost Leadership and Differentiation. These two basic ways of competitive advantages lead to four strategies that help firms achieving above average returns in an industry These four strategies are (i) Cost leadership across broader market (ii) differentiation across broader market (iii) cost leadership in focussed market and (iv) differentiation in focussed market. In the broad strategy category (i) &(ii), the company uses either cost leadership or differentiation as their main strategy *across all products and all target markets*. In case of focus strategy, the firm uses cost or differentiation *selectively for focused products or markets.* The following chart illustrates the Porter's Generic Competitive Advantage Theory

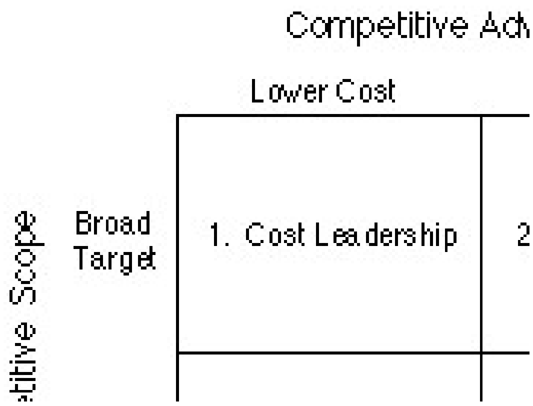


Chart 2.2 - Porter's model of generic competitive advantage
Source – Michael Porter's generic competitive advantage model

In cost leadership, a firm wants to be the lowest cost producer in the industry. The sources of becoming a cost leader may include- large output capacity leading to economy of scale, copyright on proprietary process or technology, access to cheaper raw materials etc. A producer with this strategy tries to use all avenues of cost reduction and to have better than average performance in the industry.

In case of differentiation strategy, the firm wants to differentiate its products and services by additional or unique features that are not available in other competing products. Such differentiation often creates a niche or targeted market segment where the firms want to operate. In such cases, the firm is able to command a premium in price which the customers are willing to pay.

2.8 CHAPTER SUMMARY

This chapter presents the detailed literature review. It discusses about findings of relevant research work already done in the subject matter. It is found that lot of work work has been done in the areas like integration of RE in the gid and its effect on thermal power. Substantial work has also been done in the area of cyclic operation of thermal power plants and its technical and cost implications.

However, there is no comprehensive scholarly work to holistically cover the subject matter of falling capacity utilisation of thermal power, its implications and the future roadmap. This research, which addresses this gap, therefore becomes relevant and important in the sector.

This chapter also brings out the theoretical underpinning of the research. It is discussed how theories have dealt with the subject of Capacity Utilization. Relevant theories which give guidance or value to this research are (i) Theory of Efficient Utilization of Resources and Market Failure (ii) Theory of Disruptive Innovation by Clayton Christenson (iii) Resource Based Approach to Strategy by Robert M Grant (iv) Theory of Generic Competitive Advantage by Michael Porter.

3 CHAPTER 3 – RESEARCH METHODOLOGY

3.1 CHAPTER OVERVIEW

This chapter presents the research objectives, research design and methodology for each objective, rationale for the methodology, and how validity and reliability of the research has been ensured. [7], [8]

3.2 RESEARCH OBJECTIVES

1. To find out the major factors responsible for falling Capacity Utilization (PLF) of thermal power plants in India- Objective – I
2. To find out projected PLF scenario in next 5 years and its technical and financial impact – Objective II
3. To study global scenario, to suggest and to validate Recommendation and Remedial Action – Objective III

   [7], [8]

3.3 RESEARCH METHODOLOGY FOR RESEARCH OBJECTIVE -I

3.3.1 OBJECTIVE I- TO FIND OUT THE MAJOR FACTORS AFFECTING CAPACITY UTILIZATION (PLF) OF THERMAL POWER PLANTS IN INDIA

3.3.2 RESEARCH STEPS OBJECTIVE - I

3.3.2.1 EXPLORATORY RESEARCH THROUGH LITERATURE SURVEY

Factors affecting thermal power PLF were first explored through Literature Review. The literature review resulted in identification of seven broad areas of concern (as below) which might be affecting PLF of thermal power stations.

1) Effect of Renewable Energy (*Ref Literature Review Table 2.1, Sub Theme 4, Paper Sl No 7 and* Robert KS et al [21])

2) Low Growth of demand as against projected (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 9, 10,18,23,24,25*)

3) Overcapacity (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 9, 10,18,23,24,25*)

4) Financial health of Discoms (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 14,19*)

5) Fuel Availability (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 17,22*)

6) Evacuation constraints (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 15,21*)

7) Policy issues discouraging the thermal power generation (*Ref Literature Review Table 2.1, Sub Theme 1, Paper Sl No 17, Theme 2, Paper Sl No 7,8,9,10,11*)

   [7], [8]

The seven broad areas which might be affecting PLF of thermal power stations are graphically depicted below. This is just a graphical illustration and not a Venn diagram representing interference or overlap between factors.

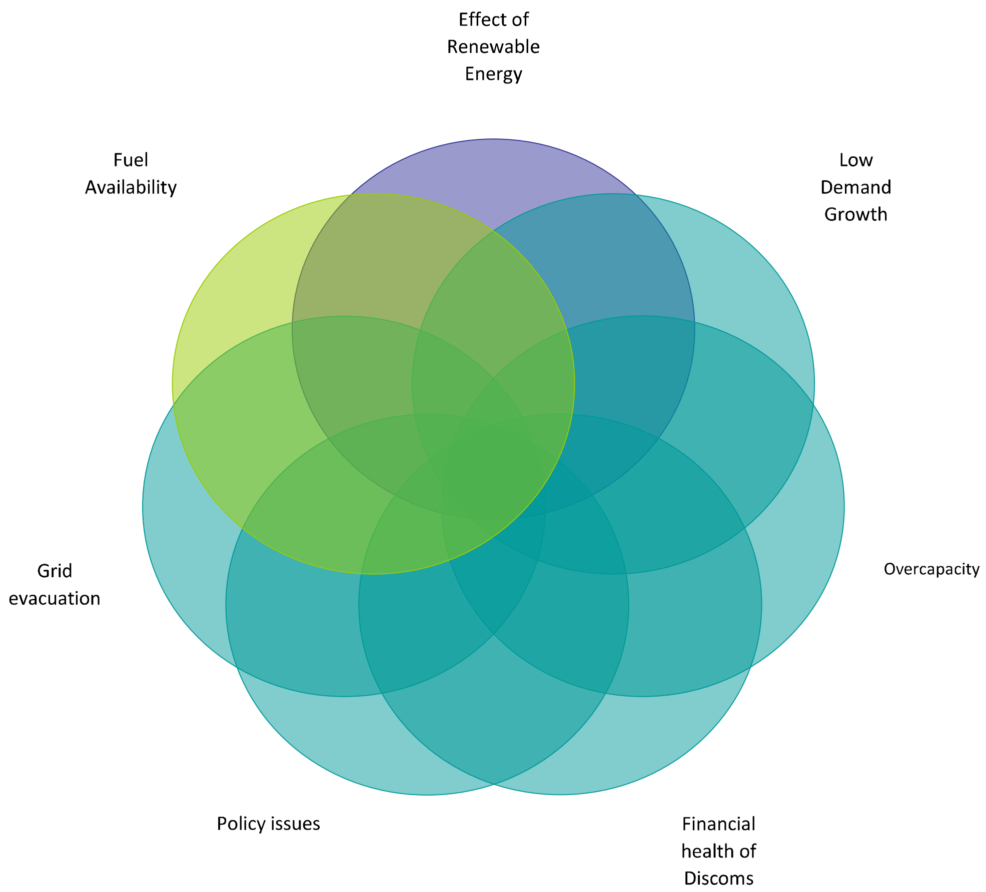


Chart C3.1 - Seven broad areas of concern which might be affecting PLF of thermal power stations. Source- Analysis carried out based on exploratory research

3.3.2.2 EXPLORATORY RESEARCH THROUGH DISCUSSION WITH EXPERTS

The seven areas of concern explored through Literature Review were further discussed with selected experts to crystallise them into clearly articulated factors that can be tested through a questionnaire. (13 experts were consulted for this work, having relevant work/academic experience of more than 20 years each, List of experts is at **Annexure B**). This step resulted in identification of 25 well defined factors. The next pursuit was to find out which of these variables/factors were major factors. These factors were then converted in the form of a questionnaire and opinion of respondents was sought as to which factor; they consider as major factor**. (Annexure A) [7], [8]**

The above two exploratory steps were thought necessary because administering a questionnaire without mentioning the factors, was not considered a robust way of seeking responses. If, in the questionnaire, we leave the respondents open by asking respondents just to "state the factors affecting the PLF of thermal power plant as per their opinion", there was high chance of some important factor being left out either because of a bias, recency effect or simply because of lack of time on the part of respondents. It was therefore thought appropriate to list all the factors (25 Nos) found through the exploratory research and seek opinion on each one of them on a Likert Scale whether each one has very major, major, neutral, low and very low impact on PLF. [7], [8]

3.3.2.3 QUANTITATIVE RESEARCH THROUGH QUESTIONNAIRE

Based on above two exploratory research steps, a questionnaire survey was run seeking opinion of respondents on a Likert Scale. The questionnaire **(Annexure A)** was administered to targeted professionals working in the power sector consisting of following –

(i) Executives from power companies in Central Sector
(ii) Executives from power companies in State Sector
(iii) Executives from power companies in Pvt Sector
(iv) Consumers
(v) Regulators
(vi) Grid Operators
(vii) Consultants
(viii) Academicians

[7], [8]

253 Respondents submitted the response. Respondents were experienced professionals in power sector. More than 75 % of the total respondents who

participated had more than 20-year experience in the sector. Following was the distribution of respondents in various categories-

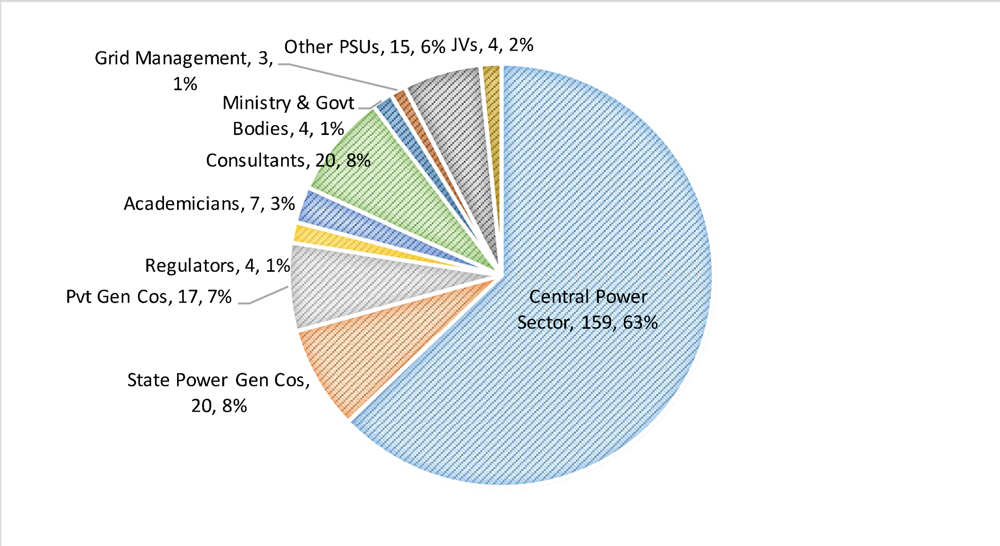


Chart C3.2 - Distribution of respondents from different background-
Source- Data from the responses received against the questionnaire under objective- I

3.3.2.3.1 SAMPLE SIZE ADEQUACY CHECK

Since we are ultimately measuring proportions, the sample adequacy check of our 253 samples was done through the following formula. [7], [8]

$n = Z^2 p (1-p)/ E^2$

Where n is the sample size required.

[In our case, Z is taken at 95 % = 1.96, p is the proportion of response in sample (proportion of respondents saying a particular factor is a major factor), E is margin of error – 7 %)

This was tested for all 25 questions. (Detailed table is given in results and analysis in Chapter 4). Based on proportion of response in each question's response set, the maximum number of sample size required at Z value of 95 % and Margin of Error 7 % comes to 227 (Illustration as shown below)

Z = 1.96 (95 % level)

p =

E = 7 % = .07

n = 1.96x1.96x 0.48 x 0.52 / 0.07x0.07 = 227,

Similar exercise was done for all the questions. The maximum for any question set was 227.

Our sample size in 253 for all questions. ***Detail with table is given in Chapter 4***

3.3.2.3.2 HYPOTHESIS TESTING FOR PROPORTION

Our main aim here is to determine which factors out of the total 25 identified in the exploratory research phase, emerge as Major Factors affecting PLF of thermal power plants. For this purpose, two methods were employed in this research (i) Factor Analysis (ii) Hypothesis Testing.

The responses were checked with Hypothesis Testing (for each question (Factor)) - whether majority of experts believe that the particular factor is indeed a Major Factor affecting PLF of thermal power plants. In essence, through Hypothesis Testing, it has been tested whether indeed majority of experts in the population feel a particular factor is a major factor affecting thermal power PLF. The responses which chose Very High Impact or High Impact have been counted under the Major Factor.

In this situation our Hypothesis is as below-

H0, p = 0.5 i.e. 50 %,

Ha, p>0.5, a one tailed test)

Our sample size is. N = 253. Null hypothesis (Ho) is – population proportion P is 0.5 (i.e only 50% i.e. just half of the respondents believe that this factor is a Major Factor. Alternate hypothesis is that p is significantly greater than 50 %. (95 % confidence level)

(H0, p0 = 0.5 i.e. 50 %,

Ha, p0>0.5, a one tailed test) (p0 is hypothesised proportion, p∧ is measured proportion)

A p∧-critical value corresponding to Z-critical value approach has been used here. In order to do this, the Z critical value at 95 % confidence level (1.96) has been taken and applied in formula below to find p critical value for our sample size (253). Our approach is that if sample p is greater than p-critical, it can be concluded that the Null Hypothesis is rejected for that factor and there is evidence to believe that that majority of experts think that this factor is a Major Factor. This was done for all the questions/factors. [7], [8]

Following calculation shows how p critical value (p-cut-off) has been calculated.

$Z = (\hat{p} - p0)/\sqrt{p0(1- p0)/n}$

$Z\_crit\ value = (\hat{p}\_cutoff – p0)/\sqrt{p0(1- p0)/n}$

Z_crit value at 95 % confidence interval is 1.96

$1.96 = (\hat{p}-0.5)/\sqrt{0.5(1-0.5)/253}$

This gives,

p ∧_crit value = 0.56

The p critical value (p-cut-off) comes to 0.56. This means that if p (proportion of respondents saying a particular factor is a Major Factor is more than 0.56 i.e. if more than 56 % percent respondents say that a particular factor is a Major Factor then we infer that it is indeed majority opinion with statistical significance. [7], [8]

Based on this test, 14 factors emerged as Major Factors.

3.3.2.3.3 FACTOR ANALYSIS

Since Factor Analysis is a powerful tool to group and identify underlying factors based on certain statistical attributes, it was decided to deploy Factor Analysis in the data so as to identify whether certain factors (out of the total 25 identified in the exploratory research) emerge as clustered together as Major Factors. SPSS Software was used for the analysis. Salient results are given in Chapter 4. This

Factor Analysis shall confirm and substantiate the results of Hypothesis Testing which was performed on the same data.

The scree plot output from SPSS indicates that there eight underlying components having eigenvalues above 1.0.

Component Matrix has been used for Factor Analysis. Component Matrix helps in identifying the underlying association of factors with a certain Component. Once the factors are clustered in Components, the researcher has to find the underlying association of the factors clustered together and interpret the results. (As per standard terminology in Factor Analysis, the term Variable is also used for what we call Factors here.)

The Pearson's Correlation Coefficients in the Component Matrix depicts moderate to high correlation. The factors showed distributed factor loadings towards multiple Components. A factor having highest factor loading towards a particular Component was clustered with that particular Component. All the 25 factors were thus clustered within eight Components. Components were then analysed based on their descriptive statistics. (Details are in Chapter 4)

Proper interpretation of Factor Analysis is a challenging task. It is challenging because here the researcher's assumptions, underlying logic, pattern of responses and the purpose of research play important role. In this research, our endeavour is to find out factors which are having higher ratings by respondents so that we can categorise them as Major Factors.

Our pursuit was to know whether a certain Component contains factors which have an attribute in common i.e. they been rated high by the respondents. For our analysis, *that* is the underlying similarity between the factors

In order to find out top factors we have considered all the Components having ***Mean Value above 3.67 or above*** as top components and all the underlying factors as top factors. The rationale is as below-

In our five-point Likert scale we have assigned the response values as - (1) Very Low Impact, (2) Low impact (3) Neutral (4) High Impact (5) Very High Impact. So in order to make cut-off points we apply the formula (Maximum Value – Minimum Value)/n = (5-1)/3 = **1.33.** (n being the number of categories that we wish to create, here we intend to create three categories - Low, Mid & High

This is our interval value for dividing the categories.

Max refers to the highest possible score of the given Likert scale (5, in our case)

Min refers to the lowest possible score (1, in our case)

n refers to the number of CATEGORIES we intend to create

Now we can get three categories (Low, Mid & High) as per our intervals -

Low i.e (1 to 1+ 1.33) i.e. (1 to 2.33),

Mid (2.34 to 2.33 + 1.33) i.e (2.34 to 3.66)

High (3.67 to 3.66 + 1.33) i.e. (3.67 to 5)

So, the components which have response mean values 3.67 or above are categorised as High (Major), Between 2.34 to 3.66 as Medium and between 1 to 2.33 as Low.

Having found out the top components, all the factors clustered with those Components were considered as Major Factors.

Details are given in Chapter 4.

3.4 RESEARCH METHODOLOGY FOR RESEARCH OBJECTIVE -II

(OBJECTIVE-II : TO FIND OUT WHAT COULD BE THE PROJECTED CAPACITY UTILIZATION I.E. PLF IN NEXT 5 YEARS)

3.4.1 DATA SOURCE AND DATA SIZE FOR OBJECTIVE - II

Secondary data from literature review has been taken for this objective. Regression has been done to do the projections.

For this we have considered 3 major Factors as independent variables. These factors are the ones which emerged as topmost factors from our analysis of Objective-I. Last 35 years' data of these Major Factors (quantitative) have been taken to run the regression.

To ascertain the data adequacy, we use the rule of thumb, which says that we need minimum 10 data sets per independent variable to run regression. Since we have 3 independent variables, we need minimum 30 data sets. We have taken here 35 data sets, which meets the requirement. [7], [8]

3.4.2 RESEARCH STEPS - OBJECTIVE –II

3.4.2.1 LINEAR REGRESSION USING ORDINARY LEAST SQUARE (OLS) PRINCIPLE.

In this study, at first, the Multiple Hierarchical Multiple Regression methodology (using excel) was chosen for predicting PLF. The regression method creates the equation using method Ordinary Least Square (OLS). The OLS method aims at minimizing the sum of square differences between the observed and predicted values. [52], [53].

Simple Linear Regression is a mathematical model which assumes that the two variables can be mathematically related and can be expressed using the following formula -

$$y_i = \alpha + \beta x_i$$

Here x is called the independent variable and y is known as the dependent variable (which the equation is trying to predict based on values of x). εi is the error term, α is a constant, β is known as regression coefficient of x).

The premise behind Simple Linear Regression is, determining those values of α and β where the error term is minimum. Since errors can be positive or negative, a simple addition of errors might result in cancellation of positive errors by negative errors, which is not our purpose. Here our aim is to minimize errors. The model therefore minimises the sum of the squared errors. The minimisation equations can be expressed as below.

$$\hat{\alpha} = \min_{\alpha} \sum_{i=1}^{n} (y_i - \alpha - \beta x_i)^2 =$$

$$\hat{\beta} = \min \sum^{n} (y_i - \alpha - \beta x_i)^2 =$$

Some of the indexes that show whether a regression model is good are as below-

R^2

R^2 is the coefficient of determination that depicts how much percentage variation of the dependent variable (y) is explained through the independent variables (x_s). For example, if R^2 is 89 % then 89 % variation in y can be explained by the x_s considered in the equation. The maximum possible value of R^2 can be 1, meaning 100 % explanation. It is evident that the larger the value of R^2, better is the regression.

Level of Significance

There can be situations when the data is such that we end up *wrongly rejecting the null hypothesis when actually it is true*. Level of Significance is the probability of such error happening. It is also known as probability of Type I Error. This level is normally *pre-stated* by the researcher. Generally, a 5 % Level of Significance is taken.[54]

P Values

The p-value is used to test whether a particular independent variable has correlation or no correlation with the dependent variable. It tests the null hypothesis that the independent variable *is not associated with (no correlation)* the dependent variable.

If the p-value for an independent variable is less than the significance level, then we conclude that our sample data provides enough evidence to reject the null hypothesis. That means that the *data supports the alternate hypothesis* that there *is* indeed a non-zero correlation (dependence) between x and y. The variable x with such low p value is therefore statistically significant and is worthy of addition to the regression model.

p-values are therefore used to take a decision whether a particular variable should be included in the regression model or not. If the researcher includes intendent variables that are not significantly correlated with the dependent variable, it will reduce the model precision. It is more prudent to omit such variables. This method helps in Hierarchical Multiple Regression. [55]

If the level of significance is 5%, p-value should be less than 0.05 or $p < 0.05$. In such cases, we can reject the null hypothesis of no correlation. [54]

3.4.2.2 HIERARCHICAL MULTIPLE REGRESSION

In a simple equation, we have only one x (one independent variable) affecting y. In many situations there could be more than one x, i.e. there could be many independent variables and the researcher would like to know which of the variables create a better regression fit. In Hierarchical Multiple Regression, we determine the *optimal set* of independent variables for the regression equation.

In this process, regression is performed with few chosen variables as the independent variables, which the researcher thinks as relevant. After running the regression model, we obtain the p values for all the variables. As a next step another multiple regression analysis will be run by including a new independent variable. In this step we can examine the contribution of new variable in the overall model. If the additional variable makes the regression model better (better p values, better R2 etc) then the researcher will include that variable, otherwise not.

In this current research, Hierarchical Multiple Regression has been run first with three and variables then with four independent variables. [56] The variables were taken from the factors identified from Objective-I. These three selected variables are basically the factors which had emerged from Objective -I. (Other variables were not considered because either they did not fall in topmost components or they were not quantifiable)

With three variables in our model, we got p values very low varying between X E (-6) to X E (-26) and high R^2 which indicated an excellent fit. When the fourth variable was added, the p values deteriorated. It was therefore decided to run the regression with 3 variables only.

3.4.2.3 SHIFT TO PARTIAL LEAST SQUARE REGRESSION

PLS liner regression is based on certain important assumptions. One of the underlying assumptions is *Heteroscedasticity* of residuals. It means that at each level of the predictor variable, the residuals are distributed with equal variance.

If this assumption does not hold good, heteroscedasticity is said to be present in the residuals. To measure *heteroscedasticity,* a test called Breusch–Pagan (BP) test done.

In our case the Breusch–Pagan (BP) test was run, wherein BP was found as 4.611 with Df=3 and p value = 0.2026. Since p value is greater than 0.05, the Null Hypothesis (H0- Homoscedasticity is present (i.e. the residuals are distributed with equal variance) cannot be rejected. Hence there is no evidence of Heteroscedasticity in our model.

Autocorrelation was not established in the data as Durbin Watson Index (1.029) was found in the indecision zone. [57]

However, the data had signs of Multicollinearity because Pearson Correlation Coefficients were found near 0.9 in some pairs. To make the model robust and to remove the deficiency due to Multicollinearity *PLS Regression* method was used.

Predication of FLF for next five years was thus done using PLS regression. Four different scenarios were plotted. The Jack-knife was used to find out the estimates of the three independent variables so that coefficients of independent variables can be can be estimated as accurately as possible for sensitivity analysis.

More details are given in Chapter 4.

3.5 RESEARCH METHODOLOGY FOR OBJECTIVE III (TO STUDY GLOBAL SCENARIO, CREATE AND TO VALIDATE RECOMMENDATIONS AND REMEDIAL ACTION)

3.5.1 RESEARCH STEPS OF OBJECTIVE III

I. Study of global scenario through literature review (Australia, Germany, Indonesia, USA, Japan and China – (all are large countries and having > 20 % installed capacity through coal) to understand what is happening with thermal power in those countries and what are the options exercised by them.

II. Recommendations/ Remedial action for thermal power plants were drawn based on results of Objective I &II and study of global scenario.

III. Validation of the Recommendations/ Remedial action was done using Delphi (Three rounds) with 15 very senior experts. Experts are in CEO/MD/Executive Director and equivalent positions. List is given in **Annexure F.**

3.5.2 DATA SOURCES AND EXPERT GROUP FOR OBJECTIVE – III

I. Study of published reports, research papers from the target countries, credible publication sources like EIA.

II. Output of Objective-I & II were also used for Objective - III

III. Validation with experts with extensive experience and leadership roles in the sector, having more than 30 years' experience – MDs, CMDs, and Executive Directors, GMs etc.- 15 Nos (List given in Annexure F)

IV. Delphi Method was used. Consensus was reached in 3 rounds. All points where consensus was reached were taken in recommendations. Points where consensus was not reached were dropped from recommendations.

3.6 VALIDITY AND RELIABILITY

3.6.1 CONSTRUCT VALIDITY: (*THIS VALIDITY CHECKS WHETHER THE DATA OR RESEARCH REALLY MEASURES WHAT IT WANTS TO MEASURE? WHETHER THE QUESTIONS WE HAVE ASKED ARE RIGHT?)*

This has been ensured by following measures

I. The Factors affecting PLF were first collected by identifying all relevant factors through Literature Survey exhaustively – **More than 200 papers, research articles have been studied**

II. The Factors so identified from literature review were discussed in depth with Expert Group of 13 members (List given in Annexure) and were further redefine and refine them to achieve, well-articulated factors on which questionnaire responses can be taken.

III. Questionnaire was then prepared and discussed with experts and also the guide. Questionnaire was also run as pilot with first 5 people.

The construct was therefore well developed and validity was taken care.

3.6.2 CONTENT VALIDITY: (*DOES THE TEST AMPLY AND FULLY COVER WHAT IT WANTS TO MEASURE? IS THE TEST MISSING ANY IMPORTANT ASPECT/QUESTION IN THIS AREA, WHICH SHOUD HAVE BEEN MEASURED?)*

This has been ensured by following means –

I. In Objective-I, the factors were first taken out from extensive literature review. These were further discussed with experts so that we do not miss out anything. A comprehensive questionnaire was then developed.

II. When questionnaire was administered to 253 respondents, in the questionnaire, there was an option that if the respondent wishes to add any factor they may do so. This ensured that no significant factor was missed.

III. Sample Data adequacy for objective I has been tested for each question/ variable by formula $n = z^2 \; p\,(1\text{-}p)/\, E^2$ with z value at 95 % - 1.96, Margin of Error – 7 %

IV. In the Hypothesis Testing the Z critical values were taken corresponding to 95% confidence level.

V. In Objective –II, for the Regression Analysis, two methods were used – At first, Excel based hierarchical multiple regression method was used and then R based PLS regression was used to safeguard from the effects of multicollinearity of the data.

VI. The Jack-knife has been used to find out the estimates of the three independent variables so that coefficients of independent variables can be can be estimated as accurately as possible.

VII. Autocorrelation was not found in the data.

VIII. One of the underlying assumptions is *Heteroscedasticity* of residuals. It means that at each level of the predictor variable, the residuals are distributed with equal variance. If this assumption does not hold good, heteroscedasticity is said to be present in the residuals. To measure *heteroscedasticity,* a test called Breusch–Pagan (BP) test done. In our case the Breusch–Pagan (BP) test was run, wherein BP was found as

4.611 with Df=3 and p value = 0.2026. Since p value is greater than 0.05, the Null Hypothesis (H0- Homoscedasticity is present (i.e. the residuals are distributed with equal variance) cannot be rejected. Hence there is no evidence of Heteroscedasticity in our model.

The content validity has therefore been taken care as above.

3.6.3 FACE VALIDITY: (*DOES THE OUTCOME OF THE RESEARCH PRIMA FACIE APPEAR TO BE SUITABLE?)*

I. The face validity has been maintained at all objectives by sharing the results with experts (13 experts at Objective -I stage and 15 experts at Objective -III stage). Refer **(Annexure B & Annexure F)**

II. The methods and results were also discussed with respected guide of the research and other professors to ensure that methods and results have face validity.

III. Two papers published in reputed Scopus indexed international journals from this work.

IV. Consensus achieved from experts during Objective -III Delphi discussions also confirm face validity.

3.6.4 CRITERION VALIDITY: *HOW WELL THE CRITERIA OF TEST PREDICT THE INTENDED CONSTRUCT WHICH BEING MEASURED.*

The methods employed in this research are well established viz (1) Hypothesis Testing (2) Factor Analysis and (3) Regression are very well-established methods for factor identification and prediction.

The Criterion validity was also established by predictions made by other similar work and study of literature.

Moreover, Concurrent Validity is established by actual PLF of India in 2020-21 which was 53.37 % against this research's predicted value of 53.68 % in one of the Scenarios.

3.6.5 RELIABILITY

Reliability measures stability of results. It shows the degree of stability and consistency of results obtained by the research. If various methods applied on the date give very divergent results, the reliability will be low. The idea of reliability is important for faith on the data.

The data for Objective 1 was generated from the respondents (253) based on their experience, authority & responsibility. This is a large sample looking into the specialised area of research. *The results were checked with Hypothesis Testing as well as Factor Analysis. Outcomes of both matched, suggesting that results are reliable.*

Major portion of the research has been published in peer reviewed respectable journals.

There were two layers of expert validation one at the initial exploratory research with 13 experts and also at final stage with 15 experts which ensures that data and results are reliable. Other important attributes of research steps as below also indicate reliability.

3.6.5.1 TEST OF SAMPLE ADEQUACY AND NORMALITY (FOR CONDUCTING Z TEST FOR PROPORTION)

3.6.5.2 ADEQUACY

In Objective – I, Sample adequacy of sample size n was ensured through the formula –

$n = Z^2\ p\ (1\text{-}p)/\ E^2$ [Z is taken at 95 % E is at 7 %)

p is the proportion of response in the sample. Complete result has been tabulated in the Results and Analysis Chapter for Objective – I where data requirement for each question is ascertained.

Our sample size in 253 which meets the minimum requirement for all the questions

3.6.5.3 NORMALITY

With sample size 253, and np∧ and p∧(1-p∧)*n are above 10 for all the observed p values, which shows normal distribution of proportion data.

To cross check the results of Hypothesis Testing, Factor Analysis was also done. Following are some of the statistics from Factor Analysis.

3.6.5.4 KAISER-MEYER-OKIN MEASURE FOR FACTOR ANALYSIS

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is above 0.742 which shows a statistically significant possibility of component reduction.

Table 3.1 : The Kaiser-Meyer-Olkin Measure of Sampling Adequacy

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.742
Bartlett's Test of Sphericity	Approx. Chi-Square	1536.343
	df	300
	Sig.	<.001

Source- SPSS output on the data of responses for objective I.

3.6.5.5 THE CRONBACH'S ALPHA (FACTOR ANALYSIS)

The Cronbach's Alpha of the data set of Objective – I is 0.790 showing a high reliability of response data set.

3.6.5.6 THE PEARSON'S CORRELATION COEFFICIENT (FACTOR ANALYSIS)

The Pearson's Correlation Coefficients between clusters range between 0.414 to 0.622 depicting a good correlation.

3.7 RESEARCH STEPS AT A GLANCE

The following table depicts the research steps at a glance and expected outcomes

Table 3.2: Research steps at a glance

Objective	**Step No**	**Process in brief**	**Expected Outcome**
Objective - I	1	Literature Review	Identification of major areas which might be affecting Capacity Utilization Factor (PLF) and Theoretical Underpinning
	2	Focus Group discussion with experts (13 Experts) to identify variables.	Identification of well-defined variables which might be affecting PLF of Thermal Power Plants
	3	Preparation and administration of Questionnaire	Questionnaire prepared with well-defined variables seeking response on Likert Scale
	4	Analysis of questionnaire using Hypothesis Testing for majority saying a particular variable as major factor (Z test for proportion).	Identifying Variables as Major Factors affecting Capacity Utilization Factor (PLF)
	5	Factor Analysis	Factor Analysis for finally arriving at the Major Factors
Objective -II	1	Regression Analysis (using Excel) for predicting PLF (dependent variable) for next five years. Four top ranking factors affecting Capacity Utilization Factor (PLF) taken as independent variables	Checking best fit regression model and method.

		(Peak Demand, Total Installed Capacity, Installed Capacity (Coal) and Installed Capacity (Renewables)). Past 35 years data of the independent variable taken for regression.	
	2	PLS Regression used for predicting PLF for next five years under four different scenarios.	Prediction of PLF for next five years under different scenarios.
	3	Sensitivity Analysis (Jack Knife used to find out the coefficients)	What is the impact of the independent variables on PLF
	4	Finding out technical financial impact of falling Capacity Utilization Factor (PLF) on thermal power plants.	Flexibilization requirements and detailed calculation of loss of revenue for three sample power stations (660 MW, 800 MW and 500 MW)
Objective-III	1	Study of global scenario- Present status and future plans regarding thermal (Through literature survey). Countries which have significant amount of thermal power in their installed capacity portfolio (> 20 %) have been considered. Australia, Germany, Indonesia, USA, Japan and China.	What are the significant developments and learning from these countries for thermal power producers?
	2	Drawing of Recommendation / Remedial Action for thermal power plants based on output of	Recommendation / Remedial Action to be drawn for thermal power plants based

		Objective-I, Objective -II and step I of Objective -III (Global experience)	on output of Objective-I, Objective -II and Global scenario.
	3	Validation of Recommendation / Remedial Action with expert group using Delphi method (Three phases of Delphi with 15 senior power sector experts)	Final recommendations to be arrived.

Source – Research Methodology adopted for the three Objective (I, II &III)

3.8 CHAPTER SUMMARY

The chapter spells out the research objectives, then describes the research design - how exploratory research was done, how the factors were identified, and how the research design was conceived. Use of Factor Analysis and Hypothesis Testing was done in Objective-I. For Objective -II. Hierarchical Multiple Regression was chosen using excel as software. However, due to data collinearity in the sample, it was thought appropriate to migrate to Partial Least Square (PLS) Regression using R. For Objective III, Delphi method has been chosen for validation of remedial measures.

4 CHAPTER 4 – ANALYSIS, RESULTS & DISCUSSION ON OBJECTIVE – I &II

4.1 CHAPTER OVERVIEW

This chapter presents the output of the research in terms of Objective I &II. In this chapter, the Major Factors affecting Capacity Utilization have been identified and projection of PLF has been done in four different scenarios for the next five years.

4.2 EXPLORATORY RESEARCH FOR FACTORS AFFECTING THERMAL POWER CAPACITY UTILIZATION

Study of the literature pointed out towards following seven areas, which are affecting Capacity Utilization (PLF) of thermal power plants.

1) Effect of Renewable Energy
2) Low Growth of demand as against projected
3) Overcapacity
4) Financial health of Discoms
5) Fuel Availability
6) Evacuation constraints
7) Policy issues discouraging the thermal power generation

[7], [8]

These areas were then discussed with experts in the power sector in Focus Group Discussion mode (13 participants in total, each having experience of more than 20 years in thermal power sector, list attached at Annexure). As a result of the discussion, the areas got refined and focused. Finally, total 25 questions (Factors) were identified on which quantitative techniques were applied through a questionnaire. The experts took lead from the areas identified by the researcher through the literature review and dissected each of the seven areas (Themes) into separate, well defined factors. For example, the area of Financial health (Sl No 3 of above), was extended beyond health of Discoms and divided into four specific questions (i) Financial health of Discoms (ii) Financial health of Generating companies of govt sector (iii) Financial health of Generating companies of private sector (IPPs) and (iv) Reduced lending by banks to thermal power sector. Similarly, each of the areas were segregated in well defined factors (questions). This part of exploratory research brought construct and content validity. Seven areas thus became 25 well defined questions/factors.

4.3 FACTORS IDENTIFIED ON THE BASIS OF LITERATURE REVIEW AND FOCUS GROUP DISCUSSIONS

Table 4.1 : Questions/ Factors identified based on the review of Literature and subsequent Focus Group discussions [7], [8]

1)Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if while demand exists
2)The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition
3)The power utilities of private sector (IPPs) are in financial distress and are unable to maintain their own power plants in good condition
4)Due to large number of thermal power loans becoming NPA, banks have reduced lending creating fund crunch for power producers
5)Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation
6)New emission norms set by Govt in 2015 for thermal power plants
7)Society's growing concern about environment is forcing power stations to reduce production
8)Disproportionately high share of thermal power in Indian grid (63.7 % of total installed capacity as on 31.03.2019)
9)Substantial addition of renewable energy (solar and wind) having must-run status in the grid

10) Grid evacuation constraint (line loading limitations) in some areas causing reduction in power generation
11)The thermal power plants are experiencing forced outages // technical problems (like boiler tube leakages etc) and are unable to generate to full capacity
12)Many thermal power plants in India are ageing and are unable to reach full load capacity
13)The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope
14) Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power
15) India has reached a stage of being power surplus (on most days in a year)
16) Although India is power deficit on totality basis, many regions have actually become power surplus
17) Large number of players in power generation is resulting in fierce competition
18) After opening up of power sector, many new and inexperienced players jumped without understanding the electricity market
19) Low fuel (coal) availability forcing thermal power generators to reduce power generation
20) Poor quality of coal having very high ash is forcing thermal power generators to reduce power generation
21) The tariff / policies are un-supportive of thermal power generators
22) Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available
23) There is lack of policy clarity on whether and how old thermal power plants are to be retired, which creates a dilemma whether to invest in their R&M
24) The Ultra Mega Power scheme did not bear desired results because of policy issues (projects risks were not addressed properly)

25) There is a general perception that coal based thermal power will be entirely phased out in the medium / long run which is inhibiting new and modern technology infusion in thermal plants

Source- Literature Review and Focus Group discussions carried out to find out the shortlist of factors affecting PLF of thermal power plants, under Objective -I. [7], [8]

4.3.1 RESEARCH QUESTIONNAIRE (OBJECTIVE -I) [7], [8]

The above factors identified through literature survey and focus group discussion with experts were made part of the questionnaire survey. Survey was then conducted to receive opinion of respondents on the 25 questions (Factors) identified through exploratory research. The responses were asked respond on Likert Scale for all the 25 questions (Factors). The responses were categorised as (i) Very High Impact (ii) High Impact (iii) Neutral/Undecided (iv) Low or very low impact. Questionnaire was prepared using Google Forms. The Questions asked in the Research Questionnaire is appended at **Annexure – A**

In the next step sample adequacy and normality of data was checked so that we can run statistical technique like Hypothesis Testing. As explained earlier in Chapter 3, each and every factor was run through Hypothesis Testing to ascertain whether it is a Major Factor.

4.3.2 ANALYSIS OF QUESTIONNAIRE AND HYPOTHESIS TESTING

4.3.2.1 SAMPLE ADEQUACY

Since we testing for proportion of responses, the sample adequacy (n) was ensured through the formula –

$n = Z^2 * p *(1-p)/ E^2$ [Z is determined as per confidence level. in our case at 95 % level, z= 1.96, p is proportion of response, E is Margin of Error, we have considered Margin of Error at 7 %). This was tested for all 25 questions. (Detail is given in table below). We find that minimum sample size of 227 meets our criteria for all questions. We have 253 samples for all the questions thus ensuring data adequacy.

Table 4.2- Table showing how the number of samples are adequate for the research

Sample Adequacy								
Sl	Z	Z Square	p	1-p	z2*p(1-p)	Margin of Error	Margin of Error Square	Sample Required
1	1.96	3.8416	0.72	0.28	0.7744666	0.07	0.004225	183
2	1.96	3.8416	0.67	0.33	0.8493778	0.07	0.004225	201
3	1.96	3.8416	0.49	0.51	0.9600158	0.07	0.004225	227
4	1.96	3.8416	0.48	0.52	0.9588634	0.07	0.004225	227
5	1.96	3.8416	0.65	0.35	0.873964	0.07	0.004225	207
6	1.96	3.8416	0.71	0.29	0.7909854	0.07	0.004225	187
7	1.96	3.8416	0.53	0.47	0.9569426	0.07	0.004225	226
8	1.96	3.8416	0.48	0.52	0.9588634	0.07	0.004225	227
9	1.96	3.8416	0.87	0.13	0.434485	0.07	0.004225	103
10	1.96	3.8416	0.4	0.6	0.921984	0.07	0.004225	218
11	1.96	3.8416	0.39	0.61	0.9139166	0.07	0.004225	216
12	1.96	3.8416	0.49	0.51	0.9600158	0.07	0.004225	227
13	1.96	3.8416	0.77	0.23	0.6803474	0.07	0.004225	161
14	1.96	3.8416	0.75	0.25	0.7203	0.07	0.004225	170
15	1.96	3.8416	0.59	0.41	0.929283	0.07	0.004225	220
16	1.96	3.8416	0.63	0.37	0.895477	0.07	0.004225	212
17	1.96	3.8416	0.52	0.48	0.9588634	0.07	0.004225	227
18	1.96	3.8416	0.48	0.52	0.9588634	0.07	0.004225	227
19	1.96	3.8416	0.62	0.38	0.905081	0.07	0.004225	214
20	1.96	3.8416	0.6	0.4	0.921984	0.07	0.004225	218
21	1.96	3.8416	0.6	0.4	0.921984	0.07	0.004225	218
22	1.96	3.8416	0.85	0.15	0.489804	0.07	0.004225	116
23	1.96	3.8416	0.65	0.35	0.873964	0.07	0.004225	207
24	1.96	3.8416	0.55	0.45	0.950796	0.07	0.004225	225
25	1.96	3.8416	0.6	0.4	0.921984	0.07	0.004225	218

Source – Sample adequacy test for the data set for Objective - I

4.3.2.2 DATA NORMAL DISTRIBUTION

As per the **Rule of Sample Proportions**, when the conditions $np \geq 10$ and $n(1-p) \geq 10$ are met, then the sampling distributing will be approximately normal. [58].

For responses to all the 25 questions in this research, both the conditions, p∧n >10 and p∧ (1-p∧)n >10, are satisfied – Hence we can run normal distribution test of proportion. Result of this test has been tabulated in the next section. In this research, sample size is 253, and np∧ and p∧(1-p∧)*n are above 10 for all the observed p∧ values, which shows normal distribution of proportion data. Following table shows the values.

Table 4.3 – Normality test of the data for test of proportion

Test of Normality					
Question	n	p	1-p	np	p(1-p)*n
1	253	0.72	0.28	182.16	51.0
2	253	0.67	0.33	169.51	55.9
3	253	0.49	0.51	123.97	63.2
4	253	0.48	0.52	121.44	63.1
5	253	0.65	0.35	164.45	57.6
6	253	0.71	0.29	179.63	52.1
7	253	0.53	0.47	134.09	63.0
8	253	0.48	0.52	121.44	63.1
9	253	0.87	0.13	220.11	28.6
10	253	0.4	0.6	101.2	60.7
11	253	0.39	0.61	98.67	60.2
12	253	0.49	0.51	123.97	63.2
13	253	0.77	0.23	194.81	44.8
14	253	0.75	0.25	189.75	47.4
15	253	0.59	0.41	149.27	61.2
16	253	0.63	0.37	159.39	59.0
17	253	0.52	0.48	131.56	63.1
18	253	0.48	0.52	121.44	63.1
19	253	0.62	0.38	156.86	59.6
20	253	0.6	0.4	151.8	60.7
21	253	0.6	0.4	151.8	60.7
22	253	0.85	0.15	215.05	32.3
23	253	0.65	0.35	164.45	57.6
24	253	0.55	0.45	139.15	62.6
25	253	0.6	0.4	151.8	60.7

Source – Application of rule of sample proportions on the data collected for Objective- I

4.3.2.3 HYPOTHESIS TESTING

Analysis was then done using **Hypothesis testing for proportion.** If majority (> 50 %) of the respondents feel that a particular factor has Very High or High Impact on thermal power PLF- such factor shall be considered a Major Factor. We have done z statistic test of proportion to ascertain whether majority of the respondents have chosen a particular factor as having Very High or High impact (a+b). Our sample size is. N = 253. Null hypothesis (Ho) is – population proportion P is 0.5 (i.e only 50% respondents believe that this factor has Very High or High impact. Alternate hypothesis is that P is significantly greater than 50 %. (95 % confidence level) [7], [8]

(H0, p0 = 0.5 i.e. 50 %,

Ha, p0>0.5, a one tailed test) (p0 is hypothesised proportion, p∧ is measured proportion)

A $p^\wedge$-critical value corresponding to Z-critical value approach has been used. In order to do this, the Z critical value at 95 % confidence level (1.96) has been taken and applied in formula below to find p critical value for our sample size (253).

Our approach is that if sample p is greater than p-critical, it can be concluded that the Null Hypothesis is rejected and there is evidence to believe that that majority of experts think that this particular factor is a Major Factor. This test was done for all the factors.

Following calculation shows how p critical value (p-cut-off) has been calculated.

$Z = (p^\wedge - p0)/\sqrt{p0(1- p0)/n}$

$Z\_crit\ value = (p^\wedge\_cutoff - p0)/\sqrt{p0(1- p0)/n}$

Z_crit value at 95 % confidence interval is 2.576

$13.96 = (p^\wedge-0.5)/\sqrt{0.5(1-0.5)/253}$

This gives,

$p^\wedge\_crit\ value = 0.56$

The p critical value (p-cut-off) comes to 0.56. This means that if p (proportion of respondents saying a particular factor as a Major Factor) is more than 0.56 i.e. if more than 56 % percent respondents say that a particular factor is a Major Factor, then we infer that this is a majority opinion (with statistical significance).

Responses were sought on the 25 Questions **(Annexure - A)** from power professionals from a broad spectrum of respondents hailing from diverse sectors like – Central Power Producers (Central PSUs), State Power Producers (State PSUs), Private Sector Power Producers (IPPs), Other PSUs, Regulators, Grid Operators, Consultants and Academicians. Responses were collected from targeted contacts using Google Form sent by electronic means (Email/ WhatsApp).

Total 253 responses were received from 760 people contacted.

The table below lists all the 25 questions (factors) and tabulates the responses of 253 respondents against all the variables. Upon Hypothesis Testing, 14 factors came significant. [7], [8]

4.4 QUESTIONNAIRE RESPONSE & ANALYSIS (OBJECTIVE -I)

Table 4.4 : Questionnaire Response & Analysis - Hypothesis Testing carried out based the responses received for all the 25 questions (Factors) [7], [8]

Factors	Respondents saying it is a Major Factor (Out of total 253) (a)	Proportion p∧ of very high & High (a/253)	p∧crit value at Z _critical value of 1.96 (with sample size 253)	H0 Accepted / Rejected	Major Factor as per Hypothesis Testing (Yes /No)
1)Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if while demand exists	181	0.72	0.56	Rejected	**Yes**
2)The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition	170	0.67	0.56	Rejected	**Yes**
3)The power utilities of private sector (IPPs) are in financial distress and are unable to	125	0.49	0.56	Not rejected	No

maintain their own power plants in good condition					
4)Due to large number of thermal power loans becoming NPA, banks have reduced lending creating fund crunch for power producers	122	0.48	0.56	Not Rejected	No
5)Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation	165	0.65	0.56	Rejected	**Yes**
6)New emission norms set by Govt in 2015 for thermal power plants	179	0.71	0.56	Rejected	**Yes**
7)Society's growing concern about environment is forcing power stations to reduce production	133	0.53	0.56	Not Rejected	No
8)Disproportionately high share of thermal power in Indian grid (63.7 % of total installed capacity as on 31.03.2019)	121	0.48	0.56	Not Rejected	No
9) Substantial	220	0.87	0.56	Rejected	**Yes**

addition of renewable energy (solar and wind) having must-run status in the grid					
10) Grid evacuation constraint (line loading limitations) in some areas causing reduction in power generation	103	0.40	0.56	Not Rejected	No
11)The thermal power plants are experiencing forced outages // technical problems (like boiler tube leakages etc) and are unable to generate to full capacity	98	0.39	0.56	Not Rejected	No
12)Many thermal power plants in India are ageing and are unable to reach full load capacity	124	0.49	0.56	Not Rejected	No
13)The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up	195	0.77	0.56	Rejected	**Yes**

14) Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power	190	0.75	0.56	Rejected	**Yes**
15) India has reached a stage of being power surplus (on most days in a year)	151	0.59	0.56	Not Rejected	**Yes**
16) Although India is power deficit on totality basis, many regions have actually become power surplus	159	0.63	0.56	Rejected	**Yes**
17) Large number of players in power generation is resulting in fierce competition	131	0.52	0.56	Not Rejected	No
18) After opening up of power sector, many new and inexperienced players jumped without understanding the electricity market	121	0.48	0.56	Not Rejected	No
19) Low fuel (coal) availability forcing thermal power generators to reduce	156	0.62	0.56	Rejected	**Yes**

power generation					
20) Poor quality of coal having very high ash is forcing thermal power generators to reduce power generation	151	0.60	0.56	Not Rejected	No
21) The tariff / policies are un-supportive of thermal power generators	**153**	**0.60**	**0.56**	Rejected	**Yes**
22) Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available	216	0.85	0.56	Rejected	**Yes**
23) **There is lack of policy clarity on whether and how old thermal power plants are to be retired, which creates a dilemma whether to invest in their R&M**	164	0.65	0.56	Rejected	**Yes**

24) The Ultra Mega Power scheme did not bear desired results because of policy issues (projects risks were not addressed properly)	138	0.55	0.56	Not Rejected	No
25) **There is a general perception that coal based thermal power will be entirely phased out in the medium / long run which is inhibiting new and modern technology infusion in thermal plants**	152	0.60	0.56	Rejected	**Yes**

Source- Hypothesis Testing carried out based the 253 responses received for all the 25 questions (Factors) [7], [8]

4.5 MAJOR FACTORS IDENTIFIED THROUGH HYPOTHESIS TESTING

Analysing the results of survey with Hypothesis Testing we find that there are 14 factors (variables) out of the 25, which can be categorised under Major Factors affecting thermal power capacity utilization in India. They are listed below-[7], [8]

1) *Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if demand exists*

2) *The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition*

3) *Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation*

4) *New emission norms set by Govt in 2015 for thermal power plants.*

5) *Substantial addition of renewable energy (solar and wind) having must-run status in the grid*

6) *The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up*

7) *Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power*

8) *India has reached a stage of being power surplus (on most days in a year)*

9) *Although India is power deficit on totality basis, many regions have actually become power surplus*

10) *Low fuel (coal) availability forcing thermal power generators to reduce power generation*

11) *The tariff / policies are un-supportive of thermal power generators*

12) *Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available.*

13) *There is lack of policy clarity on whether and how old thermal power plants are to be retired, which creates a dilemma whether to invest in their R&M*

14) *There is a general perception that coal based thermal power will be entirely phased out in the medium / long run which is inhibiting new and modern technology infusion in thermal plants*

4.6 FACTOR ANALYSIS (PRINCIPAL COMPONENT ANALYSIS)

Since Factor Analysis is a powerful tool to group and identify underlying factors based on certain statistical attributes, it was decided to deploy Factor Analysis in the data so as to identify whether certain factors (out of the total 25 identified in the exploratory research) emerge as clustered together identified as Major Factors. SPSS Software was used for the analysis. Salient results are given in next sections. This Factor Analysis would also confirm and substantiate the results of Hypothesis Testing which was done on the same data with 14 factors emerging as Major Factors.

Following are some of the select statistics of Factor Analysis which was performed using SPSS software.

4.6.1 SCREE PLOT

The scree plot output from SPSS indicates that there eight underlying components having eigenvalues above 1.0

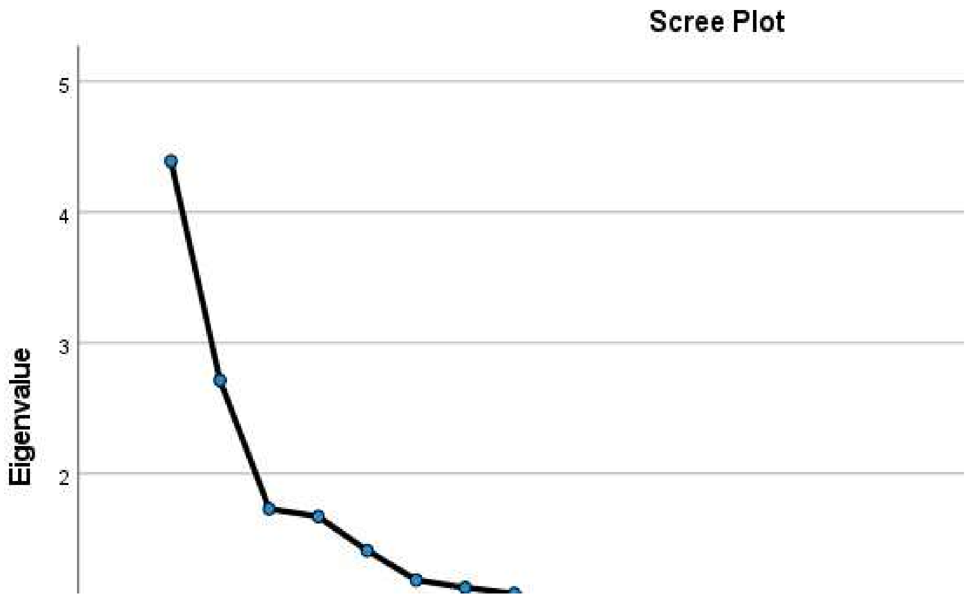


Chart C4.1: Scree Plot of Factor Analysis
Source - SPSS output of this research

4.6.2 THE KAISER-MEYER-OLKIN MEASURE OF SAMPLING ADEQUACY

The Kaiser-Meyer-Olkin Measure of Sampling Adequacy is above 7.0 which shows a statistically significant possibility of component reduction.

Table 4.5- The Kaiser-Meyer-Olkin Measure of Sampling Adequacy-

KMO and Bartlett's Test

Kaiser-Meyer-Olkin Measure of Sampling Adequacy.		.742
Bartlett's Test of Sphericity	Approx. Chi-Square	1536.343
	df	300
	Sig.	<.001

Source- SPSS output

4.6.3 EIGENVALUES

Eight Components as blow have more than 1 Eigenvalues

Table 4.6 – Eigenvalues of eight components

Total Variance Explained

Component	Initial Eigenvalues			Extraction Sums of Squared Loadings		
	Total	% of Variance	Cumulative %	Total	% of Variance	Cumulative %
1	4.390	17.561	17.561	4.390	17.561	17.561
2	2.714	10.855	28.415	2.714	10.855	28.415
3	1.731	6.922	35.338	1.731	6.922	35.338
4	1.671	6.685	42.023	1.671	6.685	42.023
5	1.411	5.644	47.667	1.411	5.644	47.667
6	1.186	4.744	52.411	1.186	4.744	52.411
7	1.127	4.508	56.919	1.127	4.508	56.919
8	1.082	4.327	61.245	1.082	4.327	61.245

Source - SPSS Output (Extraction Method: Principal Component Analysis).

Cumulative extraction sum of Squared Loadings of the eight components is 61.245 %

4.6.4 COMMUNALITIES

Table showing communalities of the data is placed at **Annexure-C**. Overall, the communalities are strong signifying that variability in a particular factor is explained well by the underlying data. The extraction method used is Principal Component Analysis.

4.6.5 DESCRIPTIVE STATISTICS

Descriptive Statistics of all the variables has been shown in **Annexure D**

4.6.6 RELIABILITY STATISTICS- CRONBACH'S ALPHA

Table 4.7 – Reliability Statistics- Cronbach's Alpha

Reliability Statistics

Cronbach's Alpha	N of Items
.790	25

Source- SPSS analysis of objective – I data

Cronbach's Alpha is 0.790 signifying a high reliability of response data set.

4.6.7 COMPONENT MATRIX

Component Matrix is the main tool of Factor Analysis. It helps in identifying the underlying association of factors (also known as variables in Factor Analysis) with a certain Component.

Once the factors are clustered in components, the researcher has to find the underlying association of the factors and interpret the results. Following Component Matrix has been used to group our 25 factors in 8 Components. The Pearson's Correlation Coefficients in the Matrix depict moderate to high correlation.

The factors show distributed loading towards multiple Components. A factor having highest factor loading towards a particular Component has been clustered with that particular Component. All the 25 factors are thus clustered within eight Components. Components are then analysed to draw conclusion.

Component Matrix[a]

Table 4.8 – Component Matrix, Principal Component Analysis.

	Component							
	1	2	3	4	5	6	7	8
VAR00002				.517			.460	
VAR00003	.416			.497				
VAR00004	.468	-.302		.431				
VAR00005	.444	-.317				.362		
VAR00006			-.409	-.306		.475		
VAR00007	.381		-.529					
VAR00008	.431		-.429		.439			
VAR00009	.388			-.390				.473
VAR00010		.643						
VAR00011	.502						.338	
VAR00012	.564	-.302		-.371				
VAR00013	.622	-.326						
VAR00014	.416						-.544	
VAR00015		.533	.387				.303	
VAR00016		.641	.358					
VAR00017		.528	.472					-.317
VAR00018	.414	.343			.384			
VAR00019	.538							
VAR00020	.463			-.304	-.332	-.467		
VAR00021	.611					-.453		
VAR00022	.443							
VAR00023		.653						
VAR00024	.455			.353	-.344			
VAR00025	.529				-.459			
VAR00026	.404		-.408		-.356			

Source- SPSS output on Factor Analysis. (Here VAR 0002, VAR 0003 correspond to Q1, Q2 of our questionnaire and so on)

a. 8 components extracted.

After the clustering of factors under different Components, following table is prepared. The factors showing maximum correlation to a particular Component are clubbed under that particular component. Following is the result –

4.6.8 COMPONENTS AND UNDERLYING VARIABLES IDENTIFIED THROUGH FACTOR ANALYSIS

Table 4.9 – Identification of underlying factors clustered in components

Component	Underlying Factors (Variables)
1	VAR0004 (Q3), VAR00005 (Q4), VAR00011 (Q10), VAR00012 (Q11), VAR00013 (Q12), VAR00018 (Q17), VAR00019(Q18),VAR00021(Q20),VAR00022(Q21),VAR00024(Q23),VAR00025(Q24)
2	VAR00010(Q9),VAR00015 (Q14),VAR00016 (Q15),VAR00017(Q16), VAR00023(Q22)
3	VAR00007(Q6), VAR00026(Q25)
4	VAR00002 (Q1), VAR00003(Q2)
5	VAR00008(Q7)
6	VAR00006 (Q5),VAR00020(Q19)
7	VAR00014 (Q13)
8	VAR00009 (Q8)

Source – SPSS output of this research

4.7 INTERPRETATION OF FACTOR ANALYSIS

Proper interpretation of the Factor Analysis results is a challenging task. It is challenging because here the researcher's assumptions, underlying logic, pattern of responses and the purpose of research etc play important role. In this research, our endeavour is to find out variables which are having higher ratings by respondents so that we can categorise them as Major Factors.

Our pursuit is therefore to know whether a certain Component contains factors which have been rated high by the respondents. That is the underlying similarity between the factors for our analysis.

For this purpose, the Descriptive Statistics (Mean) of each of the eight components was calculated using SPSS. To get the same, following syntax was used-

*Create factors as means over variables per factor.

compute fac_1 = mean (VAR00004,VAR00005, VAR00011, VAR00012, VAR00013, VAR00018, VAR00019, VAR00021, VAR00022, VAR00024, VAR00025).

compute fac_2 = mean (VAR00010, VAR00015, VAR00016, VAR00017).

compute fac_3 = mean (VAR00007, VAR00026).

compute fac_4 = mean (VAR00002, VAR00003).

compute fac_5 = mean (VAR00008).

compute fac_6 = mean (VAR00006, VAR00020).

compute fac_7 = mean (VAR00014).

compute fac_8 = mean (VAR00009).

*Label factors .

VARIABLE LABELS

fac_1 'Set1'

fac_2 'Set2'

fac_3 'Set3'

fac_4 'Set4'

fac_5 'Set5'

fac_6 'Set6'

fac_7 'Set7'

fac_8 'Set8' .

*Quick check.

DESCRIPTIVES fac_1 , fac_2 , fac_3 , fac_4 , fac_5 , fac_6 , fac_7 , fac_8

The output of above is tabulated in the table below, which depicts the Descriptive Statistics (Mean) of each of the eight components.

Table 4.10- Component Descriptive Analysis

Component	Mean
1	3.2824
2	3.8520
3	3.6260
4	3.6988
5	3.3715
6	3.6771
7	3.8452
8	3.2480

Source SPSS Output of tis research.

In order to find out top factors we have considered all Components having Mean Value above 3.67 or above, as top components. The rationale is as below-

In our five-point Likert scale we have assigned the response values as – (1) Very-Low-Impact, (2) Low-Impact (3) Neutral (4) High-Impact (5) Very-High-Impact. So, in order to make cut-off points we apply the formula (Maximum Value-Minimum Value)/n = (5-1)/3 = **1.33.** (n being the number of categories that we wish to create, here we intend to create three categories - Low, Mid & High)

1.33 is our interval value for dividing the categories.

Max refers to the highest possible score of the given Likert scale (5, in our case)

Min refers to the lowest possible score (1, in our case)

n refers to the number of CATEGORIES we intend to create

Now we can get three categories (Low, Mid & High) as per our intervals -

Low i.e (1 to 1+ 1.33) i.e. (1 to 2.33),

Mid (2.34 to 2.33 + 1.33) i.e (2.34 to 3.66)

High (3.67 to 3.66 + 1.33) i.e. (3.67 to 5)

So, the Components which have response mean values 3.67 or above are categorised as Major. The following table shows which components fall under Major category.

4.7.1 COMPONENT DESCRIPTIVE STATISTICS AND IDENTIFICATION OF TOP COMPONENTS

Identification of top components using descriptive statistics

Table 4.11 - Components and their Descriptive Statistics (Mean)

Component	Underlying Factors	Variable description in short	Descriptive Statistics - Mean	Comment
1	VAR0004 (Q3) VAR00005 (Q4) VAR00011 (Q10) VAR00012 (Q11) VAR00013(Q12), VAR00018(Q17), VAR00019(Q18), VAR00021(Q20), VAR00022(Q21), VAR00024(Q23), VAR00025(Q24)	Financial problems of IPPs, Reduced lending by banks, Grid constraints, Forced Outages, Ageing of plants, Large number of players, many new inexperienced players, Poor coal quality, Unsupportive tariff policies , lack of policy clarity, Ultra Mega scheme failed	3.2824	Not a Major Component
2	**VAR00010 (Q9), VAR00015(Q14), VAR00016 (Q15), VAR00017(Q16), VAR00023(Q22)**	Capacity addition of renewable energy, low growth of demand, supply more than demand, supply more than demand (on regional basis), when renewable is there thermal has to reduce generation	3.8520	Major Component (Rank -1)
3	VAR00007(Q6),	New emission norms, Society's growing concern	3.6260	Not a Major

	VAR00026(Q25)	on environment, perception that thermal will be phased out		Component
4	**VAR00002 (Q1), VAR00003(Q2)**	Poor financial health of Discoms, Poor Financial health of Gencos	3.6988	Major Component (Rank -3)
5	VAR00008(Q7)	Society's growing concern about environment	3.3715	Not a Major Component
6	**VAR00006 (Q5), VAR00020(Q19)**	Rising cost of thermal power, Low fuel availability	3.6771	Major Component (Rank -4)
7	**VAR00014 (Q13)**	Thermal plants are unable to cope up with flexible operation	3.8452	Major Component (Rank -2)
8	VAR00009 (Q8)	Disproportionate share of thermal	3.2480	Not a Major Component

Source – Components and Factors identified through Factor Analysis

The above table shows that Component 2,4, 6 &7 are top components having mean values above 3.66.

Having found out the top Components, all underlying factors of the top Components are considered as Major Factors. We therefore conclude that following factors are Major Factors-

VAR00010 (Q9), VAR00015 (Q14), VAR00016 (Q15), VAR00017 (Q16), VAR00023 (Q22), VAR00002 (Q1), VAR00003 (Q2), VAR00006 (Q5) , VAR00020(Q19) and V14 (Q13) (Total 10) are major factors as per Factor Analysis. (Associated with components having cluster means above 3.67). These are the 10 Major Factors which emerge out of Factor Analysis.

(***It is pertinent to clarify here that the term Factor used in this research is not same as the term Factor used in Factor Analysis. In Factor Analysis, we actually club the variables in components using the reduction process and then search***

the underlying "Factors" which bind the variable to a particular component. Here in our research, we are finding high ranking Components then identifying all the associated factors with the high-ranking components and then name them as Major Factors. Therefore, the term Factor is used here in normal management parlance and not in the statistical sense of the term)

4.8 RESULTS OF FACTOR ANALYSIS

Factor Analysis is a robust way to group factors based on an underlying similarity. Here the underlying similarity we are searching whether some particular factors can get clubbed together and be identified at Major Factors. The aim of Factor Analysis was to find out the Major Factors out of the 25 factors, thus enhancing reliability of the findings.

In Factor Analysis, the Major Factors were identified based on our decision rule described above, wherein we have taken factors associated with the Components having mean values 3.67 or above, as Major Factors. We found the 10 variables emerged as Major Factors.

The Major Factors emerging from Factor Analysis are listed below.

1) *Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if demand exists*
2) *The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition*
3) *Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation*
4) *Substantial addition of renewable energy (solar and wind) having must-run status in the grid*
5) *The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up.*

6) *Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power*

7) *India has reached a stage of being power surplus (on most days in a year)*

8) *Although India is power deficit on totality basis, many regions have actually become power surplus*

9) *Low fuel (coal) availability forcing thermal power generators to reduce power generation*

10) *Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available.*

The Hypothesis Testing had resulted in 14 factors that were categorised as Major Major Factors. After Factor Analysis, we found 10 Major Factors. [7], [8]

It is found that the 10 factors identified in Factor Analysis are also appearing in Hypothesis Testing results. This enhances reliability of the results. The result of the Hypothesis Testing combined with the Factor Analysis are tabulated below for each of the 25 factors.

4.9 COMBINED RESULT OF HYPOTHESIS TESTING AND FACTOR ANALYSIS

We depict below, in one concise table, which factors have emerged as Major Factors through Hypothesis Testing, and which have emerged as Major Factors using Factor Analysis *and where the is commonalty or divergence between the two results*. [7], [8]

The factors which both the methods confirm to be a Major Factor (common in both the methods), have been finally taken as outcome of our objective. *We find that there are 10 such factors which emerge as Major Factors using both the methods.* The table below shows the 10 factors (Viz Sl No 1, 2, 5, 9, 13, 14, 15, 16, 19 and

22 of the table below) emerging as Major Factors both as per Hypothesis Testing and as per Factor Analysis.

Factors emerging as Major Factors using both - Hypothesis Testing and Factor Analysis [7],[8]

Table 4.12- Combined results of Hypothesis Testing and Factor Analysis

Variables	Very High or High impact (a)	Proportion p∧ of very high & High (a/253)	p∧crit value at Z _critical value of 1.96 (with sample size 253)	H0 Accepted/ Rejected	Major Factor as per Hypothesis Testing (Yes /No)	Whether a major factor as per Factor Analysis (Yes/No)	Is there agreement between Hypothesis Testing and Factor Analysis	Finally Taken as Major Factor
1)*Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if while demand exists*	181	0.72	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**

2)*The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition*	170	0.67	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**
3)The power utilities of private sector (IPPs) are in financial distress and are unable to maintain their own power plants in good	125	0.49	0.56	Not rejected	No	No	Yes	Both Methods Say No

condition								
4)Due to large number of thermal power loans becoming NPA, banks have reduced lending creating fund crunch for power producers	122	0.48	0.56	Not Rejected	No	No	Yes	Both Methods Say No
5)***Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation***	165	0.65	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**
6)New emission	179	0.71	0.56	Rejected	Yes	No	Yes	One method

norms set by Govt in 2015 for thermal power plants								says Yes, the other No so not taken as Major Factor
7)Society's growing concern about environment is forcing power stations to reduce production	133	0.53	0.56	Not Rejected	No	No	Yes	Both Methods Say No
8)Disproportionately high share of thermal power in Indian grid (63.7 % of total installed capacity as on 31.03.2019)	121	0.48	0.56	Not Rejected	No	No	Yes	Both Methods Say No
9) *Substantial*	220	0.87	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say**

addition of renewable energy (solar and wind) having must-run status in the grid								**Yes**
10) Grid evacuation constraint (line loading limitations) in some areas causing reduction in power generation	103	0.40	0.56	Not Rejected	No	No	Yes	Both Methods Say No
11)The thermal power plants are experiencing forced outages // technical problems	98	0.39	0.56	Not Rejected	No	No	Yes	Both Methods Say No

(like boiler tube leakages etc) and are unable to generate to full capacity								
12)Many thermal power plants in India are ageing and are unable to reach full load capacity	124	0.49	0.56	Not Rejected	No	No	Yes	Both Methods Say No
13)*The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation*	195	0.77	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**

that coal plants are unable to cope up								
14) ***Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power***	190	0.75	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**
15) ***India has reached a stage of being power surplus (on most days in a year)***	151	0.59	0.56	Not Rejected	Yes	Yes	Yes	**Both Methods Say Yes**
16) ***Although India is power deficit on totality***	159	0.63	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**

basis, many regions have actually become power surplus								
17) Large number of players in power generation is resulting in fierce competition	131	0.52	0.56	Not Rejected	No	No	Yes	Both Methods Say No
18) After opening up of power sector, many new and inexperienced players jumped without understanding the electricity market	121	0.48	0.56	Not Rejected	No	No	Yes	Both Methods Say No
19) Low fuel (coal) availability forcing	156	0.62	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**

thermal power generators to reduce power generation								
20) Poor quality of coal having very high ash is forcing thermal power generators to reduce power generation	151	0.60	0.56	Not Rejected	No	No	Yes	Both Methods Say No
21) The tariff / policies are un-supportive of thermal power generators	153	0.60	0.56	Rejected	Yes	No	No	One method says Yes, the other No so not taken as Major Factor
22) ***Renewable energy is getting promoted***	216	0.85	0.56	Rejected	Yes	Yes	Yes	**Both Methods Say Yes**

at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available								
23) There is lack of policy clarity on whether and how old thermal power plants are to be retired, which creates a dilemma whether to invest in their R&M	164	0.65	0.56	Rejected	Yes	No	No	One method says Yes, the other No so not taken as Major Factor

24) The Ultra Mega Power scheme did not bear desired results because of policy issues (projects risks were not addressed properly)	138	0.55	0.56	Not Rejected	No	No	Yes	Both Methods Say No
25) There is a general perception that coal based thermal power will be entirely phased out in the medium / long run which is inhibiting new and modern technology infusion in	152	0.60	0.56	Rejected	Yes	No	No	One method says Yes, the other No so not taken as Major Factor

thermal plants								

Source- Results of Hypothesis Testing and Factor Analysis for all the 25 Factors

We find that out of 14 Factors that were found as Major Factors in the Hypothesis Testing, 10 are also appearing common in Factor Analysis. These 10 common factors have therefore been taken as Major Factors. These 10 Major Factors which are now final outcome of Objective – I are listed below.

1) ***Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if demand exists***
2) ***The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition***
3) ***Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation***
4) ***Substantial addition of renewable energy (solar and wind) having must-run status in the grid***
5) ***The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up.***
6) ***Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power***
7) ***India has reached a stage of being power surplus (on most days in a year)***
8) ***Although India is power deficit on totality basis, many regions have actually become power surplus***
9) ***Low fuel (coal) availability forcing thermal power generators to reduce power generation***

10) ***Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available.***

4.10 DISCUSSION ON RESULTS OF OBJECTIVE - I

This section presents discussion on all the 10 identified Major Factors affecting PLF of thermal power plants. [7], [8]

(i) Poor financial health of power distribution entities (DISCOMS) [7], [8]]

Dwindling financial health of distribution companies is a major concern in the sector. (*Ref Literature Review Table 2.1, Sub Theme 3, Paper Sl No 14,19*). State Distribution Companies (Discoms) are entrusted with last mile delivery of electricity to households, industries and commercial establishments. Unfortunately they are facing high Aggregate Technical and Commercial losses (AT&C) losses which appears to be a major reason for their financial difficulties. Most Discoms also have negative ARR-ACS difference. It is the difference between Average Revenue Realized (ARR) and Average Cost of Supply (ACS) per unit of electricity. This means that cost realised from customers per unit of electricity is less than the rate at which electricity is bought by the Discoms from Gencos. This results in losses for the Discoms. These losses (of Discoms) have important bearing on the entire power business. As a result of their financial woes, Discoms delay their payments to power generation companies, which in turn creates problems in generation sector also.

Bloomberg Quint [59] reports that the Discoms in India lose nearly Rs 360.00 ($4.63) on every MWHr of electricity supplied by them, which amounts to nearly 10% loss on the retail price. The Discoms are also heavily debt ridden. Total debt in the distribution sector was estimated at Rs 4.3 trillion ($56.4 billion), as per a report by the ADB. [59]

For improving the poor financial health of Discoms, Govt of India has come up with a scheme called Ujjwal Discom Assurance Yojana (UDAY). Brought in 2016, this scheme aims at cleaning the debt laden balance sheets of the Discoms by taking over the debt by respective state Governments, absorbing some of the losses by the State Governments and in parallel mandating the Discoms to reduce AT&C losses by deployment of several technical and commercial interventions.

While there has been some reduction in AT&C losses due to the scheme, the scheme has not been able to turn Discoms from red to green and they continue to incur huge losses. Discoms' financial losses stood at Rs 28,369 crore for FY19, up 88.6% year-on-year reports Financial Express [61]

As the things stand out today, the financial position of Discoms will remain a matter of worry for at least the next five-year horizon. This is likely to continue unless decisive reforms are undertaken in the distribution sector supported with strong social and political will to make the Discoms profitable. With central government making some serious efforts in recent years including privatisation of distribution and strengthening the UDAY scheme, some improvement is expected in this area. However, looking at the huge losses and complex nature of Discom's business, any major respite in this area (which might reverse the losses trend in Discoms and can support capacity utilization of thermal power plants) appears unlikely in next 5 years horizon.

(ii) The power producing utilities of state sector (Sate Gencos) are in financial distress and are unable to maintain their own power plants in good condition [7], [8]

Most of the state Gencos have been carved out of the erstwhile state electricity boards. They suffer from legacy challenges like financial crunch, operational inefficiencies etc. Moreover, with passage of time, the power plants of the state Gencos are getting very old and are unable to operate at full capacities. Large capital is required for maintenance, renovation and modernisation of such plants.

The generating companies lack such financial resources because of the fact that their main sources of revenue are the state-owned distribution companies (Discoms) who are themselves under financial distress. Due to this situation, there are staggering dues which the Discoms owe to the Gencos. [62] Mint (2020, Jan 05) reported that as on November 2019, the Discoms owed Rs 81085 Cr (nearly 11 Billion USD) to the Gencos. Some Discoms are also trying to renegotiate the legacy power purchase agreements with Gencos with an aim to reduce tariff. Such efforts are further likely to put pressure on Gencos. Moreover, because of many plants being of old vintage technology, their efficiency levels are also low. These plants do not compete in the merit order system, resulting in low scheduling hence low-capacity utilization.

State Gencos' fate is tied with the Discoms. Unless the financial condition of Discoms improves, the State Gencos are also likely to remain in difficulty. They will not be able to invest in modern technology and pollution control equipment thus keeping the Capacity Utilization Factors (PLF) low. Some state Gencos are putting up new supercritical units, which might run at high PLFs if other factors are favourable. However, for the existing plants any significant improvement in PLF is not foreseen in next five years' horizon.

(iii) Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation[7], [8]

It is evident that the coal-based generation is slowly losing the cost battle against renewables. The regular inflation in spares cost and increase in wages of employees are pushing up O&M cost of thermal power. Moreover, the major raw material for thermal power – coal is also becoming costlier. Following table shows the rising Wholesale Price Index (Non-coking coal) for last seven years.

Table 4.13- Wholesale Price Index (Non-coking coal)

Financial Year	**Index**

2018-19	119
2017-18	112.5
2016-17	110.5
2015-16	109.6
2014-15	109.6
2013-14	106.8
2012-13	103.2

Source - (Office of the economic advisor of India website) [60]

Coal based generation is also becoming costlier due to various other cost drivers. Coal is increasingly being perceived a bad guy all over the world due to the air, water and land pollution that it creates. More and more pressure to reduce environmental footprint is necessitating capital infusion for addition of pollution control equipment (like SOx and NOx control equipment) in the power plants.

In the year 2010, Govt of India has also introduced a special levy on coal prices, called the C*oal Cess*. This cess is levied on the coal price, both Indian and imported, on the principle that polluter should be charged to compensate for the pollution it creates. The cess amount has increased substantially from Rs 50 ($0.67) to Rs 400 ($ 5.38) per ton in a span of six years between 2010 to 2016, as reported by Economic Times [64].

These capital as well O&M costs are pushing the prices up and are adding to the woes of thermal power generators. Reuters [65] reports that the main reason that coal-based generation may lose the battle because thermal power is becoming too expensive as compared to renewable energy.

On the other hand, prices of renewable energy are falling due to more and more technological breakthroughs, policy support and economies of scale. In recent years, renewable prices have gone below Rs 3 (4 U.S. cents) per unit, a level that most of the coal-based generators are finding difficult to match. Reuters [65] also opines that in future, there is almost no chance that new coal based generators can produce electricity at lower rates than renewables, because of the ever increasing capital and O&M costs in thermal power generation. It is anticipated that this trend will continue and will keep on putting pressure on PLF of thermal power in the next five years horizon.

(iv) Substantial addition of renewable energy (solar and wind) having must-run status in the grid is causing coal based PLF to fall down [7], [8]

Indian Grid has witnessed substantial capacity addition of renewable energy in recent years. If we look at the past ten years' data, the coal-based generation growth was 2.2 % CAGR between 2016-17 to 2019-2020 whereas renewables, have been rising sharply in this period (14.86 % CAGR between 2016-17 to 2019 - 20). Going ahead, Govt of India has set ambitious plans to establish 175 GW of RE capacity in the country by the year 2022. Honourable Prime Minister Shri Narendra Modi has further upped this commitment recently by announcing that India will attain 450 GW renewable capacity by 2030. [66]

Amidst such substantial renewable capacity addition, the electricity buying entities (Discoms) have been put under obligation to buy from renewable sources under a provision called Renewable Purchase Obligation (RPO). Indian government has stipulated that by FY22 the states must procure minimum 21% quantity of their overall power purchases through renewable energy, as reported by Financial Express [67]

This stipulation means that Discoms are under obligation to buy renewable energy first (at least up to 22% of energy requirement), even if it is costlier than thermal. Regulators are determined to enforce this stipulation. The Economic Times [68] reported that the Delhi's power regulator Delhi Electricity Regulatory Commission (DERC) has slapped penalties of Rs 1.71 crore (Approx. US $ 231143) on Tata Power Delhi Distribution Limited (TPDDL) and Rs 2.88 crore (Approx. US$ 389294) each on BSES Yamuna Power Limited (BYPL) and BSES Rajdhani

Power Limited (BRPL) because they have defaulted on meeting Renewable Purchase obligations (RPO) for 3 years.

Such stipulations will have obvious bearing on capacity utilization of thermal power plants. Thermal generators will have to increasingly face this brunt. It is one of the factors that is likely to put (negative) pressure on thermal power PLF for next five years and even beyond.

(v) The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up [7], [8]

When large quantum of power is fed to the grid from renewables to meet the demand, thermal has to reduce generation (ramp down). At other times in the day, when renewable is not available (say in the evening peak time, when the Sun sets), thermal power has to increase (ramp up) generation to meet the demand. This situation forces thermal power plants to run in cyclic operation known as *flexible operation regime.*

Such flexible operation results in cyclic loading creates several challenges for the thermal power generator. Most power plants were not designed to run under such flexible regime. The main reason is that the stability of boiler flame gets endangered at lower loads. The turbine also faces difficulty at varying main steam pressure and temperature. Moreover, all the metal parts and welded joints undergo creep and fatigue damages. The plants are supposed to respond fast and maintain the ramp rate as required for grid stability. The central regulator i.e. the Central Electricity Regulatory Commission (CERC) has notified the tariff regulation 2020-24 wherein it is stipulated that in case a generator fails to achieve the load ramp rate of 1% per minute, the ROE permitted to the thermal generator shall be reduced by 0.25%, ref CERC Tariff Norms (2019-24) [16]. This is a new challenge for thermal power plants.

Faced with this new challenge, thermal power plants are bracing themselves for flexible operation. This requires major changes in O&M strategy. It also requires investment in retrofitting the units with additional functionality and monitoring. If such changes are not done, power plant units will either trip on fault or will have to be put under shutdown. This will result in further fall of plant Utilization Factor (PLF).

To remain in existence, the thermal power plants must become ready for flexible operation. If done properly, it will help in better Utilization Factor (PLF) and if not done, it will lead to the plants being shut down. This will be one of the important factors for improving capacity utilization of thermal power plants for the next five years horizon.

(vi) Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power [7], [8]

As has come out, one of the underlying factors affecting the thermal PLF is the slower growth of demand against the projected demand. The ET Energy World [69] reported that the peak power demand in India, which is an excellent indicator of the industrial activity in the country, stood at a modest 183,804 MW during initial seven months of the year 2019-20. It was, in fact, the lowest in the period since FY 2017-2018. In Nov 2019, peak demand reduced further to 155,928 MW registering a further fall of 4 % in comparison to Nov 2018. The total Energy Demand had also slowed by 2 per cent to 785,488 MUs in the first seven months of the financial year 2019-20, which was that lowest growth recorded in the period since financial year 2014-2015. This data is from pre Covid period.

While making the projections, power demand has been projected in the country considering a consistent 8-10 % growth in GDP. This might have led to errors in demand forecasting because, such consistent demand growth may not happen. Moreover, the demand should be projected more precisely based on projections of segment growth like industry, services, agriculture etc. If GDP growth is driven by services, the power demand will not grow with matching percentage because services may not be as power intensive as industry. Moreover, a portion of the demand might be met through energy conservation measures, wherein industry saves energy which can be used somewhere else even while output is not compromised.

Financial Express (2020, April 20) [70] and a TERI research paper [71] report that the system of demand projection has not been sound in the country. In the country, the power demand has been projected concurrent with the growth rate of GDP. The GDP growth rate of 8-10% has been used in the projection vide 18th Electric Power Survey (EPS), period 2012-17) [72]. However, the actual CAGR growth was much below the projections which created difference between actual demand and the projections. Further, there are regional differences in the country which need to be looked into while projecting the demand.

A more scientific, multi-input, realistic, iterative and agile demand forecasting is required in the country. It should use multiple factors like GDP growth, growth in industry, regional imbalances, and energy efficiency in the demand side etc. Moreover, realistic and segmented figures should be used. This will help planning of new capacities and inadvertent overcapacity.

It is pertinent to add here that demand growth will be a very important factor which will affect the future of thermal power. If the economic activities pick up, there will be perceptible positive increase in demand and thermal power will have to play an important role. While most of the identified factors are likely to push the PLF in a negative direction, the power demand is likely to be the most important factor which might affect capacity utilisation of thermal power in positive direction.

(vii) India has reached a stage of being power surplus (on most days in a year)

&

(viii) Although India is power deficit on totality basis, many regions have actually become power surplus [7], [8]

Since both the above points are related, we discuss here both the points together. Data from Govt of India, Ministry of Power (MOP) indicates that the country has always had energy shortage (at the national level). In 2019-20, energy shortage was 0.7 % and peak shortage was 0.5 %. [1]. Prima facie this means that all the power available in the country should be scheduled/purchased unless there are other specific factors limiting the purchase of entire power produced in the country. However, the reality is different.

As per a Brookings [73] report, India appears to have reached a surplus generation capacity. The total installed capacity in the country is more than 350 GW, whereas the peak load is about 180 GW. A significant portion of this gap is attributed to grid-level losses, variable RE capacity, and plants being under forced or planned shutdowns. The forced shutdowns could be due to reasons like lack of fuel, equipment problems etc. Excluding all the outages, a *"usable surplus"* of 30 GW still exists in the country.

The above situation means that if there are no grid evacuation constraints, fuel is available at the plants and Dicoms have financial ability to buy, and power can be sold by any producer anywhere and can be bought by anybody anywhere, we have a surplus of about 30 GW at the national level. However, in reality this *"surplus"* remains a mathematical surplus on national level. Regional disparities do exist wherein power is surplus in one region and deficit in another.

To certain extent, alternative market mechanisms to sell power (like RTM) in day ahead markets can help utilise this surplus power. Most of the power is sold in the country through long term (typically 25 years) Power Purchase Agreements (PPAs). The power producer and the buyer sign a PPA typically for 25 years. The buyer, typically a Discom, pays the fixed charges to the power producer irrespective of whether it offtakes power or not (subject to the generation asset being available to generate, typically denoted by Declared Capability of the power plant. The purchaser then pays separately for the energy charges (variable charges) as per actual energy scheduled. In a situation, when a purchasing entity (Discom) has several sources to buy power from and also has to meet RPO, it may not buy all the available power from a particular producer. Since the purchaser pays the full fixed charges, it has the right to buy or keep the asset available for buying as the need arises for the purchaser. So, the producer is asked to ramp down generation. Interestingly, at the same time, there could be a buyer elsewhere in the country, who is ready to buy power at the rate which the thermal power producer is giving to the contracted buyer or even at a higher price. In absence of an alternate market mechanism, this exchange was not feasible.

New regulations called Real Time Market (RTM) and Security Constrained Economic Dispatch (SCED) have come as breather in this situation. Under these mechanisms, in the event of the power producer not getting full dispatch schedule from contracted buyer, the power producer can take permission of the buyer to sell the additional quantum of electricity in open market (through trading of electricity via stock exchange). The stock exchange connects buyers and sellers through price clearing mechanism in short cycles. The electricity can thus get sold from a willing seller to a willing buyer. As per the regulation, any additional gain made by power producer in the variable cost, will be shared between the power producer and the original contracted buyer (because the original contracted buyer pays for the fixed charges of the power producer and it has the right to reserve the capacity for its own use in case of need by foregoing its right, the buyer is sacrificing the reserve capacity. However, all said and done, the need for accurate and reliable forecasting of demand is very important. It must be done properly, otherwise the country will face power supply glut or scarcity, both of which are undesirable.

(ix) Low fuel (coal) availability forcing thermal power generators to reduce power generation [7], [8]

In the last 3-4 years, many coal-based plants have suffered due to coal shortages. However, Govt of India has taken several steps including auction/re-allocation of coal mines so that production is given a push. The govt owned coal producer, Coal India (which is the is the largest and nearly the monopoly coal producer in India) has set an ambitious target of 1 billion tonnes of annual coal production by the year 2024, reports Economic Times, [74]. Current production of coal in India is 701 million tonnes, which is increasing at 5.66 % CAGR based on last five years data. Further, the Govt is planning to auction more than 200 coal blocks in the next five years. These steps are likely to help in making India self-reliant in coal production and the country is likely to meet all the requirements of coal. Since the capacity addition rate of thermal power has slowed down considerably to 2.2 % CAGR in last 4 years, while coal production is being ramped up, coal availability is likely to be sufficient to meet all the needs of thermal power.

The following table gives the coal production in India in MMT from 1985-86 to 2019-20. The future projection of five years of coal production has also been done considering the last five-year CAGR of 5.66 % (2015-16 to 2019-20)

Coal production in India in MMT from 1985-86 to 2019-20

Table 4.14 : Coal – Past production and future projection

Year	Actual coal production statistics (MMT)	Year	
1985-86	77.85	2004-05	382.62
1986-87	85.34	2005-06	407.04
1987-88	90.28	2006-07	430.83
1988-89	98.66	2007-08	457.08
1989-90	106.29	2005-06	407.04
1990-91	113.66	2006-07	430.83

1991-92	119.96	2008-09	492.75
1992-93	123.94	2009-10	532.04
1993-94	126.06	2010-11	532.69
1994-95	133.10	2011-12	539.95
1995-96	142.64	2012-13	556.4
1996-97	147.37	2013-14	565.77
1997-98	146.47	2014-15	609.18
1998-99	143.27	2015-16	639.23
1999-00	152.30	2016-17	657.87
2000-01	154.24	2017-18	675.4
2001-02	161.07	2018-19	730.35
2002-03	168.08	2019-20	701.0
2003-04	181.61	**CAGR of Last Five Years**	**5.66**
Projected Production assuming 2.66 % historical CAGR			
2020-21	740		
2021-22	782		
2022-23	825		
2023-24	871		
2024-25	871		
2020-21	740		
2021-22	782		

Source - Data from Coal India, CEA, MOP websites [75], [1], [10]

The above table shows that if coal companies are able to maintain the historical CAGR of 5.66 %, coal supply position appears to be sufficient to meet the demands of power stations.

Due to the anticipated slowdown of thermal capacity addition to lower levels of about 2.66 % (as projected by CEA), there may not be any significant negative impact of coal availability on PLF of thermal power plants in the long run.

However, there is word of caution here. If demand picks up more than currently anticipated, as is being experienced post Covid after mid-2021 and early 2022, the coal supplies may become a major bottleneck suddenly in the short and medium term because complacence would have set in in the coal production. Also, the Govt is not in favour of importing coal. Slow domestic production along with ban on import may result in sudden crunch of coal in the midterm. Coal companies, power producers and Govt must keep a tab about this situation.

(x) Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available. [7], [8]

While promoting renewable energy is the definitely the long-term solution, the thermal is being left suddenly in the lurch. In a way, thermal is actually supporting the renewable generation in the grid by giving ramp up ramp down support at the cost of itself. When renewable is available, thermal power backs-down to let renewable be scheduled and when renewable goes out, thermal kicks-in again. This support is not coming free of cost. Thermal is incurring cost resulting from deterioration of efficiency and degradation of equipment. Thermal is thus acting as an ancillary to renewable without being remunerated for this service. A green investment fund or some such fund may be created through tax or other measures, and the thermal sector may be supported through that fund for participating in the flexibilistaion.

While migration to renewable is inevitable, this will continue to put heavy pressure on capacity utilization of thermal power plants. Most thermal generators are also likely to switch to renewable portfolio. However, the problem will be their midterm survival for which special fiscal and policy support needs to come fast.

4.11 PREDICTION OF FUTURE PLF USING REGRESSION ANALYSIS - OBJECTIVE –II

This section presents the process adopted for Objective –II and the results obtained. For prediction of future PLF, Multiple Hierarchical Regression Analysis using Excel was first used then regression was switched over to Partial Least Square Regression (using R). Reasons are explained below in detail.

4.12 REGRESSION ANALYSIS

In this study, at first, the Multiple Hierarchical Multiple Regression methodology (using excel) was chosen for predicting PLF. The regression method creates the equation using method Ordinary Least Square (OLS). The OLS method aims at minimizing the sum of square differences between the observed and predicted values. [8], [9], [52], [53].

Simple Linear Regression is a mathematical model which assumes that the two variables can be mathematically related and can be expressed using the following formula -

$$y_i = \alpha + \beta x_i$$

Here x is known as independent variable and y as the dependent variable (which the equation is trying to predict based on values of x). εi is the error term, α is a constant, β is known as regression coefficient of x).

The aim of Simple Linear Regression is to find out the values of α and β at which the error term is minimum. Since positive errors can cancel the negative ones we minimise the squared sum of errors instead of simple sum of errors. Both errors need to be minimised by our model. The minimisation equations can be expressed as below.

$$\hat{\alpha} = \min_{\alpha} \sum_{i=1}^{n} (y_i - \alpha - \beta x_i)^2 =$$

$$\hat{\beta} = \min \sum^{n} (y_i - \alpha - \beta x_i)^2 =$$

Some of the indexes that show whether a regression model is good are as below-

R^2

R^2 is the coefficient that depicts how much variation of the dependent variable (y) can be explained through the variations in the independent variables (xs). For example, if R^2 is 89 % then 89 % variation in y can be explained by the xs considered in the equation. The maximum possible value of R^2 can be 1, meaning 100 % explanation. It is evident that the larger the value of R^2, better is the regression.

Level of Significance

There can be situations when the data is such that we end up *rejecting the null hypothesis (wrongly) when it is actually true*. Level of Significance is the probability of such error happening. It is also known as probability of Type I Error. This level is normally *pre-stated* by the researcher. Generally, a 5 % Level of Significance is taken. [54]

P Values

The p-value is used to test whether a particular independent variable has correlation or no correlation with the dependent variable. It tests the null hypothesis that the independent variable *is not associated with (no correlation)* the dependent variable.

If the p-value for an independent variable is less than our significance level, then we conclude that our sample data provides enough evidence to reject the null hypothesis of *no correlation*. That means that the *data supports the alternate hypothesis* that there *is* indeed a non-zero correlation between x and y. The variable x with such low p value is therefore statistically significant and is worthy of addition to the regression model.

p-values are therefore used to take a decision whether a particular variable should be included in the regression model. If researcher includes intendent variables that are not significantly correlated, it will reduce model precision. It is more prudent to omit such variables. This method helps in Hierarchical Multiple Regression. [55]

The level of significance 5% mandates that p-value should be less than 0.05 or $p < 0.05$. In such cases, we can reject the null hypothesis of no correlation. [54]

4.12.1 HIERARCHICAL MULTIPLE REGRESSION

In a simple equation, we have only one x (one independent variable) affecting y. In many situations there could be more than one x, i.e. there could be many independent variables and the researcher would like to know which of the variables create a better regression fit. In Hierarchical Multiple Regression, we determine the *optimal set* of independent variables for the regression equation.

In this process, regression is performed with few chosen variables as the independent variables, which the researcher thinks as relevant. After running the regression model, we obtain the p values for all the variables. As a next step another multiple regression analysis will be run by including a new independent variable. In this step we can examine the contribution of new variable in the overall model. If the additional variable makes the regression model better (better p values, better R2 etc) then the researcher will include that variable, otherwise not.

In this research, Hierarchical Multiple Regression has been run first with three and variables then with four independent variables. [56] The variables were taken from the factors identified from Objective-I. These three selected variables are basically the factors which had emerged from Objective -I. (Other variables were not considered because either they did not fall in topmost components or they were not quantifiable)

With three variables in our model, we got p values very low varying between X E (-6) to X E (-26) and high R^2 which indicated an excellent fit. When the fourth variable was added, the p values deteriorated. It was therefore decided to run the regression with 3 variables only.

The four variables which were considered as independent variables in our Regression model had emerged through topmost component of the Factor Analysis as described in the table below-

Table 4.15: Selection of Independent Variables- Table showing the topmost component and its associated variables.

Topmost Component as per Factor Analysis	Associated Variables	Related to
Component 2	**VAR00010 (Q9)**	Renewable Energy Capacity
	VAR00015(Q14)	Power Demand
	VAR00016 (Q15)	Demand and Installed Capacity
	VAR00017(Q16)	Demand and Installed Capacity
	VAR00023(Q22)	Renewable Energy Capacity

Source – SPSS analysis on the data for objective - I

Based on above, four independent variables were selected as below –

- **(i) Peak Power Demand (MW)**
- **(ii) Installed Power Capacity through Coal in MW**
- **(iii) Total Installed Capacity of Renewable Energy (MW).**
- **(iv) Total installed capacity of power in India in MW**

When regression was run with three variables (i) Peak Power Demand (MW) (ii) Installed Power Capacity through Coal in MW (iii) Total Installed Capacity of Renewable Energy (MW) then we got p values very low varying between X E (-6) to X E (-26). R2 was also very high to ensure an excellent fit of regression model. The standard errors were also found to be very low of the order X E (-5)

When regression was done with four variables as listed above, the coefficient of showed that p value of Total Installed Capacity became 0.017742 which was not significant for Alpha = 1 %. Also, the p values of other x variables increased significantly in comparison to earlier regression with three variables. Regression was therefore run with the three variables which was best fit solution in our case. i.e. (i) Peak Power Demand (MW) (ii) Installed Power Capacity through Coal in MW (iii) Total Installed Capacity of Renewable Energy (MW). Total Installed Capacity variable was dropped from the independent variables because its addition resulted in p values dropping. It made sense from analysis point of view also because the Installed Capacity of Coal and Installed capacity of Renewables taken together represent a significant portion of Total Installed Capacity. These two are already part of independent variables in our model. [9]

Following are the regression result with three and four variables respectively variables-

Regression with three variables-

Table 4.16 (a) : Regression results with three variables

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.96963
R Square	0.940182
Adjusted R Square	0.934393
Standard Error	2.050611
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	3	2048.827	682.9424	162.4117	4.86E-19
Residual	31	130.3552	4.205006		
Total	34	2179.182			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	46.03528	1.357908	33.90162	4.55E-26	43.26581	48.80475	43.26581	48.80475
Peak Demand (MW) (a)	0.000487	2.5E-05	19.4899	5.92E-19	0.000436	0.000538	0.000436	0.000538
Installed Capacity Coal& Lignite MW (c)	-0.00024	3.45E-05	-6.94093	8.72E-08	-0.00031	-0.00017	-0.00031	-0.00017
Total Renewable Energy	-0.00032	5.58E-05	-5.76887	2.37E-06	-0.00044	-0.00021	-0.00044	-0.00021

capacity (MW)(d)								

Source – Regression results with three variables using Excel [9]

Regression with four variables

Table- 4.16(b) : Regression results with four variables

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.974965
R Square	0.950556
Adjusted R Square	0.943964
Standard Error	1.895141
Observations	35

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	4	2071.436	517.8589	144.1877	3.94E-19
Residual	30	107.7468	3.59156		
Total	34	2179.182			

	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	46.128	1.2555	36.74073	1.67E-26	43.56392	48.69207	43.56392	48.69207
Peak Demand (MW) (a)	0.000275	8.76E-05	3.141862	0.00376	9.63E-05	0.000454	9.63E-05	0.000454
Total Installed capacity (MW)(b)	0.000413	0.000165	2.508957	0.017742	7.68E-05	0.000749	7.68E-05	0.000749
Installed Capacity Coal& Lignite MW (c)	-0.00066	0.000172	-3.8612	0.000558	-0.00101	-0.00031	-0.00101	-0.00031
Total Renewable Energy capacity (MW)(d)	-0.00065	0.00014	-4.63739	6.47E-05	-0.00093	-0.00036	-0.00093	-0.00036

Source – Regression results with four variables using Excel [9]

The three variables finally considered are therefore (i) Peak Power Demand (MW) (ii) Installed Power Capacity (Coal) MW (iii) Total Installed Capacity of Renewable Energy (MW). Last 35 years' time series data of these variables is taken for the regression. The following table presents the data on which regression has been finally run.

Table 4.17- Last 35 years' time series data of independent variables- (i) Peak Power Demand (MW) (ii) Installed Power Capacity (Coal) MW (iii) Total Installed Capacity of

Renewable Energy (MW). [9]

Year	Peak Demand (MW) (a)	Installed Capacity Coal& Lignite MW (b)	Total Renewable Energy capacity (MW)(c)	PLF%
1985-86	28090	28809	0	52.4
1986-87	30850	30394	0	53.2
1987-88	31990	34237	0	56.5
1988-89	36245	37943	0	55.0
1989-90	40385	41510	0	56.5
1990-91	44005	43379	18	53.9
1991-92	48055	44791	32	55.3
1992-93	52805	46597	79	57.1
1993-94	54875	49147	185	61.0
1994-95	57530	52139	576	60.0
1995-96	60981	53547	820	63.0
1996-97	63853	54154	940	64.4
1997-98	65435	55969	992	64.7
1998-99	67905	57483	1095	64.6
1999-00	72669	59187	1167	67.3
2000-01	74872	60890	1407	69.0
2001-02	78441	62131	1702	69.9
2002-03	81492	63800	2483	72.2
2003-04	84574	64955	2980	72.7
2004-05	87906	66416	3812	74.8
2005-06	93255	68433	6191	73.6
2006-07	100715	71121	7760	76.8
2007-08	108866	75002	11125	78.6
2008-09	109809	77649	13242	77.2
2009-10	119166	84198	15521	77.5
2010-11	122287	92378	18454	75.1
2011-12	130006	112022	24504	73.3
2012-13	135453	130221	27542	69.9
2013-14	135918	145273	31692	65.6
2014-15	148166	164636	35777	64.5
2015-16	153366	185172	45924	62.3
2016-17	159542	192163	57260	59.9
2017-18	164066	197171	69022	60.7
2018-19	177022	200704	77641	61.1
2019-20	183804	205135	86759	55.4

Source- Ministry of power (MOP) Govt of India, CEA -[1] [7], [8], [9], [10], [11], [12], [13].

4.12.1.1 DATA ADEQUACY

There is no missing data in the set. Since there are three independent variables in our study, we need at least 30 data sets (10 events per independent variable) to run regression (Rule of thumb). Here we have taken 35 data sets which is sufficient.

4.12.2 ANALYSIS OF REGRESSION RESULTS WITH THREE INDEPENDENT VARIABLES

Regression result with three variables is reproduced as below for ready reference (It is already depicted in previous section but is being repeated for ready reference.)

R square value is 0.940182 which shows excellent fit. The p values of the three independent variables are very low. Standard error of coefficients of three independent variables are also very low. [9]

Table 4.18- Regression with three variables

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.96963
R Square	0.940182
Adjusted R Square	0.934393
Standard Error	2.050611
Observations	35

ANOVA

	df	SS	MS	F	Significance F
Regression	3	2048.827	682.9424	162.4117	4.86E-19
Residual	31	130.3552	4.205006		
Total	34	2179.182			

	Coefficients	Standard Error	t Stat	P-value	Lower 95%	Upper 95%	Lower 95.0%	Upper 95.0%
Intercept	46.03528	1.357908	33.90162	4.55E-26	43.26581	48.80475	43.26581	48.80475
Peak Demand (MW) (a)	0.000487	2.5E-05	19.4899	5.92E-19	0.000436	0.000538	0.000436	0.000538
Installed Capacity Coal& Lignite MW (c)	-0.00024	3.45E-05	-6.94093	8.72E-08	-0.00031	-0.00017	-0.00031	-0.00017
Total Renewable Energy capacity (MW)(d)	-0.00032	5.58E-05	-5.76887	2.37E-06	-0.00044	-0.00021	-0.00021	

Source - Regression with three variables using Excel (p values of the intercept and coefficients are very low at 4.55E-26, 5.92E-19, 8.72E-08, 2.37E-06 respectively. T –Stat values are 33.90162, 19.4899, -6.94093 and -5.76887 respectively. The High t-Stat Value > 2.0 and Low P-value < 0.01 indicate that there is evidence in favour of all terms being significant.) [9]

4.12.3 RESIDUAL ANALYSIS- HETEROSCEDASTICITY, MULTICOLLINEARITY AND AUTOCORRELATION

Before predicting future PLF values, regression data was checked for Heteroscedasticity, Multicollinearity and Autocorrelation. Results are discussed below.

4.12.3.1 HETEROSCEDASTICITY (RESIDUAL ANALYSIS)

PLS liner regression is based on certain important assumptions. One of the underlying assumptions is *Heteroscedasticity* of residuals. It means that at each level of the predictor variable, the residuals are distributed with equal variance.

If this assumption does not hold good, heteroscedasticity is said to be present in the residuals. To measure *heteroscedasticity,* a test called Breusch–Pagan (BP) test done.

In our case the Breusch–Pagan test was run in which BP was found using R which came as 4.611 with Df=3 and p value = 0.2026. Since p value is greater than 0.05, the Null Hypothesis (H0- assumption that the residuals are distributed with equal variance, i.e. there is no *heteroscedasticity*) cannot be rejected. Hence there is no evidence of Heteroscedasticity in our model.

Following is the Scatter plot of Standardised Predicted Values and Standardised Residuals

Scatter plot of residuals

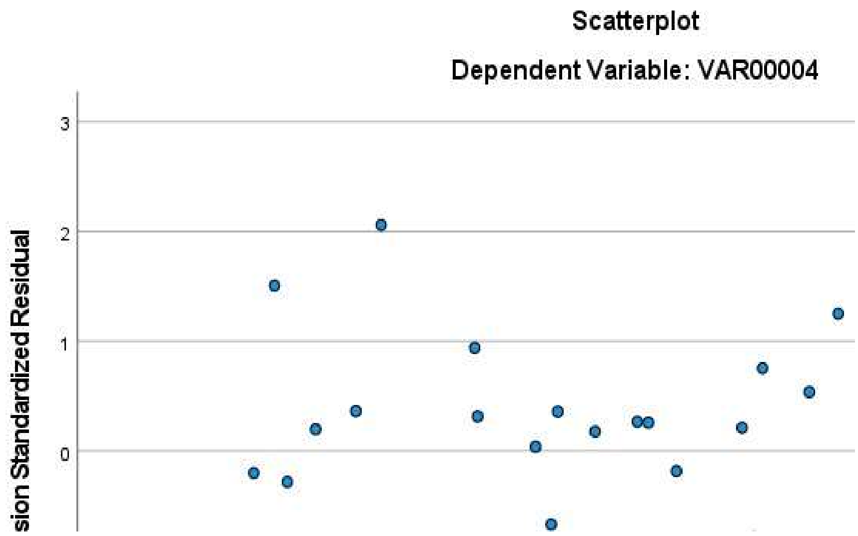


Chart C4.2- Scatter plot of residuals
Source – SPSS output

4.12.3.2 MULTICOLLINEARITY

When the data set was tested for multicollinearity, it was found that the X variables (independent variables) had high correlation (Pearson Correlation Coefficient > 0.9 in some pairs). However, all the X variables were individually highly significant and model was an excellent fit. This was expected because time series date often encounters such problem.

4.12.3.3 AUTOCORRELATION

When data was checked for **Autocorrelation,** using the Durbin- Watson Test, it was found that there Durbin Watson value (1.029) lies almost at the dl value.
As per Durbin Watson Table for 4 regresses, 35 sample size, 1 % significance- it should lie between 1.028 and 1.512). [57]

Durbin Watson Test

Table 4.19 (a) - Durbin Watson Test for autocorrelation

Model Summary[a,b]

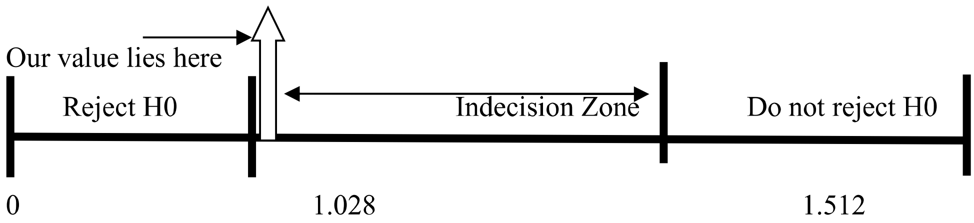
Model	R	R Square	Adjusted R Square	Std. Error of the Estimate	Durbin-Watson
1	.970[a]	.940	.935	2.048	1.029

a. Predictors: (Constant), VAR00002, VAR00001, VAR00003

b. Dependent Variable: VAR00004

Source- SPSS output

Table 4.19 (b)- Durbin Watson Test decision zones



Source- SPSS output

Our Durbin Watson value (1.029) lies almost as the indecision zone which indicates Autocorrelation is not established but there might be some possibility. Source- SPSS output of this research.

Keeping all above in view, in order to make the projection more robust, it was decided to use Partial Least Square (PLS) method using R.

4.12.4 PLS REGRESSION USED TO OVERCOME THE PROBLEM OF MULTICOLLINEARITY

As explained above, PLS method has been used in this research to make the results more accurate and robust. When there is multicollinearity in data, the PLS method of regression is preferred. In fact, PLS is powerful enough to regress data even when the data set is noisy, collinear, or even partially incomplete.

PLS acts as a data transformation and a regression tool. It performs a dimensional reduction of samples, and then runs a linear regression. PLS thus reduces the independent variables appropriately.

The way PLS handles the correlation is that while there could be many underlying independent variables, in fact, there may be very few underlying variables that might be causing most of the variation. The PLS is the technique to extract such latent underlying factors, accounting for most of the variation. This prevents us the researcher from resorting to variable selection. Hence, we reduce the severity of the assumption of Multiple Linear Regression that the predictors are noise and correlation free. The data prerequisites for PLS therefore do not mandate data to be free from Multicollinearity. [76]

Generally, time series data has characteristics of multicollinearity. PLS is therefore appropriate regression tool for time-series data. It does not suffer from the same assumptions concerning data structure as multiple linear regression model.

In our PLS model, R software was used with the same three variables with which OLS regression was run. The PLS created its own components. The components were chosen based on RMSEP (Root Mean Square Error of Prediction) criterion where the number of components for which RMSEP was minimized is chosen as a principle. The results were verified by using SelectNcomp function in R which suggests the optimal number of components. Results of the RLS regression using R are given below-

Cross-validated using 10 random segments.

	(Intercept)	1 comps	2 comps	3 comps
CV	8.123	7.641	2.315	2.373
Adj CV	8.123	7.775	2.294	2.347

The most common approach is a 10- fold cross validation. We have used the approach in this study to select the two-component model. The results of the model are as follows:

Chart below shows RMSEP minimization (Root Mean Square Error of Prediction)

TRAINING: % variance explained

	1 comps	2 comps	3 comps
X	93.05	99.46	100.00
data$`PLF%`	10.18	93.85	94.02

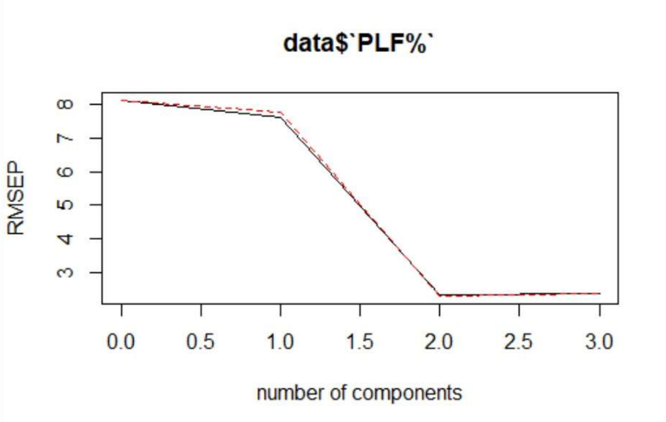


Chart C4.3 -RMSEP minimization Table and curve
Source - R Output

Since RMSEP is getting minimized at 2 components, we use 2 components in the model. As can be observed from the results above, 2 components explain 93.85% of the variance in the dependent variable, presenting a good fit. For obtaining the PLS equation, this paper uses the jack knife test in R.

For sensitivity analysis the Jack-knife test has been used (to find out the estimates of the three independent variables). Following result is obtained after the test.

Table 4.20 – PLS Jack Knife Test results

	Estimate	Std. Error	Df
`Peak Demand (MW) (a)`	**4.9721e-04**	2.1977e-05	9
`Installed Capacity Coal& Lignite MW (c )`	**-2.6945e-04**	1.7985e-05	9
`Total Renewable Energy capacity (MW)( d)`	**-2.7133e-04**	5.0504e-05	9
`	t value	Pr(>|t|)	
`Peak Demand (MW) (a)`	19.3310	1.225e-08 ***	
`Installed Capacity Coal& Lignite MW (c )`	- 10.5141	2.354e-06 ***	

`Total Renewable Energy capacity (MW)( d)`	-4.2378	0.002181 **
Signif. codes: 0 '***' 0.001 '**' 0.01 '*' 0.05 '.' 0.1 ' ' 1		

Source- Regression output using R

The t- values are significant and p-values are very small at 99% confidence level indicating that the model estimates are significant.

Here we get the new equation for PLF with new estimates as above.

4.13 PREDICTION OF PLF FOR NEXT 5 YEARS USING PLS REGRESSION

Based on above PLS regression and the equation obtained, the Utilization Factor (PLF) has been projected for next five year (i.e. 2020-21 to 2024-25) and four Scenarios have been projected. The national PLF obtained using PLS regression has also been bifurcated to Central, State and Private Sector by adding the average historical difference that has been maintained in past between national PLF and these segments as detailed in Chapter 1. While planning the scenarios, projections made by CEA, Govt of India, have been taken as the base scenario. Other scenarios are based on newspaper reports and govt plans about what is likely to happen. Table 2.1 (Sub Theme- 2. Tariff, Regulations and Policies, Sl 10)

Presented in the table below is the result of regression showing projected PLF for next five years in different scenarios. Each scenario is based on certain assumptions about the independent parameters which are described below. Following are the four scenarios considered- [9]

i. **Scenario I- CEA Projection (CEAP)-** *Based on fuel mix and demand suggested by Central Electricity Authority (CEA) vide Report (Draft) on optimal generation capacity mix for 2029-30- CEA- GOI) [6, repeated reference]*

ii. **Scenario-II- (CEAP+PHOUT)- CEA based Projection and phasing out of old capacity.** *Based on fuel mix and demand suggested by Central*

Electricity Authority (CEA) vide Report (Draft) on optimal generation capacity mix for 2029-30- CEA- GOI) [6] and assuming that 5000 MW old capacity will be phased out every year.

iii. ***Scenario-III-*** Low Coal, Aggressive Renewable Normal Demand (LCARND) - *Growth rate of Thermal Capacity reducing to 4 % and that of Renewable Capacity at aggressive 25.05 % rate (Coal addition at reduced rate by 5 % and renewable higher by 2 %, Demand growth normal at 5.5 % as compared to last 5 years' CAGR which is the BAU case)- Details in table below*

iv. ***Scenario IV-- Reduced Growth (RG)*** – Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other factors- *Details in table below*

Results of regression- Predicted PLF for five years

Table 4.21: PLF Projection - Results of Regression with four scenarios [9]

CAGR %/Year	Peak Demand (MW)	Installed Capacity Coal (MW)	Renewable Capacity (MW)	Projected PLF % Sector Wise			
Scenario I- CEA Projection (CEAP)- B*ased on fuel mix and demand suggested by Central Electricity Authority(CEA) vide Report(Draft) on optimal generation capacity mix for 2029-30- CEA- GOI*							
CAGR %	6.44	2.66	17.90	National	Central	State	Private
2020-21	193913	210592	102289	58.80	68.79	53.25	56.66
2021-22	225751	216193	120599	68.15	78.14	62.60	66.02
2022-23	238167	221944	142186	66.92	76.91	61.37	64.78
2023-24	251267	227848	167637	64.93	74.92	59.39	62.80
2024-25	265086	233909	197644	62.03	72.02	56.48	59.90
Scenario-II- CEA based Projection and phasing out of old capacity (CEAP+PHOUT)- *Based on fuel mix and demand suggested by Central Electricity Authority vide Draft report on optimal generation capacity mix for 2029-30- CEA- GOI and assuming that 5000 MW old capacity will be phased out every year.*							

CAGR %	6.44	2.66 *	17.90	National	Central	State	Private
2020-21	193913	205592	102289	60.14	70.23	54.59	58.01
2021-22	225751	206193	120599	70.84	80.93	65.29	68.71
2022-23	238167	206944	142186	70.96	81.04	65.41	68.82
2023-24	251267	207848	167637	70.32	80.41	64.77	68.19
2024-25	265086	208909	197644	68.77	78.85	63.21	66.63

Scenario-III- Low Coal, Aggressive Renewable Growth) and Normal Demand (LCARND, the BAU Case - *Growth rate of Thermal Capacity reducing to 4.04 % and that of Renewable Capacity at aggressive 25.03 % rate (Coal addition at reduced rate by 5 % and renewable higher by 2 % , Demand growth normal at 5.5 % as compared to last 5 years' CAGR which is the BAU case)*

CAGR	5.50	4.04	25.03	National	Central	State	Pvt
2020-21	193911	213417	108477	56.36	66.35	50.81	54.22
2021-22	204574	222033	135631	51.97	61.96	46.42	49.83
2022-23	215823	230997	169583	45.93	55.92	40.39	43.80
2023-24	227691	240323	212033	37.80	47.79	32.26	35.67
2024-25	240211	250026	265110	27.01	37.00	21.47	24.88

Scenario- IV- Reduced Growth (RG) – *Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other factors*

CAGR %	2.50	6.04	20.03	National	Central	State	Pvt
2020-21	188397	217520	104139	53.68	63.68	48.14	51.55
2021-22	193105	230652	125000	46.83	56.82	41.28	44.69
2022-23	197930	244577	150041	38.68	48.67	33.14	36.55
2023-24	202876	259343	180097	29.01	39.00	23.46	26.87
2024-25	207946	275000	216175	17.52	27.51	11.97	15.39

Source- Result of Regression Using PLS
* with 5000 MW being phased out every year in next five years

4.14 DISCUSSION ON RESULTS OF REGRESSION - OBJECTIVE – II

4.14.1 DISCUSSION ON FUTURE TREND OF PLF

In Scenario I- CEAP (B*ased on fuel mix and demand suggested by Central Electricity Authority (CEA) vide Draft report on optimal generation capacity mix for 2029-30, CEA-GOI*). This Scenario considers coal capacity addition rate decelerated considerably to about 2.66 % CAGR against current 5 year CAGR rate of 9.04 %, Peak demand increase considered is steeper at 6.44 as compared to current 5 year CAGR of 5.5 % and Renewable Energy addition CAGR is considered at slower pace @ 17.90 % from the latest historical 5 year CAGR rate of 23.03 %.

A combined effect of all three independent variables on this path, makes the national PLF to reach to 58.80 % in the year 2020-21. Under this Scenario, by 2024-25 - the PLF level projected is 62.03 %. (Central, State and Private sector are projected to operate at 72.12 %, 56.48 % and 59.90 % respectively.) This is a recommended path to follow.

Scenario-II- CEAP+PHOUT -. In this case national PLF varies between 60.14 % to 68.77 % in next five years. Central, State and Private sector are projected to operate at 78.85 %, 63.21 % and 66.63 % respectively. This Scenario assumes the conditions of Scenario I plus decommissioning of old plants at the rate of 5000 MW every year (Demand Growth @ 6.44 %, Coal Plant Capacity addition @ 2.66 % and Renewable Capacity addition @ 17.90 % + Phase out @ 5000 MW/Year). In this Scenario all the three segments (Central, State and Private) are able to maintain a reasonably high (above 60%) PLF in next five years. This is the most favourable Scenario for thermal power plants. This is another recommended path to follow.

In Scenario-III - LCARND-Low Coal, Aggressive Renewable and Normal Demand - Growth rate of Thermal Capacity is considered slower at 4.04 % against current 5-year CAGR of 9.03 % and that of Renewable Capacity addition accelerated at 25.03 % against last 5-year CAGR of 23.03 % and demand growth is at normal rate of 5.5 %. In this Scenario - National average PLF may drop below 46 % by 22-23 which is a warning signal. This is the most likely and the Business-as-Usual situation and needs immediate attention of policy makers, power producers and all other stakeholders.

In Scenario IV -RG- which is a specific case due to Corona - Reduced Growth (RG) – *Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one growth rate reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other factors,* In this case the PLF drops below 40 % in

2022-23. This situation is likely for 1-2 years but is unlikely in long run as the demand is showing signs of pick up after Corona. [9]

4.14.2 SENSITIVITY ANALYSIS

The Jack-knife test has been used to find out the estimates of the three independent variables. Using the estimates given by this method it is found that if peak demand increases by 5000 MW, the PLF will increase by 2.4 % (4.9721e-04 * 5000). If Installed Capacity of coal increases by 5000 MW, the PLF will decrease by 1.35 % (-2.6945e-04 * 5000) and if total renewable energy capacity increases by 5000 MW, the PLF will decrease by 1.36 % (-2.7133e-04 *5000), taking 2019-20 as base year. **The highest impact is of demand (MW) in the positive direction + 2.4 %** / 5000 MW, followed by total renewable energy (MW) in the negative direction (-) 1.36 % / 5000 MW and then by installed capacity of coal (MW) again in the negative direction i.e. (-) 1.35 % / 5000 MW. In each sensitivity test, other variables are considered to be remaining at same level.

This research shows that demand pick up is the most desirable and favourable driver for enhancing capacity utilization (PLF) of thermal power plants.

In the following chapter, Chapter 5, the Technical and Financial impact of fall is PLF has been worked out and discussed [9]

4.15 CHAPTER SUMMARY

This chapter gives output of Objective I&II. It lists out the ten Major Factors affecting Utilization Factor (PLF) of Thermal Power Plants. This is the output of Objective -I. Further, the chapter presents the Utilization Factor (PLF) projected for five years (i.e. 2020-21 to 2024-25) and under four different scenarios. **Scenario I- CEA Projection (CEAP)-** *Based on fuel mix and demand suggested by CEA vide Report (Draft) on optimal generation capacity mix for 2029-30- CEA-GOI) [6].* **Scenario-II- (CEAP+PHOUT)- CEA based Projection and phasing out of old capacity.** *Based on fuel mix and demand suggested by CEA vide Report*

(Draft) on optimal generation capacity mix for 2029-30- CEA- GOI ***and*** *assuming that 5000 MW old highly inefficient capacity will be phased out every year.* ***Scenario-III-*** Low Coal, Aggressive Renewable Normal Demand (LCARND) - *Growth rate of Thermal Capacity reducing to 4 % and that of Renewable Capacity at aggressive 25.05 % rate (Coal addition at reduced rate by 5 % and renewable higher by 2 %, Demand growth normal at 5.5 % as compared to last 5 years' CAGR which is the BAU case).* ***Scenario IV-- Reduced Growth (RG)*** – Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other factors. In this chapter PLF for next five years has also been projected for four different scenarios. Sensitivity analysis of PLF with the three intendent variables has also been presented in this chapter.

5 CHAPTER 5- TECHNICAL & FINANCIAL IMPACT OF FALLING PLF ON THERMAL POWER PLANTS (OBJECTIVE-II)

5.1 CHAPTER OVERVIEW

The chapter presents the second part of outcome of Objective -II. Projections for PLF, as detailed in the previous chapter, was the first part Objective – II. The second part is to find out the technical and financial impact of the fall in PLF. This chapter brings out how the thermal power plants will be affected due to falling PLF both technically and financially.

5.2 TECHNICAL IMPACT - FLEXIBILIZATION REQUIREMENT FOR THERMAL POWER PLANTS

After we determined the future projections of PLF in Objective -II, the next step was to find out how the falling PLF would affect the thermal power plants technically and financially. This was essential for drawing any recommendation / remedial action.

For this, Literature Review was cross referred once again with an aim to find out what will happen to the thermal power plants if the PLFs fall down. Data was also collected from operating power plants as to how plants are getting affected dur to falling PLF.

Several published papers point out that one of the most important technical fallout of falling PLF is that the thermal power plants will have to operate under "Flexible Operation Regime" or Flexibilization. In this chapter, we study what is Flexibilization and how thermal operators can handle this issue.

As we have already seen, faced with the consequences of global warming and climate change, most countries are moving towards Renewable Energy. Renewables are green energy and have almost no marginal costs. Due to this, they have preference in grid dispatch and have "must run" status. Policy provisions like Renewable Purchase Obligation (RPO) also make it mandatory for the power procurers to buy from renewable sources whenever they are available. However, Renewable Energy (RE) sources like solar and wind are highly dependent on weather conditions. They depend on time of the day and seasonal changes, and cannot produce electricity as and when needed like thermal power.

Due to their variable nature, RE technologies have altered the characteristics of electricity systems. Because of their uncontrolled variable nature, RE are not suitable for baseload operations. A base load power plant has to provide a continuous and stable supply of electricity to support the average demand. The onus has now fallen on thermal power to do the balancing act (flexible operation) whenever renewable power goes on or off the grid and provides the much-needed power. Making the conventional thermal power plants more flexible has therefore become a key prerequisite for integrating large shares of renewables effectively in the grid.

However, the conventional thermal power plants were built to run under stable electricity demand and supply patterns. This regime resulted in construction of large, thermal power plants which are actually *inflexible*. This inherent non-flexibility has created challenges for the thermal power generators because they are unable to cope up with the demands of ramp up and ramp down (Going up and down in generation, also called Flexibilization).

The result obtained in Objective -II discussed above, suggests that thermal plants may have to run at 58-66 % average PLF for next five years even in the best-case scenario. In other scenarios, PLF is going still lower to the level of 40 %. Flexibilization is therefore required in thermal power plants so that the baseload power stations are converted into *flexible generators* to cope up with fast ramp up and down of generation. Here we discuss in brief how flexibilization can be achieved, what are the key parameters and what changes might be required in thermal power plants. Detailed study of flexibilization is beyond the scope of this work hence only limited study has been done.

5.2.1 HOW FLEXIBILIZATION CAN BE ACHIEVED

Flexibilization includes applying retrofits, process control and advanced monitoring technologies to -

a) Faster start up and shutdown procedures
b) Lower the limits of safe minimum loads
c) Higher load ramp up and ramp down rates
d) Improved control systems to maintain grid stability
e) Improved monitoring of plant health

5.2.2 KEY FLEXIBILIZATION PROPERTIES [77,78, 79]

(i) **Technical Minimum Load:** We are moving towards a situation when renewable generation will be able to supply the majority of (or almost total) power demand at least in certain time blocks when renewable is operating at full capacity. Therefore, during those times of the day, thermal power will have to either keep the unit operating at very low output level or shut down temporarily. Generally, there is a minimum level of load up to which a thermal power plant can be operated safely (mainly due to limitations of sustaining fire ball in the furnace of the boiler). Such load is called Technical Minimum. Presently, CERC, the regulator considers 55% level as the Technical Minimum for coal based thermal power plants. However, our research shows that the thermal power plants shall have to operate even at 40 % level in near future. The lower the level of load that a plant can reach safely, the better will be it's availability and economic performance, because the plant will be able to avoid unit shutdown and consequent start-up costs.

(ii) **Load increase and decrease rates (Ramp rate):** Since renewable energy variations happen at a fast rate, the thermal power plants also have to increase or decrease load at fast pace to compensate for the increase or decrease in the renewable energy output. The rate at which power load is changed (MW/Min) is known as ramp rate. The plants need to enhance ramp rates so as to keep the grid frequency stable.

(iii) **Faster Start-up and Shut-down times:** In some situations, when it is not feasible to run a thermal power plant below a certain output level, the plant may have to be shut down temporarily. Then, when the plant is required to generate, it should start up fast. Fast start and shut down are thus another feature of flexibilization.

(iv) **Part Load Efficiency:** As discussed earlier, the thermal power plants were designed to operate at near full load. When they run at part load, it is suboptimal situation from the efficiency point of view. Efficiency parameters (Heat Rate and Auxiliary Power) deteriorate at part load. Since the thermal units will have to consistently run at part load, the Heat Rate and Auxiliary power consumption needs to be optimised at part load operation. This will require changed processes and monitoring systems.

The chart below shows how load ramp up – ramp down is happening for thermal power plants.

Depiction of Ramp Up and Ramp Down Phenomenon

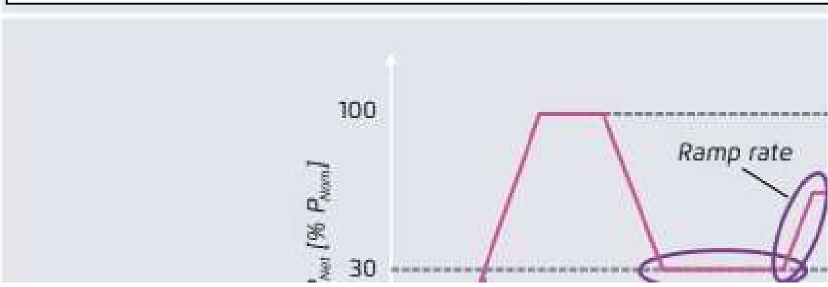


Chart C5.1- Chart showing the load ramp up and ramp down requirement

Source-http://iesr.or.id/v2/publikasi_file/Understanding-flexibility-of-thermal-power-plants.pdf [78] and Fichtner (2016) and Peter (2018)

5.2.3 TECHNOLOGICAL CHANGES REQUIRED FOR FLEXIBILIZATION

New power plants will have to be designed with better flexibility features. For new units, NTPC, the biggest power producer in the country, has already started incorporating change in specifications of the main plant wherein the Original Equipment Manufacturer (OEM) has to comply with better flexibility features at the design stage. This includes lower minimum load, faster ramp up and ramp down capabilities.

Older, existing units will require modernization or upgrade of components and control & monitoring systems. In general, following technological changes are required -

5.2.3.1 **DECREASING MINIMUM LOAD** [79]

Reduction of load in coal-fired units below a threshold limit has technical limitations. For example, load on a 500 MW cannot be normally brought down to say, 50 MW. The limitation arises because the fire flame becomes unstable, unburned coal and CO emissions increase and safety concerns arise at low loads. Such instability of flame can occur due to fast changes in coal flow rate, changes in air supply altering the air fuel ratio. It can also occur because of accumulation and sudden release of pulverized coal in coal pipes caused by widely varying flow in fuel pipes. In such situations a phenomenon called, secondary combustion can happen which is a major safety concern. Secondary combustion happens when there is partial or full failure of flame due to improper fuel air ratio or improper fuel flow. In such cases, all of a sudden, flame can re-appear causing a surge in pressure of furnace. Such situations can cause blast in the boiler.

If a plant can remain working at low load (generating power at low load without necessitating shut down) it can remain *live* and need not shut down even when power demand is low or renewable energy is supplying the power. By this, it can avoid expensive start-up and shutdown and can also ramp up fast when required.

Reducing the minimum achievable load of thermal power plants is also important from the viewpoint of integration of renewables and smoother grid frequency control because it enables a greater share of renewables to be integrated in the grid without necessitating the jerks of shutdown and start ups of a corresponding thermal plant. The lower limit to which a unit can safely operate is called Technical Minimum load. Following are the ways to reduce Technical Minimum load.

a) **Switching to lesser number of mills in operation**

When we try to reduce unit load by reducing the coal flow in coal mills, we move towards very low flows of coal and air in each mill. This can reduce fuel-air velocity and pressure, adversely affecting fuel-air ratio and can cause settling of coal in coal pipes. A better method is to reduce number of mills in operation. In this case, a smaller number of mills are kept in service with optimum loading on each mill. Switching to lower number of mills in operation can significantly reduce the minimum achievable load. However, there can be limitations in minimum number of mills that can be achieved for safe and sustained operations. Operational stability study is required to be made for each individual plant so as to find out the optimal elevation and number of mills that can be safely operated. In many NTPC units, elaborate experiments have been carried out to run the units in stable condition with lower number of mills in operation. Earlier such practice was not adopted by utilities because OEMs were not supporting changes in operation regime. However, faced with prospects of flexible operation; such practice is being increasingly adopted by utilities.

b) Oil support

Using oil as support fuel stabilizes the fire in the boiler. In this case LDO is fired in boiler in addition to the coal-fired main burners. Oil supports the flame in the furnace. This helps in lowering of coal firing rate and maintain steady flame in the boiler.

Basically, the flame instability in the boiler limits the minimum achievable load. In such situation, auxiliary fuel firing enables minimum load achievement. The auxiliary firing can also help in fast ramp up of load, thus enhancing the ramp rate.

c) **Changes in coal firing mechanism**

Indirect firing means creating a fuel storage buffer between coal mill and coal burner. In this case, an intermediate storage, a buffer bunker, is installed between the pulverisers and the burners. The buffer bunker gives "isolation" from continuous feeding by mills and thus giving flexibility in mill operations. The buffer bunker can supply fuel fast whenever a quick demand comes. Mill can be taken in full operation later as demand picks up further.

d) Faster start-up time

In order to respond fast to the changes in demand from the grid, plant operators need to fasten the plant start-up time. However, start-up procedures are generally complex. Start-up requires a combination of fuel, such as High-Speed Diesel (HSD) and coal. The startup process also has limitations imposed by metal differential temperatures in boilers and turbines because thick metal components need to be heated or cooled by maintaining certain differential temperatures limits between different parts of a component. Exceeding the limits might cause distortion in the component.

However, even with thicker components, some improvements in the duration of start-up and shut-down can be achieved by installing better monitoring equipment for temperatures and stresses in components, thereby enabling calculated (and permitted) risks in startup, ramp up and ramp down rates.

Optimized, predictive control systems can be used for start-up, ramp up and ramp down rate improvement when the unit is live (on bar). Through these systems, the operator gets real time guidance for faster ramp up ramp down and startups. They optimise several parameters such as fuel consumption of the unit and monitor thermal stress on thick-walled components to reduce boiler start-up time. They can guide the operator for faster ramp up or ramp down.

For new units, improved metallurgy with sleeker components are the options being explored by the OEMs and utilities.

5.3 FINANCIAL IMPACT

5.3.1 FINANCIAL IMPACT OF FALLING PLF (FOR A POWER PLANT OPRRATING IN REGULATORY TARIFF REGIME) [80]

When the power plants units operate under low Utilisation Factor (PLF) expense increase mainly because of the worsening of the efficiency parameters like higher Heat Rate, higher Auxiliary Power Consumption (APC) and the loss of generation incentives that a thermal power producer receives when the power plant runs at high PLF (> 85 %). Moreover, if the plant PLF is so low that it has to be shut down (Reserve Shut Down), restarting the plant involves startup costs. These costs go on increasing as the PLF goes lower. If the generating plant does not get compensated for such increased costs, it will result in losses.

Since most thermal power plants were designed to operate near full load (base load), they work most efficiently if the run near their rated, full load. Lower PLF results in worsening of the efficiency parameters, meaning thereby that the plant will consume more coal (or oil) to generate the same amount of electricity. As discussed above, following are the four main components which create direct cost implication on terms of profits/ROE with variation of PLF.[80]

a) Reduction in profit due to higher Heat Rate (lower efficiency levels) as compared to the near design, full load, Heat Rate (at 90 % PLF).

b) Reduction in profit due to higher Auxiliary Power Consumptions (APC) as compared to the near design, full load APC (at 90 % PLF).

c) Reduction in profit due to nil (zero0 generation incentive payable as compared to PLF above 85 %.

d) Reduction in profit due to start-up costs after Reserve Shut Downs (When PLF goes below technical minimum) [80]

In this research, the impact of above factors has been calculated for *three different types of coal-based units*. The three-unit sizes considered here are 660 MW (Supercritical), 800 MW(Supercritical) and 500 MW(Subcritical). These unit sizes have chosen because are they are the most common, existing unit sizes in India. Also, most of the future capacity addition is likely to be in these unit sizes only. [80]

(While main financial calculations are in Indian Rs, equivalent US$ values have also been given in bracket or in another column or just below the Indian Rupees (Rs) figure. 1 US$ = Rs 74.5 rate of conversion as existing on 5th Jan 2022 has been considered. (https://in.tradingview.com/symbols/USDINR/) **[80]**

5.3.2 BASE ASSUMPTIONS FOR FINANCIAL IMPACT OF CHANGES IN PLF [80]

For estimating any financial impact due to lower PLF, we will first establish a reference baseline of tariff (Revenue and ROE). For doing so, we use here the electricity tariff for the period CERC- 2019-2024[16] and the actual performance parameters of thermal power plants. The results obtained here will based on three different types of specific units that have been considered for analysis. Since there might be some variations in tariff from plant to plant, the values obtained will be indicative only. However, since we have considered the most occurring and most likely future sizes, the results should give a fairly accurate idea of the magnitude and extent of financial impact on thermal power plants due to fall in PLF. [80]

It is also pertinent to add here that the calculations shown here are the power plants whose tariffs are determined by CERC regulations (Plants owned by central government or the plants which supply power to more than one state). For plants operating under day ahead markets, the calculations and approach shall be different.

Our calculations are based on basic premise that the energy charges (ECR, also known as Variable Cost) that a thermal regenerator is entitled to receive through tariff is equal to the normative cost determined by the tariff.

The Central Electricity Regulatory Commission (CERC) mandated electricity tariff in India has three components. Fixed Cost, Variable Cost (or Energy Charge Rate (ECR)) and Generation Incentives. Fixed Cost covers the costs like ROE, Depreciation, Debt Servicing (Interest), Operation & Maintenance Cost, Working Capital Interest etc. The fixed charge are basically the capacity charges and are recoverable by the power generator if the plant is "available" to generate at its "declared capacity". To ensure that the power producer keeps the plant healthy and available, the tariff mandates that the power producer will be entitled to get full (100 %) of the fixed cost provided it maintains 85 % of declared capacity or above on annual basis. [80]

The Variable Cost basically reimburses the cost of fuel for producing the electricity. It is based on the defined efficiency parameters (*normative efficiency, fixed by the regulator (CEC)* based on design value with a reasonable margin provided for deterioration in performance). The efficiency levels (Heat Rate, APC) so determined are called "normative limits". It is assumed that the power producer will run the plant within these normative limits. (The limits are fixed to bind the plants to run efficiently). In case a plant operates at the parameters (Heat Rate, APC) worse than the normative limits the producer will not be able to recover the cost of fuel that it will actually spend. This will happen because the charges that it is entitled to get are calculated based on "normative values" of efficiency parameters. [80]

On the other hand, in case a plant runs at better efficiency than normative, it makes a gain known as "*marginal contribution*". However, in such cases, the power producer has to pass on half of the gain (50%) to the customer (usually the Distribution Company).

In the current scenario of dropping PLFs, it is rare for a plant to make gains through marginal contribution. The probability of making losses in the variable charges (negative marginal contribution) is rather high. When the power producers represented their predicament, CERC has allowed changes (margin) in normative parameters to compensate for such loss. However, the relief provided, appears inadequate as PLF is falling and Reserve Shut Downs (RSDs) are increasing. [80]

The third component is Generation Incentive. When a plant runs at PLF greater that 85 %, it gets incentive in electricity tariff. This incentive is kept to encourage plants to keep costs low and keep the plants healthy and available. However, this incentive is not given if PLF is below 85%. [80]

5.3.3 **BASE TARIFF CALCULATIONS** [80]

In the following table the base assumptions for determining the tariff of three different types of thermal power units have been given. Based on the assumptions we determine the tariffs of the three different plants (units). We then depict how efficiency parameters get affected due to low PLF. Finally, we find out how the Profit/ROE of these power plants will get affected due to lower PLF levels. (Tables are is on the next pages)

Major Tariff Parameters considered for this research

Table 5.1 (a) : Base assumptions of Tariff parameters

Sl N	Particulars	Plant 1	Plant 2	Plant 3	Units/Remarks
1	Plant Capacity	660 MW	800MW	500MW	MW
2	Capital Cost	4.90 (0.66)	6.10(0.82)	5.10(0.68)	Rs Cr/Mw (US$ Mn /MW)
3	Debt Equity Ratio	70-30%	70-30%	70-30%	%, Ratio
4	ROE allowed in Tariff	15.5%	15.5%	15.5%	%, as per tariff
5	Interest on Debt	10%	9%	10%	%, Assumed as per market and as per tariff
6	Working Capital (WC)	472 (63.35)	595 (79.86)	312 (41.88)	Rs Cr (US$ Mn), Approximation based on actual values.
7	Interest on Working Capital (IoWC)	12%	13%	12%	%, Assumed as per market and as allowed in tariff
08	Depreciation	5.28%	5.28%	5.28%	%, as per tariff
09	Opn. & Mtc. Cost	20.26 (0.027119)	18.23 (0.02447)	22.51 (0.03021)	Rs Lacs per MW (US$ Mn per MW), as per tariff
10	Plant load Factor	85	85	85	%, Assumed
11	Plant Availability	85	85	85	%, Assumed
12	Specific Oil	0.5	0.5	0.5	Ml per Kwhr
13	Oil Price	51000 (684.56)	51000 (684.56)	51000 (684.56)	Rs per KL, (US$ per KL), as per market
14	Gross Calorific value	10700	10700	10700	Kcal/Liter
15	Heat Rate	2317	2271	2390	Kcal/Kwhr, as per tariff
16	Coal Price	2300 (30.87)	2500 (33.56)	2200 (29.53)	Rs/Ton (US $/Ton), market data
17	Aux Power Consumption (APC)	6.25%	6.25%	6.25%	%, as per tariff
18	Useful Plant Life	25Yrs	25Yrs	25Yrs	Years, as allowed in tariff
19	GCV of Coal	3700	3800	3700	Kcal per Kg, as per actual observed values

Source - assumptions made by this research based on CERC Norms, CEA data and Vilas et al - Generation Cost Calculation for 660 MW Thermal Power Plants. Tripathi & Anand [80] http://www.ijiset.com/v1s10/IJISET_V1_I10_94.pdf [81]

Fixed Cost Calculations

Table -5.1 (b)- Fixed cost calculations

Fixed Cost						
Particulars	**Plant 1 (Rs Cr)**	**Plant 1 (US$ Mn)**	**Plant 2 (Rs Cr)**	**Plant 2 (US$ Mn)**	**Plant 3 (Rs Cr)**	**Plant 3 (US$ Mn)**
Capital Cost	3234	434.1	4880	655.0	2550	342.3
Equity	970.2	130.2	1464	196.5	765	102.7
Debt	2263.8	303.9	3416	458.5	1785	239.6
ROE (i)	150.381	20.2	226.92	30.5	118.575	15.9
Interest of Loan (ii)	226.38	30.4	307.44	41.3	178.5	24.0
Intt. on Working Capital (iii)	56.64	7.6	77.35	10.4	37.44	5.0
Depreciation (iv)	170.7552	22.9	257.664	34.6	134.64	18.1
O&M Cost (v)	133.716	17.9	145.84	19.6	112.55	15.1
Total Fixed Cost (i to v)	**737.8722**	**99.0**	**1015.214**	**136.3**	**581.705**	**78.1**
Total Power Produced (MUs) at 85 % PLF	***4914.36***		***5956.80***		***3723.00***	
Fixed Cost per Unit Rs/Kwhr (US$/Kwhr)	**1.5015**	**0.02015**	**1.7043**	**0.02276**	**1.5625**	**0.02097**

Source - assumptions made by this research based on CERC Norms, CEA data and Vilas et al- Generation Cost Calculation for 660 MW Thermal Power Plants. Tripathi & Anand [80], http://www.ijiset.com/v1s10/IJISET_V1_I10_94.pdf [81]

Variable Cost Calculation

Table 5.1 (C) : Variable cost calculation

Variable Cost Calculations - Rs Cr (US $)			
Particulars	**Plant 1**	**Plant 2**	**Plant 3**
Cost of Oil (Sp Oil x Cost of Oil) - Rs/Kwh (US$/Kwh)	0.0255 (0.00034228)	0.0255 (0.00034228)	0.0255 (0.0034228)
Heat Contribution of Oil (Kcal/Kwh)	5	5	5
Heat Contribution of Coal (Kcal/Kwh)	2312	2266	2385
Specific Coal Consumption (Kg/Kwh)	0.624864865	0.596315789	0.644594595
Cost of Coal Rs/Kwh (US$/Kwh)	1.437 (0.01928859)	1.491 (0.02001342)	1.418 (0.01903355)
Variable Cost per Unit Rs/Kwh (US$/Kwh)	1.463 (0.01963341)	1.516 0.02035288	1.444 (0.01938255)

Variable Cost on net sent out after deducting APC (Normative ECR based on Normative Heat Rate & APC) Rs/KWh (US$/Kwh)	1.5602 (0.02094231)	1.6173 (0.02170872)	1.5398 (0.02066845)

Source - assumptions made by this research based on CERC Norms, CEA data and Vilas et al- Generation Cost Calculation for 660 MW Thermal Power Plants. Tripathi & Anand [80]-http://www.ijiset.com/v1s10/IJISET_V1_I10_94.pdf [81]

Total Cost Calculation

Table 5.1 (d)- Total Cost Calculation

Tariff	**Plant 1**	**Plant 2**	**Plant 3**
Total Cost Fixed + Variable (Rs/KWh)	**3.0617** (0.04109615)	**3.3217** (0.04458617)	**3.1023** (0.04164177)

Source - Assumptions made by this research based on CERC Norms, CEA data and Vilas et al- Generation Cost Calculation for 660 MW Thermal Power Plants. Tripathi & Anand [80], http://www.ijiset.com/v1s10/IJISET_V1_I10_94.pdf [81]

5.3.4 VARIATIONS IN HEAT RATE AND APC

Following Table depicts how Heat Rate and APC might vary with Load/PLF

Table 5.2 (a)- Heat Rate variation with Load/PLF

Heat Rate Variations with Load				
Particulars	**Plant 1 (Heat Rate)**	**Plant 2 (Heat Rate)**	**Plant 3 (Heat Rate)**	**Avg % increase in Heat Rate per % PLF drop**
At 100 % MCR (PLF)	2207	2156	2256	0.17
At 80 % MCR (PLF)	2230	2179	2279	
At 70 % MCR (PLF)	2295	2244	2344	
At 60 % MCR (PLF)	2361	2310	2410	
At 50 % MCR (PLF)	2427	2376	2476	0.28
At 30 % MCR (PLF)	2604	2553	2653	

Source- OEM curves and inputs from literature review. This is only indicative figure for supercritical units. Actual variations may be different based on machine characteristics, Tripathi & Anand [80]

Table 5.2 (b)- APC variation with Load/PLF

APC Variations with Load	
5 % Change in PLF	0.2 % increase in APC

Source- OEM curves and inputs from literature review. This is only indicative figure for supercritical units. Actual variations may be different based on machine characteristics. Tripathi & Anand [80]

5.3.5 START UP COSTS

When the requisition of power from a thermal power station is so low that the plant cannot remain stable at such low load, the plant might be ordered to shut down till demand picks up. Such situation is called Reserve Shutdown. (Currently, this level is fixed by the regulator at 55 % of full load capacity). If the power requisition (also called schedule) is below this level, the unit goes under Reserve Shutdown. In such situation, the power producer is entitled for start up costs. However, as in the case of other margins, the start-up costs also do not fully compensate the oil required to start up the power station.

Table 5.3 (a)- Start-up Cost-Number of Reserve Shut Downs when PLFs fall below 55 %

Number of Reserve Shutdowns			
PLF %	**Plant 1**	**Plant 2**	**Plant 3**
50	4	4	4
45	6	6	6
40	8	8	8
35	9	9	9
30	10	10	10
25	12	12	12

Source- Data taken from operating power plants and inputs from literature review, Tripathi & Anand [80]

Table 5.3 (b) – Start-up Cost- Oil consumption in start up

Start Up Fuel Costs			
Particulars	**Plant 1**	**Plant 2**	**Plant 3**
Oil Consumption (KL)	200	300	150

Source- Data taken from operating power plants, discussion with experts and inputs from literature review, Tripathi & Anand [80]

5.3.6 FINANCIAL IMPACT (EFFECT ON MARGINAL CONTRIBUTION, INCENTIVE AND STRAT UP COSTS)

The following tables present the Financial Impact of lower PLFs on three different types of plants. Plant -1 – 660 MW Supercritical, Plant -2 – 800 MW Supercritical & Plant 3- 500 MW Subcritical. The tables show three different losses (changes) - Difference between actual and normative energy charge rate due to reduced PLF (Marginal Contribution), start-up costs if units go in Reserve Shut Down (RSD) and loss of incentive due to lower PLF below 85 %.

Further assumptions in the calculations below is that the tariff relaxation (margins in Heat Rate and APC) given by regulator (to compensate for the effect of low PLF) is able to cover only upto 55 % of PLF, beyond that, Heat Rate deteriorates sharply. Such loss is not compensated by tariff. Further, actual data and experience show that in case of Reserve Shutdown (RSD), only upto 80 % of cost of startup (oil cost) is recovered because number RSDs and oil consumption per start up are more than what is allowed by tariff. As discussed earlier, if power plant makes any gains over and above normative, due to better efficiency than normative, 50 % of such gains are to be passed on to the customers. These assumptions are based on provisions of tariff and the actual experiences from the units under consideration. [80]

The tables show how deterioration in ECR recovery, Generation Incentives, and Startup Costs caused by low PLF affect the Revenues and Return on Equity.

Tables showing Financial Impact of lower of PLF- (ECR Loss, Startup Costs and Incentives due to fall in PLF)- 660, 800 & 500 MW Units-

Table 5.4 (a):-

Financial Impact (660 MW Supercritical) (Per annum) [80]

Sl No.	PLF (%)	Heat Rate (Kcal/ Kwhr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC-Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF goes below 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/Kw Hr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs Assumption - Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100%	2207	5.50	1.437 0.0193	0.123 0.0016	3552 4.7672	4596 0.6170		8148 10.9369
2	95%	2226	5.75	1.453 0.0195	0.107 0.0014	2938 3.9442	3064 0.4113		6003 8.0573
3	90%	2245	6.00	1.469 0.0197	0.091 0.0012	2366 3.1763	1532 0.2057		3898 5.2328
4	85%	2264	6.25	1.485 0.0199	0.075 0.0010	1836 2.4643			1836 2.4643
5	80%	2283	6.50	1.502 0.0202	0.058 0.0008	1348 1.8094			1348 1.8094
6	75%	2302	6.75	1.519 0.0204	0.042 0.0006	903 1.2126			903 1.2126
7	70%	2322	7.00	1.535 0.0206	0.025 0.0003	503 0.6749			503 0.6749
8	65%	2342	7.25	1.552 0.0208	0.008 0.0001	147 0.1974			147 0.1974
9	60%	2362	7.50	1.570 0.0211	-0.009 -0.0001	0 (Compensated by tariff)			0 (Compensated by tariff)
10	55%	2395	7.75	1.596 0.0214	-0.035 -0.0005	0 (Compensated by tariff)			0 (Compensated by tariff)
11	50%	2428	8.00	1.622 0.0218	-0.062 -0.0008	-357 -0.4791		-82 -0.1095	-438 -0.5886
12	45%	2462	8.25	1.649 0.0221	-0.089 -0.0012	-461 -0.6187		-122 -0.1643	-583 -0.7829
13	40%	2497	8.50	1.676 0.0225	-0.116 -0.0016	-536 -0.7194		-163 -0.2191	-699 -0.9385
14	35%	2532	8.75	1.704 0.0229	-0.144 -0.0019	-581 -0.7804		-184 -0.2464	-765 -1.0269
15	30%	2567	9.00	1.732 0.0232	-0.172 -0.0023	-596 -0.8005		-204 -0.2738	-800 -1.0743
16	25%	2603	9.25	1.761 0.0236	-0.201 -0.0027	-580 -0.7786		-245 -0.3286	-825 -1.1072
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									46.63 6.2597
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									31%

Table 5.4 (b)									
Financial Impact (800 MW Supercritical) (Per annum) [80]									
Sl No.	PLF (%)	Heat Rate (Kcal/ Kwhr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC- Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF goes below 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/Kw Hr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs - Assumption - Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100 %	2156	5.50	1.524 0.0205	0.093 0.0012	3255 4.3693	5571 0.7478		8826 11.8476
2	95%	2174	5.75	1.541 0.0207	0.076 0.0010	2532 3.3986	3714 0.4986		6246 8.3841
3	90%	2193	6.00	1.558 0.0209	0.059 0.0008	1861 2.4986	1857 0.2493		3719 4.9914
4	85%	2211	6.25	1.576 0.0211	0.042 0.0006	1245 1.6708			1245 1.6708
5	80%	2230	6.50	1.593 0.0214	0.024 0.0003	683 0.9163			683 0.9163
6	75%	2249	6.75	1.611 0.0216	0.007 0.0001	176 0.2366			176 0.2366
7	70%	2268	7.00	1.629 0.0219	-0.011 -0.0001	0 (Compensated by tariff)			0 (Compensated by tariff)
8	65%	2288	7.25	1.647 0.0221	-0.029 -0.0004	0 (Compensated by tariff)			0 (Compensated by tariff)
9	60%	2307	7.50	1.665 0.0223	-0.047 -0.0006	0 (Compensated by tariff)			0 (Compensated by tariff)
10	55%	2339	7.75	1.692 0.0227	-0.075 -0.0010	0 (Compensated by tariff)			0 (Compensated by tariff)
11	50%	2372	8.00	1.720 0.0231	-0.103 -0.0014	-722 -0.9694		-122 -0.1643	-845 -1.1337
12	45%	2405	8.25	1.749 0.0235	-0.132 -0.0018	-830 -1.1138		-184 -0.2464	-1013 -1.3602
13	40%	2439	8.50	1.778 0.0239	-0.161 -0.0022	-900 -1.2082		-245 -0.3286	-1145 -1.5368
14	35%	2473	8.75	1.807 0.0243	-0.190 -0.0026	-932 -1.2513		-275 -0.3697	-1208 -1.6210
15	30%	2508	9.00	1.837 0.0247	-0.220 -0.0030	-925 -1.2419		-306 -0.4107	-1231 -1.6526
16	25%	2543	9.25	1.868 0.0251	-0.251 -0.0034	-878 -1.1784		-367 -0.4929	-1245 -1.6713
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									49.26 6.6124
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									22%

Table 5.4 (c)									
Financial Impact (500 MW Subcritical) (Per annum) [80]									
Sl No.	PLF (%)	Heat Rate (Kcal/ Kwhr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC-Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF < 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/KwHr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs Assumption- Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100	2256	5.75	1.447 0.0194	0.093 0.0012	2030 2.7252	3482 0.4674		5512 7.3991
2	95	2275	6.00	1.463 0.0196	0.077 0.0010	1596 2.1427	2321 0.3116		3918 5.2587
3	90	2295	6.25	1.479 0.0199	0.061 0.0008	1194 1.6022	1161 0.1558		2354 3.1602
4	85	2314	6.50	1.496 0.0201	0.044 0.0006	823 1.1045			823 1.1045
5	80	2334	6.75	1.512 0.0203	0.028 0.0004	484 0.6502			484 0.6502
6	75	2354	7.00	1.529 0.0205	0.011 0.0001	179 0.2404			179 0.2404
7	70	2374	7.25	1.546 0.0208	-0.006 -0.0001	0 (Compensated by tariff)			0 (Compensated by tariff)
8	65	2394	7.50	1.563 0.0210	-0.023 -0.0003	0 (Compensated by tariff)			0 (Compensated by tariff)
9	60	2414	7.75	1.580 0.0212	-0.041 -0.0005	0 (Compensated by tariff)			0 (Compensated by tariff)
10	55	2448	8.00	1.607 0.0216	-0.067 -0.0009	0 (Compensated by tariff)			0 (Compensated by tariff)
11	50	2482	8.25	1.633 0.0219	-0.093 -0.0013	-408 -0.5483		-61 - 0.0819	-470 -0.6305
12	45	2517	8.50	1.660 0.0223	-0.120 -0.0016	-474 -0.6366		-92 -0.1232	-566 -0.7598
13	40	2552	8.75	1.688 0.0227	-0.148 -0.0020	-518 -0.6952		-122 -0.1643	-640 -0.8595
14	35	2588	9.00	1.716 0.0230	-0.176 -0.0024	-539 -0.7235		-138 -0.1848	-677 -0.9083
15	30	2624	9.25	1.744 0.0234	-0.204 -0.0027	-537 -0.7205		-153 -0.2054	-690 -0.9259
16	25	2661	9.50	1.773 0.0238	-0.233 -0.0031	-511 -0.6856		-184 -0.2464	-694 -0.9320
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									30.31 4.0685
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									26%

Source – Data from operating power plants, CERC tariff provisions, Grid Code, literature review and calculations done by this research.

Following conclusion is drawn from the above calculations -

If PLF changes from 90 % level to 35 %, following impact will happen on an average, on annual basis.

1. The profits will be hit by Rs 46.63 Cr/ 6.2597 (Mn US$) and ROE by 31 %, for one unit of 660 MW
2. The profits will be hit by Rs 49.26 Cr/ 6.6124 (Mn US$) and ROE by 22 % for one unit of 800 MW
3. The profits will be hit by Rs 30.31 Cr/ 4.0685 (Mn US$) and ROE by 26 % for one unit of 500 MW

On an average for all plants taken together, ROE will be impacted by about 26 %. [80]

5.4 FINANCIAL IMPACT OF LOW PLF IN DAY-AHEAD MARKETS

Sale of electricity happens through various market mechanisms. They comprise of sale through long-term Power Purchase Agreements (PPAs, which are for long duration- contracts, usually of 25 years), medium term agreements (less than one year duration) and short term markets, like day-ahead and intraday.

On global level, day-ahead market is the most prevalent market regime. India, where long term PPAs were predominantly the mainstay of electricity market, is also moving towards day ahead market regime. Therefore, in this section, the day head market mechanism has been considered to estimate the impact of flexibilization.

Marginal-cost approach is used in day-ahead markets. Lower the marginal cost of production, better are the chances of sales. In this respect, renewables have advantage. Their marginal costs may be lower than thermal power. Therefore, even without the "must run" status, the renewable energy will have better chances of dispatch than thermal. Thermal has to fill the remanent gap in demand. In the day ahead markets, the flexibilization of thermal units is therefore even more important.

In above situation, non-flexible thermal units can lead to a situation when a thermal unit takes negative prices (pays to the customer to buy power). This is because some plants may have to pay a “price” to remain “live” since shutting down and restarting the plant will be economically costlier. A flexible plant will can avoid operation in such situations because it can shut down, start, ramp up ramp down quickly.

As is evident, shutdown of a power plant results in start-up costs. The optimization dilemma is “whether to run at low loads or shutdown”. In low demand, low price scenarios. If plants can remain “live” even at low tariff or negative tariff, then they can not only avoid startup costs, they can also ramp up faster when demand picks up. If plants are capable of running at very low loads, they can optimize the overall revenues by remaining live at very low load, rather than shutting down. A cost benefit analysis has to be done between costs of taking negative prices and the costs involved in shutdowns and start ups. Analysis below, shows that on overall basis, more flexibility can bring economic value for the thermal plants.

In day ahead markets, the prices of electricity will depend on the supply Vs Demand. The following graph shows a typical demand curve on all India basis.

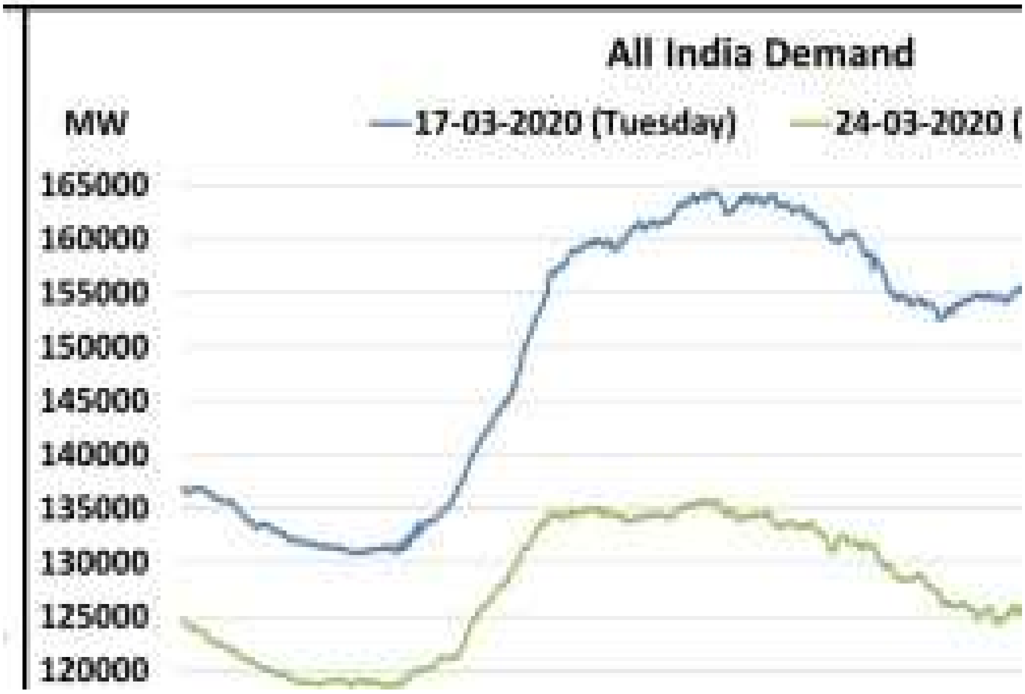


Chart C5.2 -Typical demand curve in India
Source https://posoco.in/wp-content/uploads/2020/03/24-March-2020-Demand-Comparison.pdf

Taking above demand supply as guidance and taking generally prevailing prices in IEX (Indian Electricity Exchange), an illustrative projection has been done in graph below, considering three different power plants of 500 MW capacity each with different flexibility characteristics. The graph is not as per scale but depicts approximately the three operating plants with load patterns and electricity prices in the day ahead market over a period of 48 Hrs. Similar work has been done by [77], [78], [79]

The three different plats and operating regime considered are as below-

A- 500 MW- Inflexible, Operator shuts down plant when prices are low or negative, and start up again as demand and prices pick up
B- 500 MW- Moderately flexible, reaches upto 55 % of rated capacity when prices are low. Operator keeps the plant running even when prices are low or negative to avoid shutdown and startup costs.

C- 500 MW- Flexible- Fast ramp up ramp down, reaches minimum load upto 40 % of rated capacity, does not shut down in low demand or low-price regime

The chart below shows how the prices and plant loads vary for the three plants. (500 MW each)

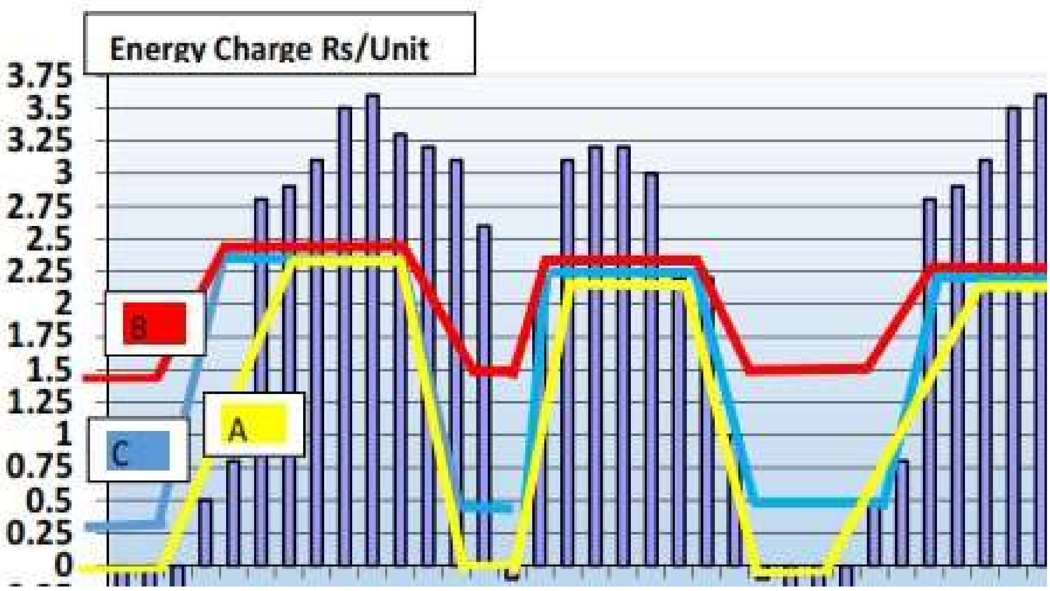


Chart C5.3 - Price and Load Variations for different sample plants-
Source- Graphical analysis of load, cost and flexibility, data assumptions from this research.

On the basis of above illustration, attempt has been made to project the revenue of the three plants for a period of 24 Hrs.

The formula used is - Revenue (Rs Million) = Average Load (MW) x Average Price (Rs/Kwhr) x Time in Hrs. The calculation is based on graphical drawing of the model with average approximate values. The exact values will depend on actual machine behavior and actual electricity prices in the market.

Results are tabulated in next section.

5.5 ILLUSTRATION OF FINANCIAL IMPACTS DUE TO FLEXIBILIZATION IN DAY AHEAD MARKET

The table below shows the calculation for all the three different plants. (500 MW capacity each)

Table 5.5 : Revenue calculation for three different plants operating under flexible regime

Plant Type	Operation Regime	Notional Revenue over 24 Hours- **Million Rs** Based on - (Load x Rate x Hrs for a period of 0-24 Hrs)
A- (Inflexible, shutdown of the plant at low loads)	Shut down when load requirement drops below 55 %	0x (-0.83) x **3** +250x0.8x**3**+500x3.25x**4**+250x2.7x**2**+ 0x (-0.2) x **2** +250x1.2 x**2**+500x3.25x**4**+250X1.25x**2**+0x9-0.6)x**2= {INR 15575 Million (- Costs of two startups} = { 15575- 153} = INR 15422 Million (USD 207 Mn)**
B- (Moderately Flexible, plant on bar even if prices are low)	Keep Live, reach minimum 55 % Load , do not shut down to avoid start up and shutdown costs	200x (-0.83) x **3** +380x0.8x**3**+500x3.25x**5**+380x2.7x**2**+ 275x (-0.2) x **1.5** +380x1.2 x**2**+500x3.25x**4**+380X1.25x**1.5**+275x(-0.6)x**2=INR 18116 Million (USD 243 Mn)**
C- (Flexible)- Fast ramp up ramp down, minimum load at 40 %)	Keep Live, utilize full Flexibilization features, bring load to 40 %	200 x (-0.83) x **3** +350x0.8x**2**+500x3.25x**6**+350x2.7x**2**+ 200x (-0.2) x **1.5** +350x1.2 x**1.0**+500x3.25x**5**+350x1.25x**1.5**+200x (-0.6)x**2= INR 20603 Million (USD 277 Mn)**

Source- Graphical analysis

The calculation shows that Plant C (Flexible- Fast ramp up ramp down, minimum load at 40 %) mops up a notional approximate revenue of INR 20603 Million (USD 277 Mn), Followed by Plant B – (Moderately Flexible Plant - keep Live, reach minimum 55 % Load and does not shut down to avoid start up and shutdown costs) at INR 18116 Million (USD 243 Mn) followed by Plant A - (Inflexible, shutdown of the plant at low loads) at INR 15422 Million (USD 207 Mn)

In our illustration, Plant C is at advantage with fast ramp up- ramp down capabilities and loads reaching upto 40 % levels. It is also evident that the plant A, which is inflexible and has to shut down and start up as per load and price conditions, gets the least revenue. Plant B sits in the middle with revenues in between A & C. **Plant C (Flexible Plant) can generate (20603-15422)*100/15422 = 33.5 % more revenues than plant A (Non-Flexible Plant).**

This is happening because the flexible plants can avoid running at higher loads during low or negative prices thus avoiding the cost sunk in keeping the plant live during the low demand and low-price conditions and can also avoid start up-shut down costs.

It is pertinent to add that, while there is clear evidence that Plant A (which is inflexible and shuts down/starts up as per load cycle) is at a clear disadvantage as compared to plant C (flexible), such definitive conclusion cannot be drawn between B & C because the revenue difference between B & C is not large. Converting an existing old Plant like B to Plant C capability by additional capital expenditure in flexibilization technology is therefore a matter of cost benefit analysis. It is because the cost incurred in converting a moderately flexible/semiflexible plant B to fully flexible plant C, has not been considered in our model. If we factor in the capital costs incurred by plant B in creating the capabilities like C, the costs incurred need to be reduced the revenue of plant C for comparison purpose. In that condition-

Revenue of Plant C = 20603 - ΔC

Revenue of Plant B = 18116

Where ΔC is cost of equipping the plant B with the additional flexibilization capabilities, distributed to per day basis over the residual life of the plant. In our illustrative example, if this cost is prohibitively high, i.e. higher than Rs 2487 Million per day (20603-18116 = 2487) for the remaining life of plant, then the Plant B is better off without the additional flexibility retrofitted at huge expense. Further to this, the comparison of revenues between the three plants shall also be affected by the electricity prices we have assumed over the period of 24 Hours.

A detailed modelling with actual flexibilization characteristics of a plant, load/demand curve of the market, prevailing day ahead electricity prices, costs and outage of plant to do to retrofit will be required to be done to take decision about investments in the flexibilization capabilities of a particular unit/plant. Since most large thermal power stations contain multiple units, it may also be prudent to do a modelling study whether to invest in flexibilization of all units or investing to make only few units highly flexible and few moderately flexible with differential capital investments.

5.6 CHAPTER SUMMARY

This chapter describes how the Return on Equity (ROE) for thermal power plants will be affected by falling PLFs. Calculations show that if PLF drops from 90 % to 35 %, the impact on ROE will be to the tune of 26 %, on an average.

It is also found that in day ahead market, a flexible plant will have edge over a non-flexible plant. It is found that a fully flexible Plant can generate upto 33.5 % more revenues than a non-flexible plant.

6 CHAPTER 6 – STUDY OF GLOBAL SCENARIO (OBJECTIVE III)

6.1 CHAPTER OVERVIEW

In this chapter, the study of global scenario in terms of thermal power plants is presented.

6.2 STUDY OF GLOBAL SCENARIO

As we proceed to find out recommended path for thermal power in India, based on the findings of Objective –I &II, a study about the current state and future plans about thermal power, in other countries in the world was thought necessary so that learnings from them can be incorporated in Recommendations/ Remedial actions. For this purpose, following five countries have been studied. These countries have substantial coal reserves and a significant part of their country's installed capacity (>20 %) comes through thermal power.

i. **Australia**

ii. **Germany**

iii. **Indonesia**

iv. **USA**

v. **Japan**

vi. **China**

There are number of European countries that have completely stopped using coal based generation. These countries are Albania, Belgium (free since 2016), Cyprus, Estonia, Iceland, Latvia, Lithuania, Luxembourg, Malta, Sweden (free since 2020) and Switzerland are such countries. About two years back, on 12th Jun 2020, Austria's major electricity company Verbund AG, closed its Mellach coal-based power plant, marking the end of fossil fuel era in Austria [82].

However, some European countries have very low installed capacity of thermal power, hence transition to "coal free" portfolio would be relatively easy.

But we need to compare India's situation with countries who have significant coal based generation portfolio. Therefore, for the purpose of this work, countries which have significant amount of thermal power in their installed capacity portfolio (> 20 %) have been considered. Keeping this in mind- Australia, Germany, Indonesia, USA, Japan and China have been studied. Following are the salient observations from these countries.

6.3 **AUSTRALIA** [83],[84],[85],[86]

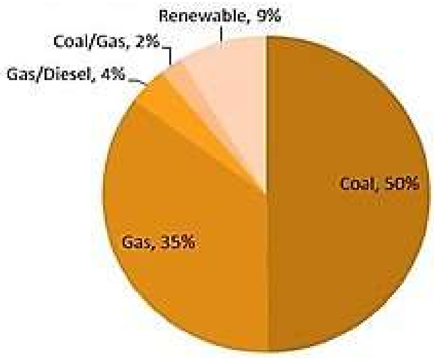
6.3.1 PRESENT SCENARIO- AUSTRALIA

The two largest energy markets in Australia are, Western Australia's South-West Interconnected System (SWIS) and The National Electricity Market (NEM).

It is evident that more than 50% of the energy comes from Coal in both the markets. In the National Electricity Market, Coal (Hard Coal + Brown Coal (Lignite)) accounts for 77 % of electricity generation.

Their distribution in terms of energy is shown in the chart below:

SWIS



NEM

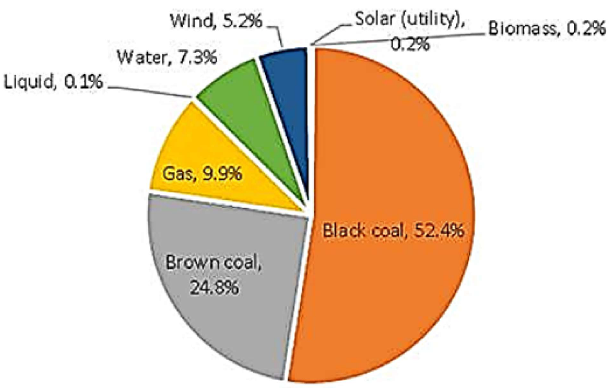


Chart C6.1 - Energy generation from different sources in Australia
Source: Australian Renewable Energy Agency

6.3.2 FUTURE OUTLOOK- AUSTRALIA

Emission and Climate Change concerns have been mounting in Australia. According to The Climate Change Authority (CCA), Australia, the coal fired thermal power plants contribute 88**%** of the total emissions of all electricity generation sources. Such concerns are obviously affecting the thermal power plants. Parallelly, renewable energy is picking up in Australia. As per the Renewable Energy Target (RET) scheme, at least 20 % of Australia's electricity generation would come from RE sources by 2020.

The country's old coal-based plants may be decommissioned even earlier than originally planned schedules, if competition from RE sources make them comparatively uneconomical, according to a new assessment by the Australian Energy Market Operator.

The Energy Market Operator predicts that by 2040, the rooftop solar capacity in Australia is likely to increase by up-to 200 %, providing nearly 22% of total energy of the country. The Operator also predicts that the quantum coal-based capacity that may be phased out by 2040 could be of the order of 63% of Australia's coal-based capacity. It is estimated that more than 30,000 MW worth large-scale renewable energy will take place of the existing thermal generation.

The renewable energy is planned to be supported by pumped hydro storage, large scale grid battery storage and small-scale distributed batteries installed in households, offices and commercial complexes.

Utilization Factor (PLF) of thermal power plants has fallen to nearly 50 % for old plants and around 60 % for new plants in Australia.

6.4 GERMANY [87], [88], [89], [90], [91],[92], [93], [94]

6.4.1 PRESENT SCENARIO- GERMANY

Germany supplies nearly 25% of its demand from Coal fired power plants (2020). (Coal + Lignite) as shown in the chart below.

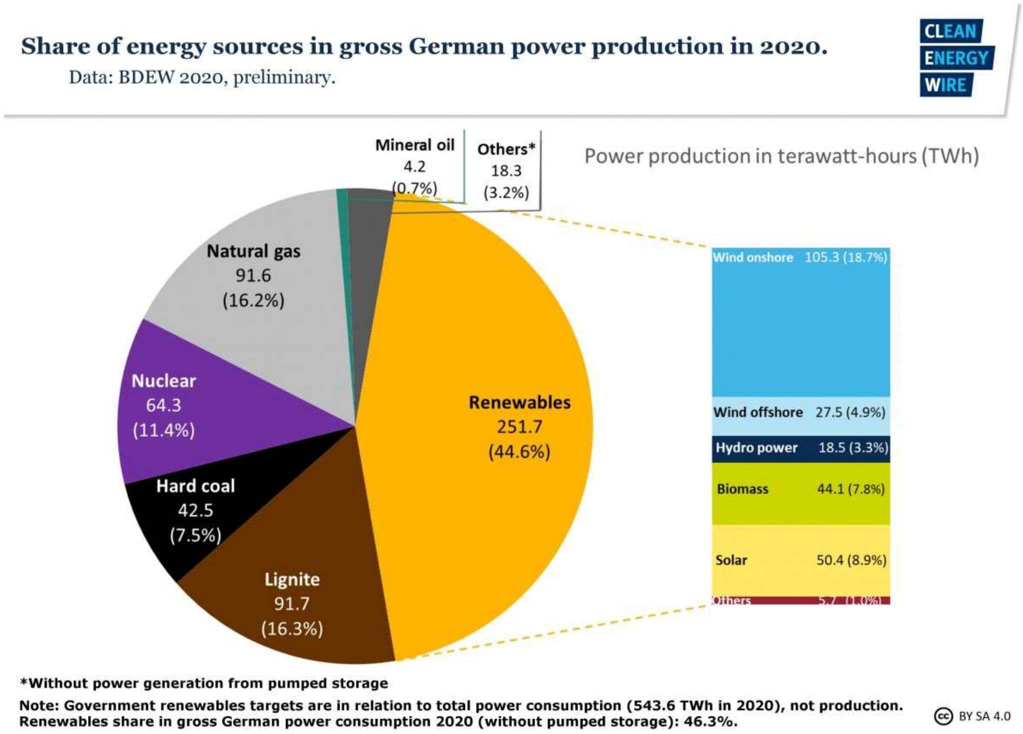


Chart C6.2 -Share of energy sources in German power production
Source BDEW 2020, preliminary.

Germany is one such country which is moving towards renewable and phasing out of thermal in a big way.

One of the remarkable features is that Germany has a comprehensive regulation for ensuring security of power supply and to see that power plant decommissioning does not put the grid in danger. As per the regulation, any power plant phase out must be informed to the Federal Network Agency (BNetzA) at least twelve months in advance of the planned shutdown date. Upon receiving such notice, the Transmission System Operator (TSO) carries out system simulation studies as to what will happen without the particular plant. If the plant is found still relevant for grid stability, the TSO instructs that the plant must be kept in service. In such situations, the operator will be reimbursed the costs incurred for keeping the plant in service.

PLFs of thermal power plants have been seeing a steep downward trend in Germany also. Following chart shows the declining trend for some of the power stations. Illustrated plants are having PLFs of nearly 20 %, 32%, 50 % and 44 %.

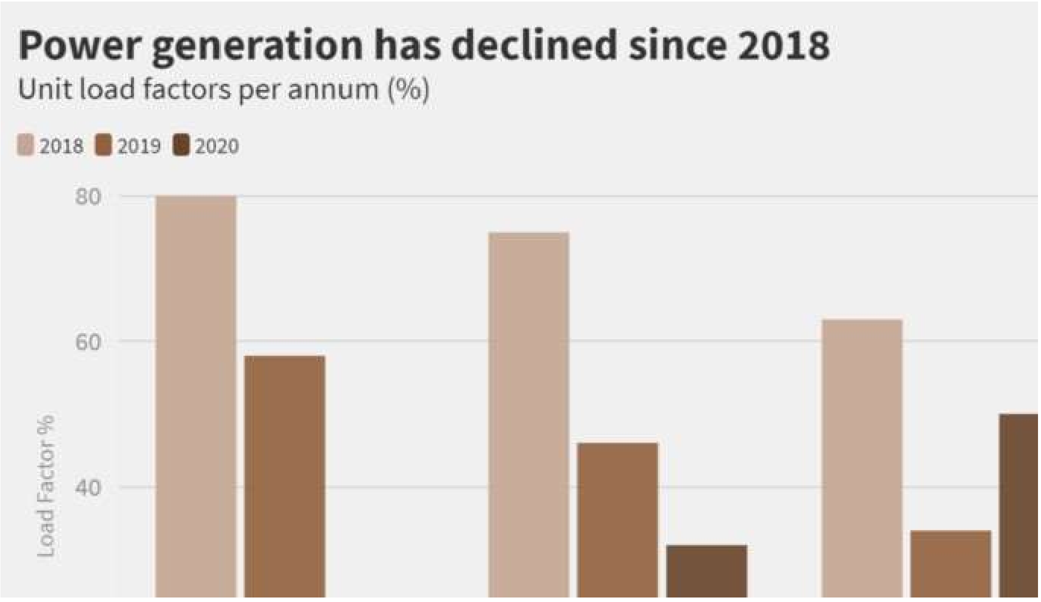


Chart C6.3- Declining PLF of coal-based plants in Germany
Source https://www.somo.nl/compensation-for-stranded-assets/

6.4.2 FUTURE OUTLOOK- GERMANY

Germany is pursuing renewable energy very aggressively. The country has announced that it will phase out coal by 2038. A separate $45 billion compensation fund has been kept to help the phasing out of coal mines and thermal power plants and to support the re-skilling of the workforce engaged in such sectors.

A recent agreement has been made between govt, power producers and operators. This agreement aims to make Germany a coal-free zone by 2038. This agreement has chalked out an 18-year time line for phasing out of coal-fired power stations in the country.

This will indeed be a mega transition towards renewable energy sources anywhere in the world. If everything happens as per plan, by 2038, the coal-fired stations are likely to become history in Germany.

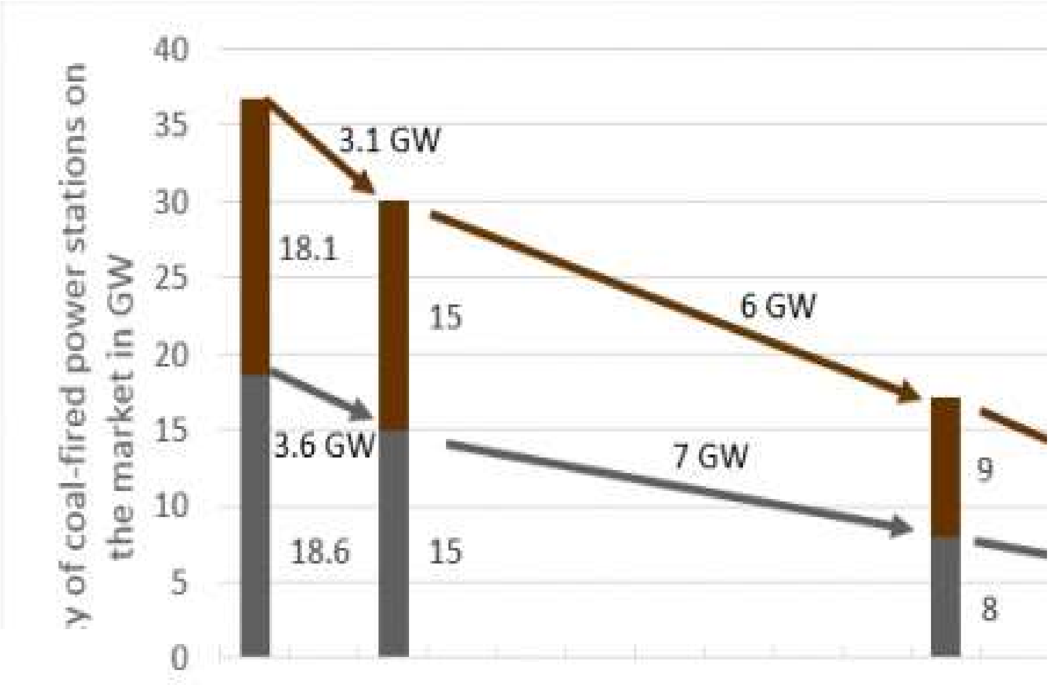


Chart C6.4 -Shutdown plan of German Coal Fired Power Plants
Source- Brainpool [88]

To support the transition to renewable energy, Germany is also pursuing energy storage technologies aggressively. The development of grid-scale battery energy storage system saw a whopping 700 % increase from 54 MW Hr in 2016 to 371 MW Hr in 2018. Germany is also actively encouraging home battery energy storage systems. Home battery energy storage systems had already crossed 300,000 number (8.5 KwHr of average capacity) by the year 2020. In Germany nearly 70% of home solar PV systems have battery storage. Germany's home energy storage market itself has touched an impressive level of 2.3 GwHr by 2020.

6.5 INDONESIA [95], [96], [97], [98], [99], [100]

6.5.1 PRESENT SCENARIO- INDONESIA

Coal based generation has a prominent role in the power sector in Indonesia. One of the prominent reasons behind this is the abundant availability of coal. In terms of coal production, Indonesia has fifth position in the world after China, the United

States of America, Australia and India. In the year 2020, thermal power capacity in Indonesia was about 59.5 GW which is about 85 % of the total installed capacity of 70 GW. In terms of energy production in 2020, the country produced 83.2% of its power generation from thermal power sources. Out of this, coal-based generation alone was about 56 % of the total generation. Indonesia is still pursuing thermal power as a mainstay of generation. Although internal rethink is going on at national policy level, thermal power capacity in Indonesia is expected to retain its dominance and is expected to reach 92.53GW by 2030. The major part of the portfolio will still be coal-based electricity generation. Following charts give the relevant data.

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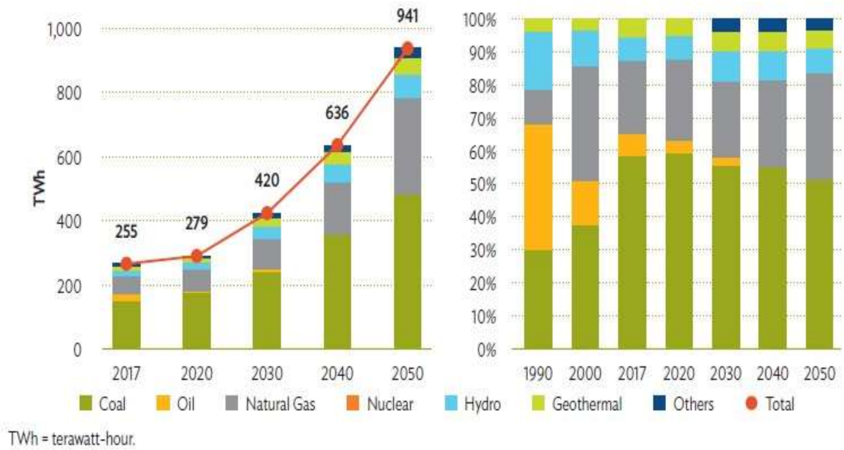

Chart C6.5- Power Generation by Source- Indonesia
Source- Country Report- Cecilya Laksmiwati Malik- March 2021

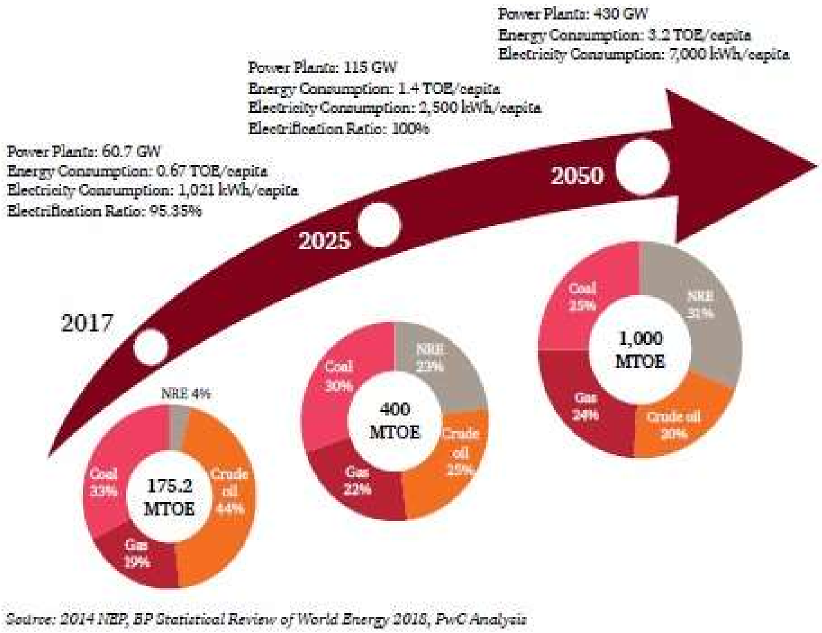

Chart C6.6 - Future plan of Indonesia in the Power Sector
Source - 2014 NEP, BP Statistical Review of World Energy 2018, PWC Analysis

The above graphs show that presently coal is the most dominant source of power production in Indonesia. It is also apparent that although the proportion will reduce, coal will still be dominant player even by 2050.

6.5.2 FUTURE OUTLOOK- INDONESIA

As brought out above, Indonesia is a country where coal generation remains a strong player. However, things are changing in Indonesia also.

Indonesia's Ministry of Energy and Mineral Resources has come out with the 2021 electricity supply business plan (2021 RUPTL) in October 2021. In a marked departure in strategy as compared to the previous plan released in two years back in 2019, there is an evident shift from fossil fuels towards renewable. The plan indicates emphasis on larger renewable capacity additions. As per the 2021 RUPTL there is a plan to add 21 GW of renewables. Compared to the previous 2019 RUPTL, this shows a 25% increase in renewable portfolio. In a major shift from the previous strategy, fossil fuel generation capacity additions are to decline by 50% and are likely to remain just under 20 GW. On the other hand, the proportion of capacity additions from renewables shows a marked increase from previous plan level of 30% to 52%. This shows a clear resolve to gradually shift away from fossil fuels.

However, in spite of Indonesia's push for more renewables and cleaner energy, coal is expected to dominate the fuel mix with more than 50% share until 2027. This is due to better coal availability and relatively nascent renewable energy policies.

As a strategy to shift towards better environment protection, Indonesia is emphasising on limiting the fugitive dust emission and GHG emission levels by improving the technology used in thermal power plants. The country is going ahead with Ultra Super Critical (USC) technology, which ensures better fuel efficiency and lower emissions. Indonesia's biggest coal-based thermal power plant PLTU Jawa 7 (2 X 1,000 megawatt (mw)) is now commercially operating with this technology. The USC technology can increase efficiency of power plants by about 3-5 % compared to subcritical technologies. This helps in reducing greenhouse emissions.

6.6 USA [101], [102], [103], [104], [105]

6.6.1 PRESENT SCENARIO- USA

By the end of 2020, the United States had about 11,17, 475 MW of total electricity generating capacity. Out of this, Natural Gas based generation is the biggest component amounting to 4,83,000 MW. Coal amounted to 2,18,000 MW, Renewables 1,81,000 MW, Hydro Power 1,03,000 MW, Nuclear 97,000 MW and Diesel & others 36000 MW. The following chart shows US generation capacity by source between 1990 and 2020. The chart shows marked increase in gas-based generation. Major driver of this was the discovery and large-scale harnessing of Shale Gas in the country.

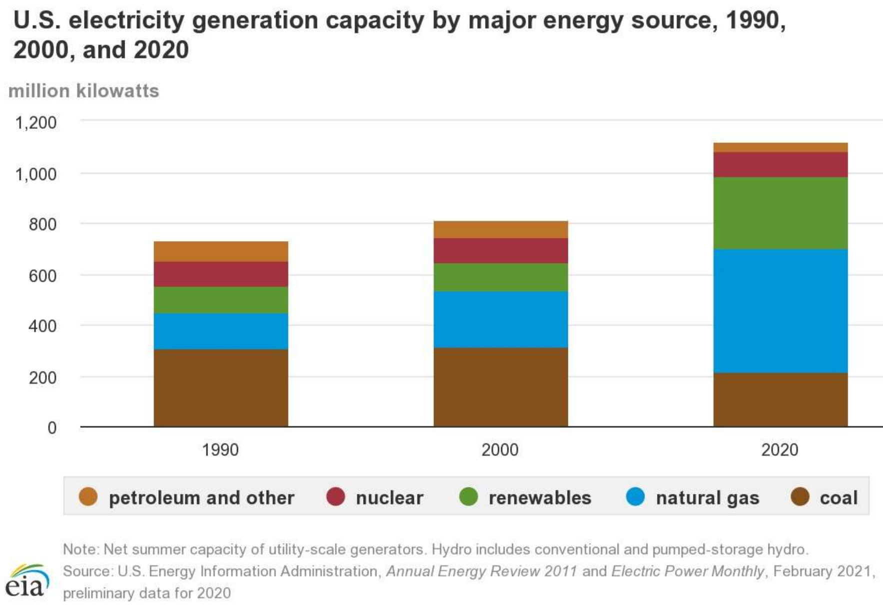

Chart C6.7 : US electricity generation capacity by fuel
Source - EIA

According to EIA's estimate of retirement plans of thermal plants, 33 gigawatts (GW) worth capacities have already announced their plans to shut down.

Moody's has reported that in the USA, the speed and magnitude of the decline in coal-based power generation is still uncertain. However, the already announced plan of shutting down of coal-based plants, is likely to reduce the coal-based generation from the current levels of around 20 % to as low as 11% of total U.S. power generation by 2030.

In the USA, the major drivers of transition from coal to other sources are – (i) availability of cheap natural gas (ii) lower than expected electricity demand (iii) thrust on clean energy and (iv) integration of renewable energy.

6.6.2 FUTURE OUTLOOK - USA

In USA, the Coal-fired power plants are facing significant pressure. Retirement of capacities totalling about 102 gigawatts (GW) have already been announced between 2010 and 2019. As estimated, 69 GW of coal-based plants are further due to retire by 2025.

Energy Information Administration (EIA) predicts that as per Affordable Clean Energy (ACE) Rules, the low efficiency coal-based plants will have to be retired by 2025. These Rules, promulgated by the U.S. Environmental Protection Agency (EPA) in 2019 mandate improvement in Heat Rates of their coal-fired power plants to reduce CO2 emissions, or else shut down the units.

There is another visible change. Coal-fired plants that are retiring post 2015 are relatively bigger in capacity and younger in age than those retiring prior to 2015. For example, the units that retired in 2018 had an average capacity of 350 MW with average age of 46 years, as compared to 129 MW and 56 years respectively for those retiring *before* 2015.

In the decade 2010 to 2020, the Utilization Factor (PLF) of coal based thermal power plants has dwindled from 67 % to 40 %. The total installed coal based generation capacity of 2,18,000 MW of the country is likely to fall by about 35 % based on the retirements plans already announced by 2021.

EIA projects that after 2025, only the highly efficient coal-fired plants will remain operating. This situation is likely to continue at least until 2050 because natural gas prices are expected to rise and coal power plants are likely to remain competitive in this time frame.

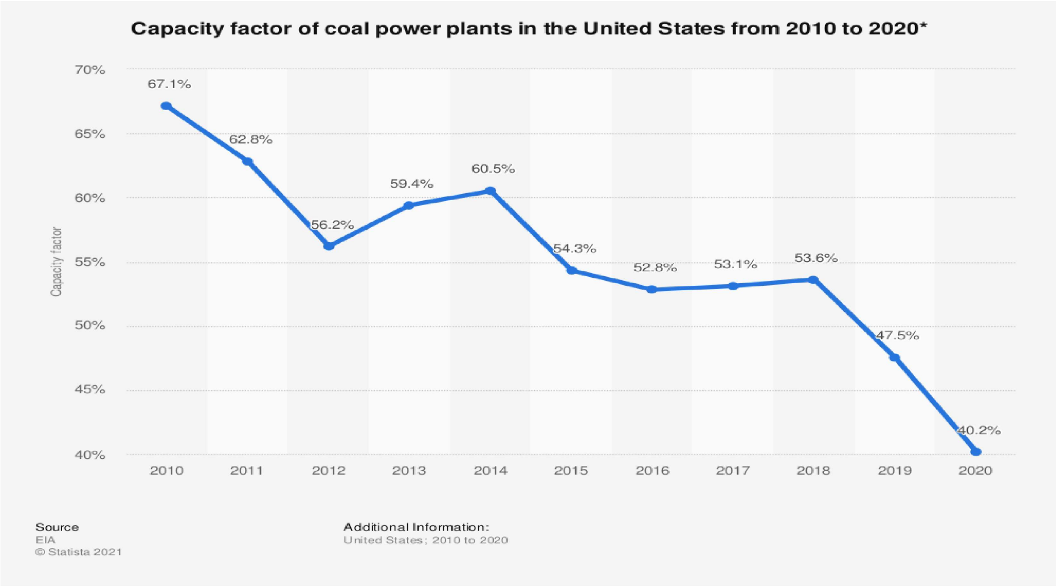

Chart C6.8 : Capacity Utilization Factor of Coal based power plants in USA
Source – Statista

US is also actively pursuing Energy Storage Technologies in order to achieve smooth the transition from fossil fuels to renewable energy. There was nearly 708 MWHr of grid-scale battery-storage already installed in the U.S, by the end of 2017. These storage facilities are owned and is operated by companies that provide ancillary (support) services to the grid. These companies are mainly the Independent System Operators (ISOs) and Regional Transmission Organizations (RTOs). The ISOs and RTOs are regulated non-profit organizations, that work independently to support and regulate power distribution.

There is another important technological trend emerging in the USA. In future, US coal-based power plants are likely to be a fleet of smart, small capacity, agile, technology-driven power units, instead of large capacity, baseload facilities. Alongside the planned phasing out of coal power units in the coming years, new research and funding will happen towards the development of this "new generation" smart plants. These new coal fleet may be of 100 MW to 350 MW sizes, with high efficiency, high flexibility and near-zero emissions. This is how coal power industry is seeking new methods to minimise its financial, technological and environmental risks.

6.7 JAPAN [106], [107], [108], [109], [110], [111], [112]

6.7.1 PRESENT SCENARIO IN JAPAN

31.6 % of Japan's electricity came from coal based thermal power in the year 2020. However, as is happening in many countries in the world, Japan has also embarked on a major shift towards renewable energy. Since 2011, renewable energy (RE) has been the mainstay of Japan's low carbon strategy. Other than thermal, shrinking of nuclear power is also happening in Japan.

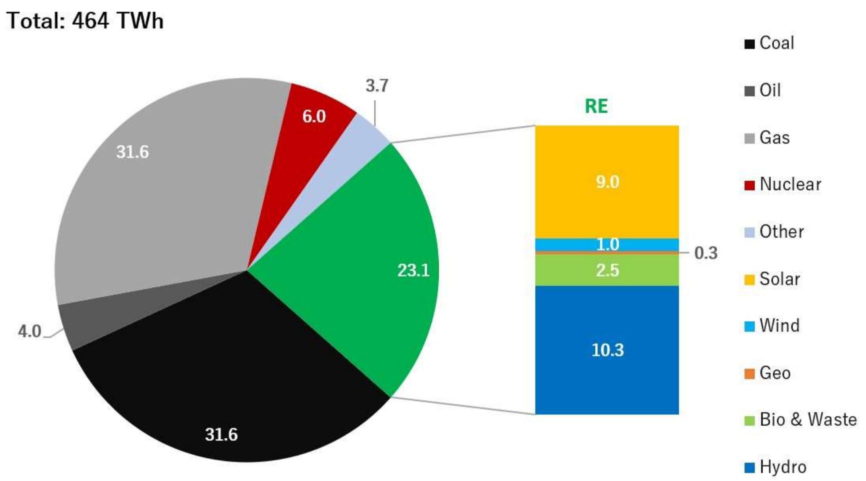

Chart C6.9- Japan electricity generation by fuel
Source- Japan Renewable Energy Institute

Share of coal in country's total installed capacity has remained nearly stagnant at 14-15 % for last 4-5 years. In terms of energy generated this share is around 31. 6 % ; During this period the share of Renewable Energy saw substantial growth from 10% to 23%.

6.7.2 FUTURE OUTLOOK IN JAPAN

The installed capacity share as well as the capacity utilization of coal-based generation has been coming down in Japan. The Cross-Regional-Coordination of Transmission-Operators of Japan (OCCTO) had prepared the Electricity Supply Plan in 2017 which showed that the PLF coal-based power plants will come down from the level of 80% in 2015 to the level of 69% in 2026.

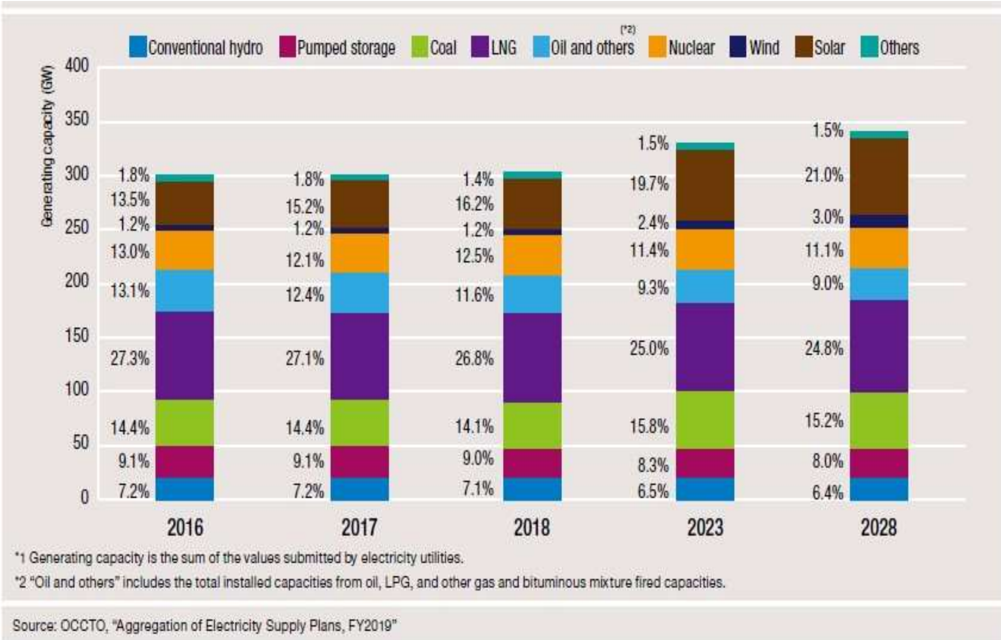

Chart C6.10 - Japan's generation capacity projection by fuel type
Source - OCCTO

Japan's biggest power generator JERA aims to achieve net zero emissions of CO_2 by 2050. It has announced plans to decommission all the inefficient coal-fired power plants by the year 2030. Although shutting down of the inefficient coal power stations has been part of the govt's plan, it is for the first time that a utility has clearly announced the intention to act in accordance with the policy.

To bring clarity, a government panel is trying to come out with a policy to fix the *parameters defining inefficient coal-fired plants*. However, JERA has independently announced that it considers "supercritical or less" technology as inefficient plants.

To meet the goal of carbon neutrality as early as 2050, Japan is planning a significant boost in renewable energy. It is also planning to create futuristic electricity generation mix by measures like hydrogen-based fuel, ammonia, carbon capture and storage technologies.

Under above backdrop, some experts in the country have cautioned towards imminent risks in such fast transition. An outlook document by the Govt prepared in 2021, after taking into account the available power supply and the demand pattern, showed that the country might fight fall short of meeting peak demand phases, if such fast transition is executed.

A latest report of Ministry of Economy, Trade and Industry of Japan predicts that the deficit situation may come in the coming decade as the country goes ahead with its plans to shut down a total 31200 MW of thermal power generation. The report says that any major reduction in thermal capacity, which forms about 70 percent of the current energy mix, could endanger supply position during peak demand seasons.

Due to such precautionary note, Japan is not halting the thermal power completely. It is going to add thermal power at about 1.5% (CAGR) during 2020-2025. Modern, low carbon and efficient technologies like ultra-supercritical are expected to replace the old and aging power plants.

6.8 CHINA [113], [114], [115], [116], [117]

6.8.1 PRESENT SCENARIO IN CHINA

China’s current installed capacity (2020) is nearly 2000 GW. The country’s installed capacity has grown to be the highest in the world. Coal had the biggest share of installed capacity in the country (54%) in 2018 (Chart below). However, it is seen that a slowdown in thermal capacity addition has happened during in China to reduce the thermal overcapacity and also due to environmental concerns.

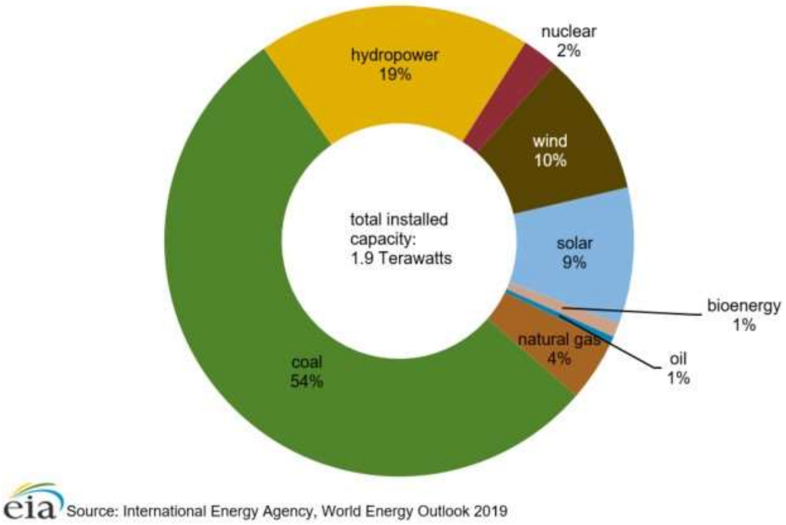

Chart C6.11 - Installed Capacity in China
Source - EIA

There are two major trends in the Chinese power system. The first trend is of fast increasing share of Renewable Energy (RE) primarily in the form of solar and wind. The second trend is the ongoing power market liberalization and reforms. These two trends are likely to impact the role, relevance and economics of the thermal power plant plants in China.

Due to integration of renewable energy, thermal power plants are required to operate in cyclic or flexible operation regime. However, the power operators are not investing in flexibilization technologies.

Even in present era, China still uses benchmarking pricing or the single part tariff system for thermal power plants. Under this system thermal power plants' revenues are solely dependent on the amount of power they produce. Therefore, there is no tariff incentives for the thermal power plants to modify and improve their flexibility. The current power market design is considered a major hindrance for the development of flexibility in the thermal power plants. Chinese government has therefore recently decided to launch new power market reforms to address these issues.

As more and more capacity got added both in coal based as well as in renewable, the PLF of coal-based power plants has decreased by 15-20 % (on an average) in China. As the growth in power demand slows and the share of RE increases, the Capacity Utilization (PLF) of thermal power is likely to decrease further.

6.8.2 FUTURE OUTLOOK IN CHINA

In recent years, China added massive renewable energy portfolio, mainly in wind and solar power. In 2020, the country has added nearly 72 GW of wind and nearly 48 GW of solar power. It shows that China is aggressively adding renewable capacity.

Reports also show that China has added 11000 MW of fresh coal-based capacity in the first six months of 2020, while 53000 MW was further in pipeline at that time. It shows that China is going ahead with new thermal power plants along-with aggressive addition in renewable energy portfolio.

However, there is slow down in coal capacity addition. Nearly 83 power plants of wind, solar natural gas and nuclear, shall be taking place against the coal-based power. The country is also trying to limit the coal- based capacity to avoid overcapacity. The initial plans were to limit coal power to 1100 GW by 2020.

As thermal power constitutes nearly 75 % of power production in China, its green transition will need sound transition policies. In order to successfully transform the established power system, the China National Energy Administration (NEA) is implementing concrete reforms to push the market design and institutional conditions in the desired direction.

There have been regional efforts for energy transition. Natural gas is taking place of coal-based stations in eastern and north-eastern regions of the country where stricter environmental regulations are in place. The government also plans to replace older coal-based plants with new advanced emission technology-based coal plants to facilitate clean coal generation.

There are two major programs currently running in China. The 'China Thermal Power Transition' program focuses on integrating higher shares of Renewable Energy (RE) to enter into a low carbon future. The objective of this program is to bring in short and long-term term policy changes in the thermal power market by improving operational flexibilization and bringing in suitable market conditions to sell power from thermal power plants. The program also seeks to proactively involve the thermal power sector.

The second important program called Development of Economic Incentives and Regulation Supporting Flexibility is aimed at developing economic incentives and conditions to support, fund and nurture power plant flexibility. The program also aims to develop a new Power Dispatch Regulation to create the provisions that support flexibilization of thermal plants.

An important feature of the program is to demonstrate scalable, practical and cost-efficient solutions for improving thermal power plant flexibility by undertaking several *demonstration projects* in China. This is aimed at infusing plant flexibility in the country at a large scale. By the end of the program (5 year), the aim is to have 100 GW of thermal plants (100-150 plants) retrofitted with flexibilization capabilities in North China. This is equivalent to nearly 20% of the installed thermal capacity in the region.

The program will create a platform for sharing the experiences and outcomes and for engaging relevant stakeholders, particular the thermal power producers - to be proactive instead of resisting the transition to a low carbon future.

6.9 GLOBAL SCENARIO OF DECOMMISSIONING OF THERMAL POWER PLANTS [118], [118], [119], [120],]121],[122],[123]

Our study of global scenario shows that many countries viz USA, Germany, Australia are planning for systematic decommissioning the thermal power plants. This study of global scenario was important for this research because when we wish to draw remedial action for thermal power plants in India, global experience must be factored in. Based on our study, the post decommissioning options typically include the following-

6.9.1 DECOMMISSIONING OPTIONS

Decommissioning process includes steps like stopping the plant, decommissioning, removal of plants and materials, structure demolition, segregation, cleaning, and restoration of the plant site for alternate use. Some sites could be suitable for power generation through alternate fuel/ technology, some could be suitable for ports, renewable energy plants, or any other industrial or commercial use. Costs for decommissioning of a 500-MW coal-fired plant may lie between USD 5 million to 15 million after deducting the scrap value. The complete decommissioning process takes between 18 to 30 months. [117]

6.9.2 OUTRIGHT SALE ON *AS - IS- WHERE - IS* BASIS

Most thermal power sites are near pit head (near coal mines) but some are near load centers (cities or industrial hubs). Depending on the location, proximity to rail, road, water bodies they can have value for alternate usage. Some sites could have good demand and can be sold on "as is where is" basis. For such sites, buying company may even be willing to incur the costs involved in decommissioning.

The value of any site will depend on the alternate usage it may have. It is advisable to engage real estate professionals and valuation consultants to do valuation studies. These experts will examine the following factors:

(i) Area, shape, altitude, climate, pollution, water availability, and other physical attributes.
(ii) Lease or free hold, transfer of title, land use change and other statutory clearances etc.
(iii) Liabilities on the project.
(iv) Connectivity with road, rail, air etc
(v) NPV, IRR of alternate projects on the site.

6.9.3 CONVERSION TO NATURAL GAS

Conversion of coal-based power plant to natural gas fired plant can be a solution in some situations. Most critical will be availability of gas. Next will be modifying the boiler for gas firing.

Gas fired boilers do not need FGD, ESP, Ash Dyke etc thus saving many environmental hassles.

For such conversions, costs involved may be about USD 50-60 million per unit and time required may be about 18 months.

6.9.4 REPLACEMENT WITH GAS TURBINE PLANT

Instead of retrofitting the existing plant from coal fired to gas fired boiler, another option is to replace with new gas turbine plant. Gas turbines have fast ramp rates and have far lesser environmental footprint.

In such replacement of plant, some of the plant auxiliary facilities can still be utilised. Construction of new gas turbine plants at an existing coal plant location may take between 1-3 years and may be completed in parallel to decommissioning of existing coal-based facilities. Costs may range between USD 25 to 75 million.

6.9.5 KEEPING THE SITE FOR FUTURE USE

In some cases, it may be difficult to sell a site immediately or the generating company may not like to sell the project site because it believes that the site could be used for its future projects.

In such cases, they may opt to decommission the plant, sell the salvage and then prepare and keep the site ready for future use. In such cases the coal plant would reduce the costs of maintenance, security and would also reduce risk of accidents and environmental issues.

6.10 VARIOUS STEPS IN DECOMMISSIONING OR RETIRING OF PLANTS [118], [119] , [120], [121], [122]

6.10.1 SITE SURVEY AND ANALYSIS

This involves complete analysis of the plant site with investigations and surveys by experts. Plan for decommissioning and dismantling are drawn at this stage.

6.10.2 IDENTIFYING THE RISK AREAS

This step involves identification of hazardous items areas like insulation, asbestos, oils It also involves identification of high risk zones like building structures that may fall on other structures, safety issues, environmental hazards, statutory permits and compliances.

6.10.3 DISPOSE, AUCTION, REUSE, RECYCLE DECISION

For each of the package, what items fall in *Dispose, Auction, Reuse, and Recycle* category are decided at this stage.

6.10.4 SCOPE OF WORK, CONTRACT PACKAGES AND PARTIES

At this stage the expert team decides scope of work, number of contract packages for decommissioning works, timelines, progress review methods etc. At this stage, the team also shortlists suitable parties for each package.

6.10.5 STRUCTURE REMOVAL MECHANISM ASSESSMENT

This step involves in-depth inspections and modelling for assessing structural integrity and collateral damages as structures are demolished.

6.10.6 DISCUSSION WITH POTENTIAL AGENCIES AND DEVELOPMENT OF DECOMMISSIONING METHODS, TIMELINES, TECHNOLOGIES

The team discusses with different stakeholders about the possible methods, technologies timelines for decommission.

6.10.7 PRODUCTION OF DISMANTLING PLANS

The expert team creates plans, tools and equipment list, L1/L2/L3 networks, PERT and CPM Charts. This also involves identifying resource requirements, financial provisions, sensitivity analysis forecasting based on scrap sale price indices.

6.10.8 FINAL PACKAGING AND AWARD

Work is divided in contract packages, detailed scope of work are developed, cost estimates are made and tenders are invited. After evaluation, award is made.

6.10.9 SITE SUPERVISION

Owner's engineering and site supervision for dismantling are done by consultant or the utilities themselves.

6.10.10 TYPICAL COSTS IN DECOMMISSIONING AND DISMANTLING

Costs will depend on several factors including quantity of insulation, asbestos, oils, scrap and other hazardous materials that need to be removed, proportion of plant and material above gerund and below ground, labour costs, demolition technologies used, proximity to scrap markets, possibilities of alternate usage of material within the company, costs on consultants, actual demolition costs, costs for new construction, and commercial operation. Salvage material can be sold at the market value.

6.11 SPECIFIC ACTIONS IN SELECT COUNTRIES WITH RESPECT TO DECOMMISSIONING WHERE DECOMMISSIONING HAS STARTED [117], [118], [119], [120],[121], [122]

6.11.1 USA

Since 2011, power producing companies in the USA have closed 200 coal fired plants. Out of these, 35 were demolished, 15 were sold for redevelopment and more than 100 were converted into the combined cycle natural gas plants.

6.11.2 UK

In the UK, utilities have started converting coal to natural gas plants and also into bio mass fed plants.

Some utilities are using the biomass firing inside the boilers instead of coal to reduce the CO2 emissions. For example, wood pellets are fired in boiler by a company called DRAX. Compressed wood pellets are stored in the covered domes to protect them from moisture. Currently about 600MW + energy is being produced by these plants.

Plants near sea are being converted to desalination plants and giving clean drinking water.

6.11.3 GERMANY

Germany is doing some novel experiments. They are redeveloping older power plants into the giant batteries, using salt thermal batteries, li-ion batteries and Carnot batteries.

A Carnot Battery is basically a storage technology which stores electricity in the form of thermal energy. In this system, electricity is converted into heat and is stored for further use. This is called “charging”. When electricity is needed, the heat energy is converted into electricity. This is called “discharging”.

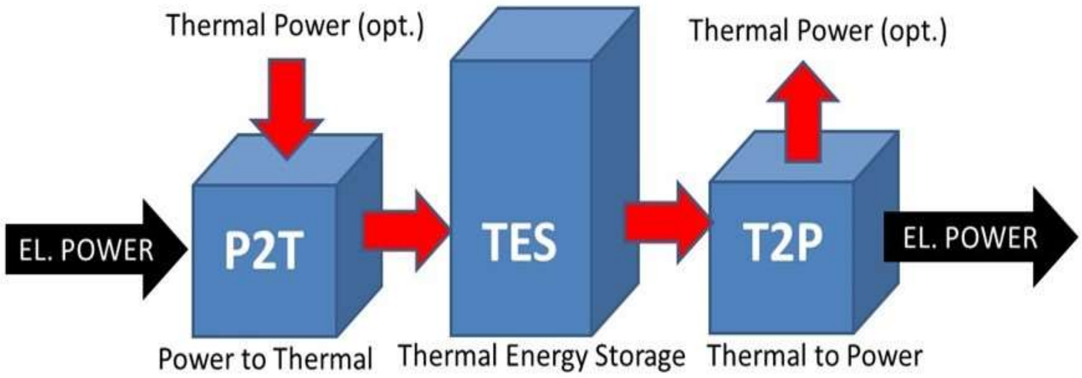

Figure F 6.1 - A Carnot Battery (P2T- Electrical Power to Thermal Storage TES- Thermal Energy Storage, T2P- Thermal Storage to Electrical Power)
Source- Energy Transition

These "Carnot batteries" can hold the excess renewable energy produced during renewable energy is available in abundance and then release the power back into the grid when needed.

Germany is thus planning to utilise the decommissioned thermal power plant sites to install battery type energy storage of large capacities.

6.12 CHAPTER SUMMARY

This chapter brings in important insights from global scenario. It is found that PLF of thermal power plants are going down in almost all the countries studied (Australia, Germany, Indonesia, USA, Japan and China). For example, in the USA, coal-based plans are operating at average PLF of as low as 20 %. All countries, except Indonesia have major energy transition plans from thermal to renewable. Moreover, all countries except Indonesia have already started decommissioning of plants. Some of the learning from the study of global scenario has been used for recommendations/action plan.

7 CHAPTER 7 – DEVELOPMENT AND VALIDATION OF RECOMMENDATIONS / REMEDIAL ACTIONS USING DELPHI METHOD - (OBJECTIVE-III)

परैश्च परीक्षयेत् यद्दुदासीनः

पश्यति न तदनुष्ठातेति प्रायो वादः

- Kadambari-Baanbhatta

"Plan should be got examined by outsiders. The argument is, what the neutral person sees, the one who executes may not see most of the time."

7.1 CHAPTER OVERVIEW

As the famous Indian writer Banabhatta (7th century) says, we should get any plan examined by outside experts. Because, the creator of the plan can get attached to the plan while the external person is unattached and can give independent views.

Based on the analysis of Objective-I (Major Factors), Objective-II (PLF Projections, study of Technical & Financial Impact and study of Global Scenario, Recommendations / Remedial Actions were prepared by the researcher. These were then validated with 15 senior industry experts. **Delphi method** was used for arriving consensus. The Recommendation / Remedial Actions were shared with experts in the form of a questionnaire **(Annexure - E)**

7.2 THE DELPHI METHOD

Delphi is a qualitative research design, to work out consensus solutions to problems or situations. This is done by arriving at agreeableness after few rounds of discussions. The aim is to arrive at the most amenable consensus within a group of experts, which becomes the best workable solutions to the problem**.** [124], [125]

As far as the number of experts is concerned, Delbecq et al. (1975) have noted that "If it a homogeneous group of experts, then 10 to 15 participants are enough" [124], [125]. The number of experts in this research was kept at 15, which is considered adequate for Delphi design.

For this research, experts having extensive experience and leadership roles in the sector, having more than 30 years' experience - MDs, CMDs, and Executive Directors, GMs etc.- 15 Nos were chosen. **(Annexure F)**

A response sheet in the form of a questionnaire **(Annexure- E)** was sent to experts in the First Round. Telephonic discussions were also held regarding key findings and Recommendations/Remedial Action. Results were tabulated. (Details are given in the next section). Then the second round was done through questionnaire as well as telephonic discussions. In the third round final recommendations were compiled. Exact process is tabulated blow in detail.

After Round-1, wherever, there were low agreement (<40 % or below experts agreed to the point) those points were straightway dropped from Round – 2 and were not made part of recommendations.

After Round-1, wherever, there was 100 % agreement already, those points were taken directly to recommendations.

Wherever agreement fell between 41-99 %, those points were taken up for consensus in Round - 2. After Round 2, some experts changed their stance some did not. On points where consensus was achieved, such points were included in recommendations. For the points on which the consensus could not be achieved even after Round- 2, those points were finally dropped from recommendations. In Round 3 final consensus points were listed.

7.2.1 THE DELPHI PROTOCOL FOLLOWED

The following tables give the process protocol followed

7.2.1.1 PROTOCOL OF THREE ROUNDS

How the three rounds progressed is given in tabular form below –

Table 7.1 (a) : Delphi rounds- how they progressed

Round 1		**Round 2**		**Round 3**	
Action	Result	Action	Result	Action	Result
15 Experts were contacted were sent questionnaire and also contacted over phone	All 15 responded with observations and gave their views	After assimilating the views the opinions all 15 were contacted again through questionnaire and telephonic discussions	10 Experts responded on questionnaire. 8 agreed on the recommendations 2 had some additional / different views on 1-2 points. Telephonic discussions also held.	Discussion held with those who had some additional / different views on 1-2 points.	Consensus Points were taken in recommendations

How the three rounds of Delphi were held- Source – Delphi Method

In the first round 15 experts were consulted telephonically and through questionnaire. Findings were shared. Their opinions were sought telephonically and also through questionnaire response. All 15 responded in first round. In the second round, questionnaire was sent again to all 15 with the findings and majority view. 10 experts responded with their views through second round of questionnaire. 8 experts agreed to the all the round 2 findings. 2 experts had some supplementary / different views on few points. Remaining 5 who did not reply electronically and the 2 experts who had some supplementary / different views on 1-2 points. These 7 experts (5 +2) were consulted via phone and opinion was sought again. The final outcome were the points where consensus was reached either in round 1 or round 2. These points were finally listed and shared in Round 3.

7.2.1.2 PROTOCOL OF AGREEMENT ON DIFFERENT POINTS

Following table shows how agreements were reached in different rounds.

Table 7.1 (b) : How the point wise agreement progressed in Delphi

Points sent through questionnaire (In addition to sharing of findings and Remedial Measures over phone)	Points where 100 % Agreement was there (Consensus) in Round 1 itself - These were Taken directly to Recommendations (Round 3)	Points where less than or equal to 40 % Agreement in Round 1-. Dropped from Recommendations	Taken to Round 2 for arriving at consensus	Consensus arrived after R2	Consensus points after Round 1 + 2	Consensus could not be reached after Round 1+2	Points finally included in Recommendation in Round 3
Total Points – 30 **(**Main Points - 21 Sub Points - 09)	**6**	**2**	**22 (30-6-2)**	**18**	**6 + 18 = 24**	**06 (02+04)**	**24 (including main points and sub points)**

Source- Delphi method of validation of Recommendations/ Remedial Actions

7.2.2 CONTACT PROTOCOL - NAMES AND DATES OF CONTACT WITH THE EXPERTS FOR DELPHI

Table 7.1 (c) : Names of experts and dates of contact for Delphi

Name	Designation/Affiliation	Dates Contacted
Sh R S Sharma	MD Bajaj Energy, Ex CMD NTPC, EX MD Jindal Power	**06.05.2021, 13.08.2021, 10.09.2021**
Sh K R C Murthy	Managing Director, Chhattisgarh State Power Genco.	**20.04.2021**
Sh Arun Kumar Sharma	Member Chhattisgarh State Regulatory Commission	**20.04.2021**
Dr P P Kulkarni	Regional Executive Director NTPC	**20.04.2021,09.09.2021, 10.09.2021**
Dr. Sarat Kumar Acharya	CMD Neyveli Lignite Corporation	**23.04.2021, 19.09.2021, 20.09.2021**
Sh R K Srivastava	Executive Director NTPC Energy Technology Research Alliance	**20.04.2021, 08.09.2021**
Sh Pradip Chanda	Professor, NTPC School of Business	**22.09.2019, 21.04.2021**
Sh A N Sar	Chief Executive Officer & Whole Time Director, Bajaj Energy	**20.04.2021, 09.09.2021**
Sh Aditya Mishra	Chief Operating Officer, Bajaj Energy	**20.04.2021, 19.09.2021**
Sh A K Ahuja	Executive Director, Corporate Planning, NTPC, Consultant	**21.04.2021, 10.09.2021**
Dr Yogendra Saxena	Senior Sustainability Consultant	**07.05.2020, 04.05.2021**
Sh Virendra Singh	Dir (Technical) Haryana DISCOM	**06.05.2021**
Sh M G Mue	Superintending Engineer, Gujarat Energy Transmission Corporation Limited	**06.05.2021**
Sh B S Negi	DGM, Satluj Jal Vidyut Nigam Limited	**06.05.2021, 08.09.2021**
Sh Saptarshi Roy	Director (HR), NTPC	**06.05.2021, 10.09.2021**

Source- Compiled list of experts for Delphi

7.2.3 RESULTS OF DELPHI - VALIDATION OF RECOMMENDATIONS/ REMEDIAL MEASURES

Following table summarises the result of Delphi Round 1,2,3

Table 7.2 - Validation of Recommendations/ Remedial Measures- Delphi Round 1,2, & 3

Questions	Round 1 Delphi- Questionnaire Response Choices- SA- Strongly Agree- A- Agree N - Neutral or undecided, D - Disagree- SD- Strongly Disagree, VS - Very Strong Challenge S- Strong Challenge N-Neutral WK-Weak Challenge VWK- Very Weak Challenge	Action after Round 1 of Delphi	Action after Round 1	Round 2 Response	Result of Round 3- Final Recommendations
1) *In spite of increase of other sources of generation like*	SA-10, A-5	100 % SA+ A- Included in Recommendations	Consensus Reached . Taken to recommendation	Taken to recommendations	Included in Recommendations

renewables, coal based thermal power plants will still be important for India's power sector			s		
2) Coal based thermal power plants will remain vital in Indian power generation sector at least for next 10 Yrs, 15 Years, 20 Years	Yrs-10-8, 15-2, 20-5	Upto 10 Years is agreed by 66 %- 15-13 % , 20 -25 % Taken as 20 Years in recommendations	Taken to Round 2	Consensus on 20 Years	Included in Recommendations
3) Coal based power plants may have to be finally phased out by 2050	SA-6, A-3, D-6	80 % agreement	Taken to Round 2	No consensus reached	Dropped from Recommendation
4) Currently the national average Plant Load factor (PLF) of thermal power is around 55 %. It is likely to reduce further if necessary steps are not taken	SA-4 (26%), A-8,N-1,DA-2	80 % agreement -	Taken to Round 2	Consensus reached	Included in Recommendations

5)	In your opinion what could be the range of national average PLF of the coal stations in next 5 years if present trend continues	50-55-9 (60 %), 45-50-6 (40%)	60 % agreement	Taken to Round 2	Consensus on the findings of this research as per Scenarios	Included in Recommendations
6)	If demand picks up at 1-2 % higher rate than present increase rate in the country and new coal capacity addition is significantly slowed down as suggested by CEA, what could be the range of national average PLF of the coal stations in next 5 years	50-60-'11 (73 %), 40-50-2 (13%), 60-70-3 (20 %)	73 % saying 50-60 %	Taken to Round 2	Consensus on 50-60 %	Included in Recommendations
7)	After 10 years, all power in India will be sold through day ahead/ exchange/trade	SA-3 (20 %),A-6 (40%),N-2 (13%),DA-2(13%)	60 % agreement	Taken to Round 2	Consensus could not be reached	Dropped from recommendations

instead of long term PPAs					
8) Some future challenges for the coal based thermal power plants are listed here- Please indicate your opinion about for each challenge whether it is strong or weak challenge. You can select any choice for any challenge-					
I. Ash Utilization	VS-7, S-8	100 % agreement	Consensus Reached . Taken to recommendations	Taken to recommendations	Included in Recommendations
II. Water Availability	VS-7, S-8, N-0	100 % agreement	Consensus Reached . Taken to recommendations	Taken to recommendations	Included in Recommendations
III. Emission Control	VS-5, S-10	100 % agreement	Consensus Reached . Taken to	Taken to recommendations	Included in Recommendations

			recommendations		
IV. Tariff Realization	VS-4, S-6, 4-N-4, WK-1	67 % agreement -	Taken to Round 2	Consensus could not be reached	Dropped from Recommendations
V. Closing old plants	VS-3, S-09, N-2, WK-1	80 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
VI. Attracting Talent	VS-3, S-6, N-4, WK-1, VW-1	60 % agreement	Taken to Round 2	Consensus could not be reached	Dropped from Recommendations
VII. Generation Cost	VS-4, S-6, N-3, WK-2	66 % Agreement	Taken to Round 2	Consensus could not be reached	Dropped from recommendations
VIII. Flexible Opn	VS-6,S-6,N-2,W-1	80 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
IX. Managing public perception	VS-6, S-5, N-4	73.33 % agreement	Taken to Round 2	Consensus could not be reached	Dropped from Recommendations
X. Land Acquisition	VS-9, S-5, N-1	93 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
9) Since considerable investments have gone into the thermal power plants	S-9, A-3, D-1, N-1	80 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations

and they are vital for the operation of grid, these plants must be supported through tariff and policy so that they operate with sustainable capacity utilization, remain profitable and survive in business for at least next 20 years and meet the grid requirements.					
10) *Since every business has to face the market, thermal power should also be left alone to face the market and no intervention should be done.*	A-6, D-6, SD-1, N-2	40 % agreement	40 or less percent agreement-Dropped not taken to Round 2	Dropped from recommendations	Dropped from Recommendations
11) Rate of new capacity addition should	SA-3, A-3, D-6, N-1	40 % agreement	40 or less percent agreement-	Dropped from recommendations	Dropped from Recommendations

be slowed down so that existing plants are utilised optimally.			Dropped not taken to Round 2		
12) Rate of fresh coal based capacity addition should be changed as below so that there is no overcapacity leading to low PLF(Present rate of coal capacity addition is 9 %, calculated as CAGR of last 5 years) A. We should continue to add coal capacity at historical rate of 9 % CAGR B. No new capacity should be added for next 3 years since we have adequate coal capacity for next 3 yrs C. Rate of new capacity addition rate	SD 3%-5, SD-6%-3, Hist R-1, No CA-4	Divergent Views as there were several options 33 % agreement on 3 % rate, 40 % agreement on 6 % rate- 73 % agree on slowdown of new capacity addition rate	Taken to Round 2	Consensus on scenario projections	Included in Recommendations

should be reduced to 6 % instead of current 9 % D. Rate of new capacity addition rate should be reduced to 3 % instead of current 9 % E. Rate of new capacity addition rate should be increased to 12 % instead of current 9 %					
13) Coal based power stations must invest in Flexibalisation (Flexible Operation) Technologies	SA-10, A-5	100 % agreement	Consensus Reached. Taken to recommendations	Taken to recommendations	Included in Recommendations
14) Coal based power stations must invest in Pollution Control Equipment (Sox Nox ESP Modernisation)	SA-8, A-6, N-1	80 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
15) Coal based	SA-11, A-4	100 %	Consens	Taken to	Included

power stations must invest in Pollution Control Equipment (Sox Nox ESP Modernisation)		agreement	us Reached . Taken to recommendations	recommendations	in Recommendations
16) All old and inefficient plants should be shut down with specific timelines so that capacity utilization of existing/new high efficiency plants gets enhanced. For the long term (beyond 30 years) all thermal power producers should create an exit plan from thermal power.	SA-09, A-4,N-1, DA-1	87 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
17) Since electricity markets will be more and more based on trading/ day	SA-8, A-6, N-1	93 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations

ahead, thermal plants must invest in advanced techno commercial modelling software and create specialist groups for harnessing market related dynamics.					
18) Since coal is helping integration of renewable energy in the grid by providing ramp up and ramp down support as needed, it is actually providing ancillary service to Grid. Coal generation should be supported through policy/monitory remuneration for	SA-7, A-6, N2	87 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations

this service.					
19) For all plants that meet minimum environment and efficiency parameters, and are cleared by regulator and grid operator, their fixed cost should be pooled in the country and total fixed cost should be covered by a central dispatcher. All plants, cleared by regulator / grid operator should get this capacity charge, irrespective of fuel source. This cost should be distributed to all the off takers. Competition can be generated through energy	SA-4, A-6, DA-2, N-2	73 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations

charges.					
20) To help and promote greener thermal power, the advanced, supercritical based coal plants with state of the art pollution control and efficiency level above say 41 % (criteria to be decided by regulator), may be categorised under "must run" and may be given status similar to renewable.	SA-5, A-7, N-1, D-2	80 % agreement	Taken to Round 2	Consensus reached	Included in Recommendations
21) For the long term (beyond 30 years), an exit plan for thermal power should be prepared and coal plants should be compensated for the exit (A separate policy should be issued	SA-5, A-6, D-2, N-1	73 % agreement	Taken to Round 2	Consensus reached	Included in the Recommendations

by CERC/MOP)					
Other Suggestions/Comments	I. Time to initiative Sustainability practices, Climate Change and GHG control with stricter norms for emissions. II. Indian power system is a unique interconnected system with strong interconnections. Lot many alternatives India can have. However 02 suggestions/ observations I would like to mention: 1) During initial phase of JNM for solar power, coal power was notionally mixed up	New aspects/ comments taken to Round 2	New aspects/ comments taken to Round 2	Consensus reached on selected points	Relevant comments taken Recommendations

	with costly solar power for reducing the cost of mixed power. Similarly policy may be adopted for mixing present day low cost solar with thermal power for rationalizing the power tariff. 2) Renewable without storage is intermittent power and difficult to make it dispatchable. Appropriate mechanism (through policy adoption, market structure and fast response technology which is existing today) of				

	rationalized mixing of renewable power with thermal power may make it smooth system operation. III. Must install high capacity Ultra Supper Critical Technology units in future. IV. There is urgent need of policy shift towards more of our head thermal power plants and with ultra super critical plants with MS and HR temp of 600 and pressure of 300 kg/cm2 Net heat rate of 2000/ 2050 must be				

	targeted to make them more viable . Pit head power plants with this NHR shall be cheaper than solar plants in VC . VC of coal based plants will require to be seen with respect to combined cost of renewables with cost of storage sources Coal based plants must compete with solar and wind power cost together with storage sources It will not be right for india to plan for exit of coal based plants rather it				

	should be to make them more efficient , cheaper and cleaner . V. Coal plants to be essentially used for base load requirements.				

Source- This research

7.2.4 CHAPTER SUMMARY

This is the chapter where research moves towards recommendations. The chapter presents how Delphi was followed in three hounds, gives the names of experts and shows how the consensus was achieved. The next chapter finally summarises Key Findings, Conclusions and Recommended Remedial Actions which have emerged as part of this research.

8 CHAPTER 8 – KEY FINDINGS, CONCLUSIONS AND RECOMMENDATIONS / REMEDIAL ACTIONS

8.1 Chapter Overview

This chapter presents the final outcome of this whole research. The findings are summarised, Conclusions and Recommendations/Remedial Action have been spelt out.

8.2 Outcome of each research step – At a glance

Outcomes of each research steps (of the three objectives) is summarised here.

Table 8.1- Research steps and outcomes at a glance

Objective	**Step No**	**Process in brief**	**Outcome**
Objective - I	1	Literature Review	Identification of 7 major areas which might be affecting Capacity Utilization Factor (PLF)
	2	Focus Group discussion with experts (13 Experts) to identify variables.	Identification of 25 well defined factors which might be affecting Capacity Utilization Factor (PLF)
	3	Preparation and administration of Questionnaire	Questionnaire prepared with 25 factors, seeking response on Likert Scale whether a particular factor is • Having very high impact • Having high impact • Neutral or undecided • Having low impact • Having very low impact 253 responses received

	4	Analysis of questionnaire using Hypothesis Testing for majority saying a particular factor as Major Factor (Z test for proportion).	14 Major Factors affecting PLF of thermal power plants identified.
	5	Factor Analysis to find out Major Factors	10 factors emerged as Major Factors. These 10 are common in both Hypothesis Testing and Factor Analysis. This is outcome of Objective -I.
Objective -II	1	Regression Analysis (using Excel) for predicting PLF (dependent variable) for next five years. Four top ranking factors affecting Capacity Utiisation Factor (PLF) taken as independent variables (Peak Demand, Total Installed Capacity, Installed Capacity (Coal) and Installed Capacity (Renewables)). Past 35 years data of the independent variables taken for regression.	Multiple hierarchical regression done with three and then with four independent variables and moved back to three variables (Peak Demand, Installed Capacity (Coal) and Installed Capacity (Renewables)) due to better fit of regression. Analysis showed that data had Multicollinearity. To overcome this limitation, shifted to Partial Least Square (PLS) Regression (using R) which does not have underlying presumption of data not showing Multicollinearity.
	2	PLS Regression used for predicting PLF for next five years under four	Prediction of PLF for next five years under four different scenarios. (Outcome of Objective – II)

		different scenarios. (Jack Knife used to find out the coefficients)	
	3	Sensitivity Analysis	What is the impact of the three independent variables i.e. (Peak Demand, Installed Capacity (Coal) and Installed Capacity (Renewables)) on PLF (Outcome of Objective – II)
	4	Finding out technical and financial impact of falling Capacity Utilization Factor (PLF) on thermal power plants.	Flexibilization requirements and detailed calculation of loss of revenue for three sample power stations (660 MW, 800 MW and 500 MW) - Outcome of Objective – II)
Objective-III	1	Study of Global Scenario- present status and future plans regarding thermal (Through Literature Survey). Countries which have significant amount of thermal power in their installed capacity portfolio (> 20 %) have been considered. Australia, Germany, Indonesia, USA, Japan and China.	What are the significant developments and learning from these countries for thermal power producers?
	2	Drawing of Recommendation / Remedial Action for thermal power plants	Recommendation / Remedial Action plan drawn for thermal power plants based on outcomes of Objective I, II

		based on output of Objective-I, Objective -II and step I of Objective - III (Global experience)	and study of Global Scenario.
	3	Validation of Recommendation / Remedial Action with expert group using Delphi method (Three phases of Delphi conducted with 15 senior power sector experts)	Final Recommendation / Remedial Action.

Source- Delphi process for validation of Recommendations/ Remedial Actions

8.3 KEY FINDINGS

Following sections present the key findings of the Objective I &II *(Objective – III was arriving at the final Recommendations/ Remedial Actions, which are brought out separately in next section.)*

8.3.1 MAJOR FACTORS AFFECTING THE PLF OF THERMAL POWER PLANTS. (OBJECTIVE -I)

From the analysis of Objective –I it is concluded that following are the 10 Major Factors affecting PLF of thermal power stations. Outlook on all these factors has been discussed in detail earlier in the thesis.

1) *Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if demand exists*
2) *The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition*

3) *Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation*

4) *Substantial addition of renewable energy (solar and wind) having must-run status in the grid*

5) *The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up.*

6) *Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power*

7) *India has reached a stage of being power surplus (on most days in a year)*

8) *Although India is power deficit on totality basis, many regions have actually become power surplus*

9) *Low fuel (coal) availability forcing thermal power generators to reduce power generation*

10) *Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available.*

8.3.2 PROJECTION OF PLF FOR NEXT FIVE YEARS (OBJECTIVE -II)

The following table shows the projected PLF in next 5 years under four different scenarios-

Table 8.2- Projection of PLF for next five years under four different scenarios

CAGR %/Year	Peak Demand (MW)	Installed Capacity Coal (MW)	Renewable Capacity (MW)	Projected PLF % Sector Wise			
Scenario I- CEA Projection (CEAP)- B*ased on fuel mix and demand suggested by CEA vide - Report (Draft) on optimal generation capacity mix for 2029-30- CEA- GOI*							
CAGR %	6.44	2.66	17.90	National	Central	State	Private
2020-21	193913	210592	102289	58.80	68.79	53.25	56.66
2021-22	225751	216193	120599	68.15	78.14	62.60	66.02

2022-23	238167	221944	142186	66.92	76.91	61.37	64.78
2023-24	251267	227848	167637	64.93	74.92	59.39	62.80
2024-25	265086	233909	197644	62.03	72.02	56.48	59.90
Scenario-II- CEA based Projection and phasing out of old capacity (CEAP+PHOUT)- *Based on fuel mix and demand suggested by CEA vide - Report (Draft) on optimal generation capacity mix for 2029-30- CEA- GOI, and assuming that 5000 MW old capacity will be phased out every year.*							
CAGR %	6.44	2.66 *	17.90	National	Central	State	Private
2020-21	193913	205592	102289	60.14	70.23	54.59	58.01
2021-22	225751	206193	120599	70.84	80.93	65.29	68.71
2022-23	238167	206944	142186	70.96	81.04	65.41	68.82
2023-24	251267	207848	167637	70.32	80.41	64.77	68.19
2024-25	265086	208909	197644	68.77	78.85	63.21	66.63
Scenario-III- Low Coal, Aggressive Renewable Growth) and Normal Demand (LCARND, the BAU Case - *Growth rate of Thermal Capacity reducing to 4.04 % and that of Renewable Capacity at aggressive 25.03 % rate (Coal addition at reduced rate by 5 % and renewable higher by 2 % , Demand growth normal at 5.5 % as compared to last 5 years' CAGR which is the BAU case)*							
CAGR	5.50	4.04	25.03	National	Central	State	Pvt
2020-21	193911	213417	108477	56.36	66.35	50.81	54.22
2021-22	204574	222033	135631	51.97	61.96	46.42	49.83
2022-23	215823	230997	169583	45.93	55.92	40.39	43.80
2023-24	227691	240323	212033	37.80	47.79	32.26	35.67
2024-25	240211	250026	265110	27.01	37.00	21.47	24.88
Scenario- IV- Reduced Growth (RG) – *Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other*							
CAGR %	2.50	6.04	20.03	National	Central	State	Pvt
2020-21	188397	217520	104139	53.68	63.68	48.14	51.55
2021-22	193105	230652	125000	46.83	56.82	41.28	44.69
2022-23	197930	244577	150041	38.68	48.67	33.14	36.55
2023-24	202876	259343	180097	29.01	39.00	23.46	26.87
2024-25	207946	275000	216175	17.52	27.51	11.97	15.39

Source- Regression analysis using PLS with R

* with 5000 MW being phased out every year in next five years

In Scenario I- CEAP (B*ased on fuel mix and demand suggested by CEA vide Report(Draft) on optimal generation capacity mix for 2029-30- CEA, GOI*). This Scenario considers coal capacity addition rate decelerated considerably to about 2.66 % CAGR against last 5-year CAGR rate of 9.04 %, Peak demand increase considered is steeper at 6.44 % as compared to last 5-year CAGR of 5.5 % and

Renewable Energy addition CAGR is considered reduced to 17.90 % from last 5-year CAGR of 23.03 %. A combined effect of all three independent variables on this path, makes the national PLF to reach to 58.80 % in the year 2020-21. Under this Scenario, by 2024-25 - the PLF reaches 62.03 %. (Central, State and Private sector are projected to operate at 72.12 %, 56.48 % and 59.90 % respectively.). This is a recommended path.

Scenario-II- CEAP+PHOUT -. In this case national PLF varies between 60.14 % to 68.77 % in next five years. Central, State and Private sector are projected to operate at 78.85 %, 63.21 % and 66.63 % respectively. This Scenario assumes the conditions of Scenario I *plus* decommissioning of old plants at the rate of 5000 MW every year (In this case, demand Growth is considered @ 6.44 %, Coal Plant Capacity addition @ 2.66 % and Renewable Capacity addition @ 17.90 % + Phase out @ 5000 MW/Year). In this Scenario all the three segments (Central, State and Private) are able to maintain a reasonably high (above 60%) PLF in next five years. This is another recommended path.

In Scenario-III - LCARND-Low Coal, Aggressive Renewable and Normal Demand - Growth rate of thermal capacity is considered at 4.04 % and that of renewable capacity addition at 25.03 % and demand growth is at normal rate of 5.5 % . In this Scenario - National average PLF may drop below 46 % by 2022-23 which is a warning signal. This is Business as Usual situation and needs immediate attention of policy makers, power producers and all other stakeholders.

In Scenario IV – which is a specific case due to Corona - Reduced Growth (RG) – *Peak Demand, Coal Based Capacity and the Renewable Energy Capacity CAGR of each one growth rate reducing by 3 % (as compared to last 5 years' CAGR) due to Corona and other factors,* In this case the PLF drops below 40 % in 2022-23. This situation is likely for 1-2 years but is unlikely in long run as the demand is showing signs of pick up after Corona.

8.3.3 SENSITIVITY ANALYSIS (OBJECTIVE -II)

The Jack-knife test has been used to find out the estimates of the three independent variables. Using the estimates given by this method it is found that (i) If peak demand increases by 5000 MW, the PLF will increase by 2.4 %. If Installed Capacity of coal increases by 5000 MW, the PLF will decrease by 1.35 % and if renewable energy capacity increases by 5000 MW, the PLF will decrease by 1.36 % taking 2019-20 as base year. **The highest impact on PLF is of power demand (MW) which is in the positive direction i.e. + 2.4 % / 5000 MW of demand increase**, the next impact is of renewable energy capacity addition (MW) in the negative direction (-) 1.36 % / 5000 MW and then the impact of capacity of addition of coal (MW) again in the negative direction i.e. (-) 1.35 % / 5000 MW. In each sensitivity, other variables are considered remaining at same level.

8.3.4 FINANCIAL IMPACT OF FALLING PLF (OBJECTIVE -II) [80]

The following tables present the Financial Impact of lower PLFs on three different types of plants. Plant -1 – 660 MW Supercritical, Plant -2 – 800 MW Supercritical & Plant 3- 500 MW Subcritical. The tables show three different losses (changes) - Difference between actual and normative energy charge rate due to reduced PLF (Marginal Contribution), start-up costs if units go in Reserve Shut Down (RSD) and loss of incentive due to lower PLF below 85 %. Further assumptions in the calculations below is that the tariff relaxation (margins in Heat Rate and APC) given by regulator (to compensate for the effect of low PLF) is able to cover only upto 55 % of PLF, beyond that, Heat Rate deteriorates sharply. Such loss is not compensated by tariff. Further, actual data and experience show that in case of Reserve Shutdown (RSD), only upto 80 % of cost of startup (oil cost) is recovered because number RSDs and oil consumption per start up are more than what is allowed by tariff. As discussed earlier, if power plant makes any gains over and above normative, due to better efficiency than normative, 50 % of such gains are to be passed on to the customers. These assumptions are based on provisions of tariff and the actual experiences from the units under consideration.

The tables show how deterioration in ECR recovery, Generation Incentives, and Startup Costs caused by low PLF affect the Revenues and Return on Equity.

Tables showing Financial Impact of lower of PLF- (Marginal Contribution, Incentives and Startup Costs variation due to PLF)- 660, 800 & 500 MW Units- [80]

Table 8.3 (a):

Financial Impact per annum **(660 MW- Supercritical)** [80]

Sl No.	PLF (%)	Heat Rate (Kcal/Kwhr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC-Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF < 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/KwHr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs if RSD is required - Assumption - Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100%	2207	5.50	1.437 0.0193	0.123 0.0016	3552 4.7672	4596 0.6170		8148 10.9369
2	95%	2226	5.75	1.453 0.0195	0.107 0.0014	2938 3.9442	3064 0.4113		6003 8.0573
3	90%	2245	6.00	1.469 0.0197	0.091 0.0012	2366 3.1763	1532 0.2057		3898 5.2328
4	85%	2264	6.25	1.485 0.0199	0.075 0.0010	1836 2.4643			1836 2.4643
5	80%	2283	6.50	1.502 0.0202	0.058 0.0008	1348 1.8094			1348 1.8094
6	75%	2302	6.75	1.519 0.0204	0.042 0.0006	903 1.2126			903 1.2126
7	70%	2322	7.00	1.535 0.0206	0.025 0.0003	503 0.6749			503 0.6749
8	65%	2342	7.25	1.552 0.0208	0.008 0.0001	147 0.1974			147 0.1974
9	60%	2362	7.50	1.570 0.0211	-0.009 -0.0001	0 (Compensated by tariff)			0 (Compensated by
10	55%	2395	7.75	1.596 0.0214	-0.035 -0.0005	0 (Compensated by tariff)			0 (Compensated by
11	50%	2428	8.00	1.622 0.0218	-0.062 -0.0008	-357 -0.4791		-82 -0.1095	-438 -0.5886
12	45%	2462	8.25	1.649 0.0221	-0.089 -0.0012	-461 -0.6187		-122 -0.1643	-583 -0.7829
13	40%	2497	8.50	1.676 0.0225	-0.116 -0.0016	-536 -0.7194		-163 -0.2191	-699 -0.9385
14	35%	2532	8.75	1.704 0.0229	-0.144 -0.0019	-581 -0.7804		-184 -0.2464	-765 -1.0269
15	30%	2567	9.00	1.732 0.0232	-0.172 -0.0023	-596 -0.8005		-204 -0.2738	-800 -1.0743
16	25%	2603	9.25	1.761 0.0236	-0.201 -0.0027	-580 -0.7786		-245 -0.3286	-825 -1.1072
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									46.63 6.2597
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									31%

Table 8.3 (b)									
Financial Impact per annum **(800 MW- Supercritical)** [80]									
Sl No.	PLF (%)	Heat Rate (Kcal/K whr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC-Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF < 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/KwHr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs if RSD is required - Assumption- Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100%	2156	5.50	1.524 0.020	0.093 0.0012	3255 4.3693	5571 0.7478		8826 11.8476
2	95%	2174	5.75	1.541 0.020	0.076 0.0010	2532 3.3986	3714 0.4986		6246 8.3841
3	90%	2193	6.00	1.558 0.020	0.059 0.0008	1861 2.4986	1857 0.2493		3719 4.9914
4	85%	2211	6.25	1.576 0.021	0.042 0.0006	1245 1.6708			1245 1.6708
5	80%	2230	6.50	1.593 0.021	0.024 0.0003	683 0.9163			683 0.9163
6	75%	2249	6.75	1.611 0.021	0.007 0.0001	176 0.2366			176 0.2366
7	70%	2268	7.00	1.629 0.0219	-0.011 -0.0001	0 (Compensated by tariff)			0 (Compensated by tariff)
8	65%	2288	7.25	1.647 0.0221	-0.029 -0.0004	0 (Compensated by tariff)			0 (Compensated by tariff)
9	60%	2307	7.50	1.665 0.0223	-0.047 -0.0006	0 (Compensated by tariff)			0 (Compensated by tariff)
10	55%	2339	7.75	1.692 0.0227	-0.075 -0.0010	0 (Compensated by tariff)			0 (Compensated by tariff)
11	50%	2372	8.00	1.720 0.023	-0.103 -0.0014	-722 -0.9694		-122 -0.1643	-845 -1.1337
12	45%	2405	8.25	1.749 0.023	-0.132 -0.0018	-830 -1.1138		-184 -0.2464	-1013 -1.3602
13	40%	2439	8.50	1.778 0.023	-0.161 -0.0022	-900 -1.2082		-245 -0.3286	-1145 -1.5368
14	35%	2473	8.75	1.807 0.024	-0.190 -0.0026	-932 -1.2513		-275 -0.3697	-1208 -1.6210
15	30%	2508	9.00	1.837 0.024	-0.220 -0.0030	-925 -1.2419		-306 -0.4107	-1231 -1.6526
16	25%	2543	9.25	1.868 0.025	-0.251 -0.0034	-878 -1.1784		-367 -0.4929	-1245 -1.6713
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									49.26 6.6124
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									22%

Table 8.3 (c)									
Financial Impact per annum **(500 MW- Subcritical)** [80]									
Sl No .	PLF (%)	Heat Rate (Kcal/Kwhr)	APC (%)	Actual Variable Cost (VC) Rs US$	Diff between Actual Variable Cost and Normative ECR (VC-Normative ECR) Rs US$	Marginal Profit// Loss (-) Assumptions- (i) only 80 % of loss will be covered by Tariff if PLF < 55 % (ii) Any additional gain will be shared in 50-50 ratio)- Rs Lacs US$ Mn	Incentive Loss (Rate assumed @53 Piase/KwHr (Avg of Peak and Off peak Hours) Rs Lacs US$ Mn	Start-up Costs if RSD is required - Assumption- Only 80 % cost will be covered by Tariff Rs Lacs US$ Mn	Total Gain/Loss Rs Lacs US$ Mn
1	100%	2256	5.75	1.447 0.019	0.093 0.0012	2030 2.7252	3482 0.4674		5512 7.3991
2	95%	2275	6.00	1.463 0.019	0.077 0.0010	1596 2.1427	2321 0.3116		3918 5.2587
3	90%	2295	6.25	1.479 0.019	0.061 0.0008	1194 1.6022	1161 0.1558		2354 3.1602
4	85%	2314	6.50	1.496 0.020	0.044 0.0006	823 1.1045			823 1.1045
5	80%	2334	6.75	1.512 0.020	0.028 0.0004	484 0.6502			484 0.6502
6	75%	2354	7.00	1.529 0.020	0.011 0.0001	179 0.2404			179 0.2404
7	70%	2374	7.25	1.546 0.0208	-0.006 -0.0001	0 (Compensated by tariff)			0 (Compensated by tariff)
8	65%	2394	7.50	1.563 0.0210	-0.023 -0.0003	0 (Compensated by tariff)			0 (Compensated by tariff)
9	60%	2414	7.75	1.580 0.0212	-0.041 -0.0005	0 (Compensated by tariff)			0 (Compensated by tariff)
10	55%	2448	8.00	1.607 0.0216	-0.067 -0.0009	0 (Compensated by tariff)			0 (Compensated by tariff)
11	50%	2482	8.25	1.633 0.021	-0.093 -0.0013	-408 -0.5483		-61	-470 -0.6305
12	45%	2517	8.50	1.660 0.022	-0.120 -0.0016	-474 -0.6366		-92 -0.1232	-566 -0.7598
13	40%	2552	8.75	1.688 0.022	-0.148 -0.0020	-518 -0.6952		-122 -0.1643	-640 -0.8595
14	35%	2588	9.00	1.716 0.023	-0.176 -0.0024	-539 -0.7235		-138 -0.1848	-677 -0.9083
15	30%	2624	9.25	1.744 0.023	-0.204 -0.0027	-537 -0.7205		-153 -0.2054	-690 -0.9259
16	25%	2661	9.50	1.773 0.023	-0.233 -0.0031	-511 -0.6856		-184 -0.2464	-694 -0.9320
Loss of Revenues per annum if the PLF drops from 90 % to 35 % Rs Cr US$ Mn									30.31 4.0685
Reduction in Profit if the PLF drops from 90 % to 35 % as % of ROE									26%

Source – Data from operating power plants, tariff provisions, Grid Code, literature review and calculations done by this research.

The calculations show that if PLF changes from 90 % level to 35 %, following impact will happen on an average, on annual basis.

1. The profits will be hit by Rs 46.63 Cr/ 6.2597 (Mn US$) and ROE by 31 %, for one unit of 660 MW
2. The profits will be hit by Rs 49.26 Cr/ 6.6124 (Mn US$) and ROE by 22 % for one unit of 800 MW
3. The profits will be hit by Rs 30.31 Cr/ 4.0685 (Mn US$) and ROE by 26 % for one unit of 500 MW

On an average for all plants taken together, ROE will be impacted by about 26 %.

8.4 CONCLUSION [7,8,9,80]

Here we present a brief discussion on the findings of Objective I, II and the study of Global Scenario show. (Based on these, final Recommendations/ Remedial Actions have been suggested which are given in the next section in this chapter.)

It is found that thermal power plants will play significant role in Indian power sector for at least next 20 years. However, the thermal power plants in India are facing unprecedented crisis as of now.

Over the years, Capacity Utilization (known as Plant Load Factor, PLF) has been going down. The national average was 78.6% in 2007-2008 which came down to 55.4 % by 2019-20. This is worrisome. We are facing a strange situation where the country needs power, there is peak and energy deficit of electricity and there are high efficiency, low cost thermal power plants ready to generate power, but they are not being utilised. The thermal power plants are valuable assets, created with massive capital investments. Their falling PLF may push them to become non performing assets. This situation therefore needs attention of all the stakeholders. This research identifies ten Major Factors which are causing the fall of PLF. Discussion on future outlook of these factors has also been done. Steps should be taken in all the ten areas so that the problem can be resolved. Remedial measures have also been suggested in the research.

We have projected four future scenarios for PLF of thermal power. In Scenario I - PLF varies between 58.80 % in the year 2020-21 to - 62.03 % in 2024-25. In Scenario II - PLF is between 58.80 % in the year 2020-21 to - 62.03 % in 2024-25, In Scenario-III- National average PLF drops below 46 % by 2022-23 which is warning signal. Scenario – I and II are the two recommended paths that should be taken in the best interest of the country and the thermal power.

Environment, flexibilization, water consumption ash utilization and techno-commercial software solutions are some of the critical areas where thermal power must invest immediately. All future thermal capacities should be ultra-supercritical technology only.

Since considerable investments have gone into the thermal power plants and they are vital for the operation of grid, these plants must be supported through tariff and policy so that they operate with sustainable capacity utilization, remain profitable and survive in business for at least next 20 years to meet the grid requirements.

Policy incentives/interventions support should be given to thermal power as detailed out in recommendation section of the research.

Flexible operation of thermal power plants (Flexibilization) has become imperative due to changes in the electricity market and fast and substantial addition of renewable energy into the grid. However, flexibilization has bearing on the costs and profits of thermal power plants. In this paper, we have calculated the direct impact on three different types of power plant units (660 MW, 800 MW, 500 MW). It is found that if PLF drops from 90 % to 35 %, the Return on Equity (ROE) of the thermal power plants will reduce by about 26 %. [80]

Steps must be taken so that the thermal power plants remain economically sustainable because the grid them for survival and meeting the demand for at least next 20 years.

8.5 FIANL RECOMMENDATIONS/ REMEDIAL ACTIONS

This section contains the final recommendations/ remedial measures. The recommendations are based on findings of the research, researcher's recommendations and final validation of the recommendations with experts (Objective -III***).***

There is always a possibility that the researchers own perceptions creep in while charting out the recommendations. Care has been taken against that. In order to bring clarity and to establish the one-to-one correspondence of each recommendation with the research findings, **Annexure G,** ***has been prepared, which depicts the correspondence of each recommendation with the findings of this research.***

Following are the Recommendations and Remedial Actions.

1. In-spite of substantial increase in renewable energy sources in the country, coal based thermal generation will remain vital in the total electricity generation in the country, at least for next 20 Years.

2. Since considerable investments have gone into the thermal power plants and they are vital for the operation of grid, these plants must be supported through tariff and policy so that they operate with sustainable capacity utilization, remain profitable and survive in business for at least next 20 years and meet the grid requirements.

3. One of the future scenarios projected in this research is –LCARND. In this scenario Low Coal Capacity Addition Rate, Aggressive Renewable Capacity Addition Rate and Normal Growth Rate of Electricity Demand is considered. In this scenario, coal capacity addition is considered at a reduced rate @ 4.04 % (Slowed down from last 5 Year CAGR of 9.06 %), renewable capacity addition is considered at a higher rate @ 25.03 %, up by 2 % compared to the last the 5-year CAGR of 23.03 % and demand growth @ 5.5 % (same as last 5

year CAGR rate). ***In this Scenario, the national average PLF may drop below 46 % by 2022-23 which is a warning signal***. This is, in fact, Business as Usual situation and needs immediate attention of policy makers, power producers and all other stakeholders.

4. Another projected Scenario is CEAP – based on CEA suggested Plan, which assumes Demand Growth at a higher rate @ 6.44 % against the last 5-year CAGR of 5.5 %, Coal Capacity addition at a slowed down rate @ 2.66 % against the last 5-year CAGR of 9.04 % and Renewable Capacity addition at a slower rate @ 17.90 % against last 5-year CAGR of 23.03 %. ***The national PLF varies between 58.80 % in the year 2020-21 to - 62.03 % in 2024-25 in this scenario***. There is yet another Scenario projected in the search which is denoted as CEAP+PHOUT. This scenario is equivalent to Scenario CEAP (as described just above) coupled with phasing out of old thermal power capacity @5000 MW/year, (Here also the demand Growth is considered @ 6.44 %, Coal Plant Capacity addition @ 2.66 % and Renewable Capacity addition @ 17.90 % + additional condition is phasing out @ 5000 MW/Year). ***In this case the National PLF will be between 58.80 % in the year 2020-21 to 62.03 % in 2024-25***. These are the two recommended paths (CEAP or CEAP+PHOUT) that should be followed in the country which is in the best interest of thermal power plants and the country. Capacity planning is recommended through these two paths.

5. In both the above recommended scenarios, the new coal capacity addition rate is recommended to be slowed down considerably to 2.66 % per annum as compared to last 5-year CAGR of 9.04 %.

6. Demand of power has emerged as the most important driver of PLF. Sensitivity analysis shows that a 5000 MW increase in demand results in increase of PLF by 2.4 %. *Growth of electricity demand will be the main vehicle for future high utilisation of thermal power.* While all efforts should be made to spur demand, accurate forecasting of demand is also extremely important. The prediction of

demand has not been very robust in the country. This has resulted in demand and supply mismatch and overcapacities in some regions.

7. Since coal-based generation is actually helping the grid by providing ramp-up ramp-down support as and when needed, it is actually providing ancillary services to Grid. Coal generation may be supported through some policy/monitory support for this extra service.

8. This research shows that lowering of PLF from 90 % to 35 % may result in loss of ROE to the tune of 22 % - 31 % for unit sizes of 660 MW (31 %), 800 MW (22%) and 500 MW (26%). On an average, the ROE can get affected by 26 %. This is happening because the compensation provided in tariff to thermal power plants, for Heat Rate, APC and Startup Costs may not be not adequate to compensate for the losses because PLFs are dipping too low. Moreover, the thermal power plants lose incentives if the PLF goes below 85 %. It should be reviewed after a detailed study of actual position in various power plants.

9. Top five areas where coal based power stations must invest immediately are -

a) Water consumption reduction technologies
b) Flexibilization Technologies.
c) Pollution Control Technologies (Sox/Nox/ESP)
d) Ash Utilization
e) Advanced Techno commercial modelling software

10. All future plants should be ultra-supercritical technology only.

11. All old and inefficient plants should be shut down with specific timelines so that capacity utilization of existing/new high efficiency plants gets enhanced

12. One of the suggested ways to sustain well performing thermal plants is that, for all the plants that meet minimum environment and efficiency parameters, and are cleared by regulator and grid operator as system relevant, their fixed cost

may be pooled in the country and total fixed cost may be paid/covered by a central dispatcher. All plants, so cleared by regulator / grid operator should get the capacity charge, irrespective of fuel source. This cost can be distributed to all the off takers. Competition can be generated through energy charges.

13. One of the options to help and promote greener thermal power is that the advanced supercritical technology-based coal plants with state-of-the-art pollution control and efficiency level above, say 41 % (criteria to be decided by regulator), and system relevant for Grid, may be categorised under "must run" for next 10 years and may be given status similar to renewable.

14. If the coal companies continue to augment the national coal production even at the historical CAGR of 5.66 % (Last five years CAGR) and the new thermal capacity addition of thermal power is reduced to 2.66 % (As suggested in CEA projections), there does not seem to be likelihood of PLF getting affected due to *coal shortage in the long term*. However, if demand picks up unexpectedly, as is being experienced post Corona in mid-2021 and 2022, the coal supplies may become a major bottleneck in *short and medium term* because complacence would have set-in in the coal production, coal transportation and coal stock at the power plant end. Also, the Govt is not in favour of importing coal. Low domestic production along with ban on import may result in crunch of coal in the short/ midterm. Coal companies, power producers and Govt must keep a tab about this situation. However, problem of fuel shortage for thermal power plants is not foreseen in the long term.

15. Bad financial health of Discoms (Distribution companies, the bulk power purchasing utilities that buy power from the thermal power producers) is a major concern. Efficiency, transparency, accountability must be enhanced. Programs like UDAY should be implemented well. There is also urgent need of training the entire Discom staff on modern technology, maintenance systems, commercial issues, environment norms, financial skills etc.

16. Since electricity markets will be more and more based on trading/ day ahead, thermal plants must invest in advanced techno commercial modelling software and create specialist groups for harnessing market related dynamics.
17. For the long term (Beyond 30 years) an exit plan for thermal power should be prepared by each producer. Coal plants may also be suitably compensated for the exit (A separate study should be done and policy should be issued by CERC/MOP exclusively for exit).
18. Learning from other countries should be utilised if decommissioning of thermal plants is required. Particularly, the learnings from countries like UK and Germany may be utilised. Converting into Carnot batteries, setting up battery storage plants are some of the options.
19. Learning from China, there could be a Govt supported scheme wherein few selected plants in every region in the country are converted into Flexible plants and benefits are demonstrated so that other power plants get assured of the benefits before they invest.
20. Learning from Germany, while preparing scheme for closure of power plants, comprehensive regulatory framework should be in place to guarantee security of grid and to ensure that closure of a particular power plant does not endanger the grid. Planned power plant closures (decommissioning) must be intimated to a specified agency, at least 12 months before the shutdown date. The responsible transmission agency should then do simulation studies to verify the system-relevance of the power plant. If the plant is still found system-relevant, then the power plant has to be kept available for power generation, and the costs should be reimbursed to the operator.
21. Learning from USA, future thermal plants may be of smaller capacities (say 100-350 MW), leaner and agile, with highly flexible abilities, having near zero emissions, thus reducing technological, financial and environmental risks to the power producers.

22. Electricity storage technologies should be supported (along with renewable energy) with intensive R&D, policy push and incentives so that renewable energy can sustain the grid when coal-based generation is reduced/ phased out.

23. If decisive steps are not taken urgently to support the thermal power plants, many of the new, efficient thermal power assets created with large capital investment may face unsustainably low level of utilization and may become unavailable very soon.

8.6 CHPATER SUMMARY

This chapter presents the study of global scenario as to what is happening to thermal power generation in other countries.

In this research, countries which have significant amount of thermal power in their installed capacity portfolio (> 20 %) have been considered. Keeping this in mind- Australia, Germany, Indonesia, USA, Japan and China have been studied. Thereafter, using the outputs of Objectives I & II and combining the learning from global scenario, recommendations/ remedial measures have been drawn. The recommendations/ remedial measures were then validated with experts using Delphi method. Three rounds of Delphi were used to arrive at consensus. The final recommendations/ remedial measures are then presented in the chapter.

9 CHAPTER 9 - CONTRIBUTION TO LITERATURE, LIMITATIONS OF THE RESEARCH AND SCOPE FOR FURTHER RESEARCH

9.1 CHAPTER OVERVIEW

This chapter presents how this research has added to the body of knowledge, what are the limitations of this research and what could be avenues for future research in this domain.

9.2 CONTRIBUTION TO LITERATURE

9.2.1 CONTRIBUTION TO UNDERSTANDING OF CAPACITY UTILIZATION

This is a unique work which addresses the issue of falling Utilization Factor/Plant Load Factor (PLF) of thermal power plants in India and clearly defines the factors responsible for the same. This is also a comprehensive work where projection of PLF has been done for the next five years and actionable roadmap is suggested. The work will be useful to power producers, lenders, policy makers, regulators and the customers of bulk power (Distribution companies).

This research substantiates or challenges following well established theories in management and economics.

9.2.2 CONTRIBUTION TO THE THEORY OF MARKET FAILURE *BY PAUL A. SAMUELSON*

Our research shows that in electricity markets, tariffs are complicated. Information is too complex and changing very fast. Several important policy guidelines have come up in last five years. Information asymmetry is evident at many places. Producers, consumers, Govt, regulators, lenders have their own “silos” of information and data. This research has also shown how demand projection of power was inaccurate, believing which, thermal power plants went ahead and added capacities. The forecasting of demand is done by third parties (for example, by the Govt policy body the Central Electricity Authority, CEA) and not by power producers. Also, the pace at which renewables will be added was not judged properly by thermal power producers or even by planners. All this has resulted in overcapacity in thermal power. This means that the major market players are not having enough information or knowledge to plan right energy mix. This shows clearly that information asymmetry can exist in complex markets and may lead to market failure.

Further, since thermal power does contribute to pollution, this is an externality that necessitated Govt intervention. Govt intervened through regulatory provisions. (Electricity prices are controlled by regulator). Priority of one electricity supply source over other (renewable over thermal) is also decided by the regulator. Regulator acted to aggressively promote renewable energy. However, while doing so, the regulator acted selectively and did not take into account the serious effects of the policy interventions on thermal power.

The recent crisis in October 2021 when the whole country was staring at imminent blackouts due to low coal reserves in thermal power stations, was a testimony to imminent market failure. Oblivious of the demand and supply situation, with too much emphasis on promoting renewable power, thermal power and coal production (*both being touted as the bad guys*), the inefficient handling of the public good came to glaring light with the power crisis in Oct 2021 when at least 7-8 major states in the country were grappling with long power cuts. "As on 3rd October 2021, coal-based plants of around 6,960 MW aggregate capacity were under forced outage due to coal shortage. 72 out of total 135 plants in the country had coal stocks of less than 3 days against 14 days of recommended level [26]". It was partly because of sudden rise of demand and partly because thermal was no longer the "blue eyed" boy of the power portfolio and certain sense of neglect towards to thermal power had creeped in critical stakeholders.

There has also been growing negative public perception about thermal power as a "bad" and "polluting" industry. This perception is right but that does not mean that coal based power should be suddenly left in lurch. While the protection of environment is definitely a paramount goal, a suitable exit plan for thermal power should be in place so that assets do not suddenly become stressed or stranded and grid security gets in danger.

The economic activities that we wish to sustain require a balance of energy supply sources. The base load which is required for the sustaining the demand is provided by the thermal power plants. This research shows that thermal will continue to play vital role for at least next 20 years. If we need to sustain the economic growth, the thermal power will therefore be required in the grid. It is essential for the Govt to intervene and do right planning for sustenance and honourable exit of thermal along with advent of renewables.

The other important aspect that comes to the fore that in case of complex markets like electricity, the Govt should not limit itself to "part intervention" wherein it takes selective interventions to handle externalities. Such markets would need consistent wholistic intervention based on emerging situations. While acting to nullify the externalities, the Govt should take into account the negative impacts that might happen on an important player of the market, which the market needs for its sustenance. Otherwise, the selective intervention can become a source of market failure.

9.2.3 CONTRIBUTION TO THE THEORY OF DISRUPTIVE INNOVATIONS *BY CLAYTON CHRISTENSON*

One of the findings of this research is that emergence of renewables is a major factor affecting the utilisation factor (PLF) of coal-based plants. In fact, this factor has emerged as one of the most important factors affecting the utilisation or PLF of thermal power plants.

This research confirms that renewable energy has really emerged as disruptive innovation for thermal power. Renewable energy shows all the traits of disruptive innovation for the thermal power business model. Starting from a humble beginning it is challenging the mighty thermal power. The theory of disruptive innovation thus gets substantiated through this research work.

9.2.4 CONTRIBUTION TO RESOURCE BASED APPROACH TO STRATEGY *BY ROBERT M GRANT*

We find that in the current circumstances, in the case of thermal power developers, the hitherto valuable assets (plant and machinery) of large thermal power stations might become source of competitive "disadvantage" unless the developers diversify fast to create other (Renewable Energy) assets. Many thermal power generators might remain stuck up with thermal assets which may no longer be sources of competitive advantage because it is very difficult to "upgrade" or "replace" these resources.

Due to their nature of installation the thermal power stations have huge land and equipment virtually "locked in". These plant and equipment were set up with thousands of tons of steel, concrete and equipment. Even if the thermal power operators wish to upgrade or exit their resources it is extremely difficult to do so.

Our research therefore shows that in the case of traditional, capital intensive, equipment-based, brick and mortar and industries like thermal power, the very assets that were the source of competitive advantage can become major source of competitive "disadvantage". Huge money might remain locked in, both as debt and equity, in large immovable, infrastructure assets. These plants (assets) cannot be shifted, scrapped or sold easily. Decommissioning is lengthy and costly. This research shows that *Strong resources at one point of time can become weaknesses* *at another point of time. Agility of the company in changing, replacing or upgrading the resources is therefore critical to success and survival. It is even more important for all the industries which have large, capital intensive, brick and mortar, machinery based assets that are difficult to change, modify or dispose. Such firms must have keen eyes on the future and must invest with prudence and caution because change (in assets or technology) is more difficult and costly for them as compared to the firms that have low capital intensive, movable, knowledge based assets. Such firms should also be very cautious about market projections and emerging disruptive innovations. Inaccurate projections can be extremely costly for such companies because they would unwittingly invest in non-retractable resources.*

My work therefore challenges as well as enriches this theory by Robert M Grant.

One of the recommendations of this research is that for the long term (beyond 30 years), an exit plan for thermal power should be prepared by each producer. They should find out alternate use of the land and buildings in order to upgrade the resources.

9.2.5 CONTRIBUTION TO THE THEORY OF GENERIC COMPETITIVE ADVANTAGE *BY MICHAEL PORTER*

Historically, electricity was considered as a product which was "undifferentiated". Power producers almost always concentrated on Cost Leadership strategy. However, the renewable energy has emerged as a differentiated product. Now renewable is considered as "*green power*" which is indeed a differentiated product. Similarly, in future, there might be tags like *red power* or *blue power* or *grey power* based on the source of generation. Such differentiated products or services (within the electricity markets) can be sold at premium prices. This research work therefore indicates that cost leadership may not work for long term even if the product is generic (undifferentiated) in nature. Sooner or later, differentiation is likely to come into play. This means that any firm may not be able to sustain on the strategy of cost leadership for long term even if the product or service appears generic in nature. The firm must look for avenues for differentiation otherwise some differentiated product or service will ultimately disrupt the market. Thermal power companies who remained riveted to cost leadership are ultimately facing the brunt of renewables. They are now forced to add renewables also in their portfolio and follow the differentiation path.

This research therefore adds new dimension to the theory of generic competitive advantage in the sense that a firm may not be able sustain cost leadership strategy in the long run because some competitor or some substitute product will force the firms to differentiate. Our research therefore helps in enriching this theory.

9.3 LIMITATIONS OF THIS RESEARCH

There are few limitations of the research which are as below.

1. Being a relatively new phenomenon in India, there is lack of data, literature and experts with understanding about the impact of various factors on Capacity Utilization Factor (PLF) of thermal power plants in India.
2. Impact of rise in cost factors (cost of fuel, spares, debt and labour) on Capacity Utilization Factor (PLF) of thermal power has not been studied in this research.
3. All the Major Factors affecting Capacity Utilization Factor (PLF) which emerged through research in Objective -I could not be incorporated in the regression model in Objective -II because some factors were qualitative in nature or data was not available for past 35 years.
4. Time is the essence of this research. If the research is delayed it will not be able to give the impact and direction to thermal power operators that this work desires.
5. Due to Covid pandemic period, which ran through a significant period of time, face to face discussion could not be done with experts in the Delphi method. Discussions/consensus rounds were done through electronic media / google form / telephonic discussions.

9.4 SCOPE FOR FURTHER RESEARCH

1. This research has not studied the effect on power plant emissions caused by PLF changes of the thermal power stations. This could be avenue for future research.
2. The prices of solar, wind and thermal power are changing fast. Change in power prices from different sources will have impact on capacity utilization of thermal power. This aspect has not been covered in this work and may be avenue of future research.
3. Substantial research and investments in battery storage are also happening. Advent of commercial and cost effective battery storage will have impact on capacity utilization of thermal power. This aspect can also be avenue of future research.
4. This research does not consider the cost on thermal plants on account of equipment degradation caused by cyclic operation induced creep and fatigue emerging out of flexibilization. This could be area of new research.
5. As a sequel to my work, a theory might be developed with respect to information asymmetry causing market failure in case of public goods.

9.5 CHAPTER SUMMARY

This chapter presents how this research either reinforces or challenges some established theories like (i) Theory of Efficient Utilization of Resources and Market Failure (ii) Theory of Disruptive Innovation by Clayton Christenson (iii) Resource Based Approach to Strategy by Robert M Grant (iv) Theory of Generic Competitive Advantage by Michael Porter etc. The chapter also lists five limitations of this research and suggests five areas where further research can be done.

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ANNEXURES

ANNEXURE A :

RESEARCH QUESTIONNAIRE (OBJECTIVE I)

As you are aware, Utilization Factor [PLF] of coal based thermal power station in the country has a seen a consistent downward trend in last few years and the future outlook is also not very clear. This situation is affecting the power producers, lenders, Discoms, consumers and almost everybody else connected with power sector. This research is an attempt to find out the factors that are responsible for capacity utilization of coal based plants in India so that they can be addressed and future trend can be predicted. We seek your expert opinion about rating of factors that are responsible for downward trend/low-capacity utilization of coal based thermal power in India. Please rate the following based on your understanding/ experience.

Please rate the factors as per your opinion whether the factor has –

- Having very high impact
- Having high impact
- Neutral or undecided
- Having low impact
- Having very low impact

1.1) Poor financial health of power procuring companies (Discoms) is forcing them to reduce power procurement even if while demand exists, is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

1.2) The power utilities of state sector (State Gencos) are in financial distress and are unable to maintain their own power plants in good condition which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

1.3) The power utilities of private sector (IPPs) are in financial distress and are unable to maintain their own power plants in good condition which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

1.4) Due to large number of thermal power loans becoming NPA, banks have reduced lending creating fund crunch for power producers which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

1.5) Generating electricity from coal is no longer attractive business due to rising costs, forcing the thermal generators to cut down generation which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

2.1) New emission norms set by Govt in 2015 for thermal power plants is a factor affecting thermal power Capacity Utilization (PLF) in India

2.2) Society's growing concern about environment is forcing power stations to reduce production and is a factor affecting thermal power Capacity Utilization (PLF) in India

3.1) Disproportionately high share of thermal power in Indian grid (63.7 % of total installed capacity as on 31.03.2019) is a factor affecting coal based thermal power Capacity Utilization (PLF).

3.2) Substantial addition of renewable energy (solar and wind) having must-run status in the grid is a factor affecting coal based thermal power Capacity Utilization (PLF).

4.1) Grid evacuation constraint (line loading limitations) in some areas causing reduction in power generation is a factor affecting coal based thermal power Capacity Utilization (PLF).

5.1) The thermal power plants are experiencing forced outages // technical problems (like boiler tube leakages etc) and are unable to generate to full capacity which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

5.2) Many thermal power plants in India are ageing and are unable to reach full load capacity which is a factor affecting coal based thermal power Capacity Utilization (PLF).

5.3) The thermal power plants were designed as base load (full load) operation whereas the grid conditions today demand flexible operation that coal plants are unable to cope up which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

6.1) Low growth of power demand in the country as compared to projected is resulting in underutilization of thermal power and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

6.2) India has reached a stage of being power surplus (on most days in a year) which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

6.3) Although India is power deficit on totality basis, many regions have actually become power surplus which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

6.4) Large number of players in power generation is resulting in fierce competition and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

6.5) After opening up of power sector, many new and inexperienced players jumped without understanding the electricity market which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

7.1) Low fuel (coal) availability forcing thermal power generators to reduce power generation and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

7.2) Poor quality of coal having very high ash is forcing thermal power generators to reduce power generation and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

8.1) The tariff / policies are un-supportive of thermal power generators which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

8.2) Renewable energy is getting promoted at the cost of thermal generators because thermal plants are supposed to generate when nobody else is able to generate and then back down when others are available, this is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

8.3) There is lack of policy clarity on whether and how old thermal power plants are to be retired, which creates a dilemma whether to invest in their R&M and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

8.4) The Ultra Mega Power scheme did not bear desired results because of policy issues (projects risks were not addressed properly) which is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

9) There is a general perception that coal based thermal power will be entirely phased out in the medium / long run which is inhibiting new and modern technology infusion in thermal plants and is a factor affecting coal based thermal power Capacity Utilization (PLF) in India.

Any other factor/factors that you feel plays or will impact Capacity Utilization (PLF) of thermal power in India. (Please also specify the factor and mention in bracket - Very high impact/high impact/low impact / very low impact, as the case may be)

ANNEXURE B :

LIST OF EXPERTS FOR (OBJECTIVE I)

Sl No	Name	Designation/Affiliation
1	**Sh G C Mohanta**	Additional General Manager, NTPC
2	**Sh Sandeep Naik**	Director, Ministry of Power
3	**Dr Ashok Kumar Tiwari**	GM, MPPKVVCL Jabalpur
4	**Sh Manoj Barsaiyan**	Dy General Manager, NTPC
5	**Dr T K Roy**	Additional General Manager & Fulbright Scholar, UK
6	**Dr B P Rath**	Senior Design Expert, NTPC
7	**Shankar Bandopadhyay**	Executive Director, Centre for Power Efficiency & Environmental Protection
8	**Dr A P Dash**	Professor and Dean, NTPC School of Business
9	**Sh A K Sharma**	Member, Chhattisgarh State Electricity Regulatory Commission
10	**Dr M Muthuraman**	Additional General Manager, Environment Management, NTPC
11	**Dr Pradip Chanda**	Professor, NTPC School of Business
12	**Pushpendra Chaurasiya**	Dy General Manager, Operations, NTPC
13	**Sanjay Srivastava**	Additional General Manager, Operation Services

ANNEXURE C :

FACTOR ANALYSIS - COMMUNALITIES OF ALL THE 25 VARIABLES

Communalities

	Initial	Extraction
VAR00002	1.000	.665
VAR00003	1.000	.591
VAR00004	1.000	.576
VAR00005	1.000	.539
VAR00006	1.000	.626
VAR00007	1.000	.641
VAR00008	1.000	.666
VAR00009	1.000	.625
VAR00010	1.000	.687
VAR00011	1.000	.596
VAR00012	1.000	.709
VAR00013	1.000	.679
VAR00014	1.000	.658
VAR00015	1.000	.604
VAR00016	1.000	.660
VAR00017	1.000	.695
VAR00018	1.000	.540
VAR00019	1.000	.423
VAR00020	1.000	.711
VAR00021	1.000	.689
VAR00022	1.000	.283
VAR00023	1.000	.594
VAR00024	1.000	.584
VAR00025	1.000	.660
VAR00026	1.000	.613

Extraction Method: Principal Component Analysis.

Communalities - Source- SPSS Output of Factor Analysis

ANNEXURE D :

FACTOR ANALYSIS - DESCRIPTIVE STATISTICS OF ALL THE 25 VARIABLES

	N	Minimum	Maximum	Mean	Std. Deviation
VAR00002	254	1.00	5.00	3.7835	1.03895
VAR00003	254	1.00	5.00	3.6142	1.07466
VAR00004	254	1.00	5.00	3.2323	1.08401
VAR00005	254	1.00	5.00	3.2441	1.10132
VAR00006	254	1.00	5.00	3.6299	1.14072
VAR00007	254	1.00	5.00	3.7795	1.04759
VAR00008	253	1.00	5.00	3.3715	1.14274
VAR00009	254	1.00	5.00	3.2480	1.05833
VAR00010	252	1.00	5.00	4.1468	.97287
VAR00011	254	1.00	5.00	3.0197	1.14018
VAR00012	254	1.00	5.00	2.9055	1.14162
VAR00013	254	1.00	5.00	3.2126	1.08987
VAR00014	252	1.00	5.00	3.8452	1.09865
VAR00015	251	1.00	5.00	3.9203	1.05528
VAR00016	253	1.00	5.00	3.4941	1.12906
VAR00017	254	1.00	5.00	3.5236	1.04325
VAR00018	254	1.00	5.00	3.2913	1.09696
VAR00019	254	1.00	5.00	3.1969	1.14230
VAR00020	254	1.00	5.00	3.4843	1.14315
VAR00021	254	1.00	5.00	3.4213	1.14195
VAR00022	254	1.00	5.00	3.4646	1.12320
VAR00023	254	1.00	5.00	4.1811	.93604
VAR00024	254	1.00	5.00	3.6654	1.02258
VAR00025	254	1.00	5.00	3.4528	1.04623
VAR00026	254	1.00	5.00	3.4724	1.10926

Descriptive Statistics - Source- SPSS output of Factor Analysis

ANNEXURE E :

RECOMMENDATIONS / REMEDIAL MEASURES – QUESTIONNAIRE - (OBJECTIVE III)

The suggestive Recommendations and Remedial Measures based on findings of the Research were shared with the experts and opinion was sought.

xxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxxx

Respected Sir - I had done a survey regarding future of thermal power plants in India. You were a respectable senior expert who gave your kind view. I express sincere thanks. Based on your views and views of other experts, following points are summarised as per majority opinion. All the experts (15 Nos) who participated in this process are very senior professionals. Before that a Survey questionnaire was also sent to 253 respondents. Now I have drawn the summary. We hope that you would find all points in order as they have emerged after extensive research. As part of Delphi method, to conclude, I now request your kind agreement to these points. Although the form might look long, at this stage there is just one response needed. (1) Findings are OK or (2) if you still have difference on a particular point, you may chose - Other points are OK and I have something to add to point no. Here you can write the point number and can give your view. Your views are very valuable in the sector. I shall be extremely grateful to you for this.

1)	*In spite of increase of other sources of generation like renewables, coal based thermal power plants will still be important for India's power sector*
2)	*Coal based thermal power plants will remain vital in Indian power generation sector at least for next - 10 Yrs, 15 Years, 20 Years*
3)	Coal based power plants may have to be finally phased out by 2050
4)	*Currently the national average Plant Load factor (PLF) of thermal power is around 55 %. It is likely to reduce further if necessary steps are not taken*
5)	In your opinion what could be the range of national average PLF of the coal stations in next 5 years if present trend continues
6)	If demand picks up at 1-2 % higher rate than present increase rate in the country and new coal capacity addition is significantly slowed down as suggested by CEA, what could be the range of national average PLF of the coal stations in next 5 years
7)	After 10 years, all power in India will be sold through day ahead/ exchange/trade instead of long term PPAs

8) Some future challenges for the coal based thermal power plants are listed here- Please indicate your opinion about for each challenge whether it is strong or weak challenge. You can select any choice for any challenge- *i. Ash Utilization* *ii. Water Availability* *iii. Emission Control* iv. Tariff Realization *v. Closing old plants* vi. Attracting Talent vii. Generation Cost *viii. Flexible Opn* ix. Managing public perception x. *Land Acquisition*
9) Since considerable investments have gone into the thermal power plants and they are vital for the operation of grid, these plants must be supported through tariff and policy so that they operate with sustainable capacity utilization, remain profitable and survive in business for at least next 20 years and meet the grid requirements.
10) *Since every business has to face the market, thermal power should also be left alone to face the market and no intervention should be done.*
11) Rate of new capacity addition should be slowed down so that existing plants are utilised optimally.
12) Rate of fresh coal based capacity addition should be changed as below so that there is no overcapacity leading to low PLF(Present rate of coal capacity addition is 9 %, calculated as CAGR of last 5 years) (i) We should continue to add coal capacity at historical rate of 9 % CAGR (ii) No new capacity should be added for next 3 years since we have adequate coal capacity for next 3 yrs (iii) Rate of new capacity addition rate should be reduced to 6 % instead of current 9 % (iv) Rate of new capacity addition rate should be reduced to 3 % instead of current 9 % (v) Rate of new capacity addition rate should be increased to 12 % instead of current 9 %
13) Coal based power stations must invest in Flexibalisation (Flexible Operation) Technologies
14) Coal based power stations must invest in Pollution Control Equipment (Sox Nox ESP

	Modernisation)
15)	Coal based power stations must invest in Pollution Control Equipment (Sox Nox ESP Modernisation)
16)	All old and inefficient plants should be shut down with specific timelines so that capacity utilization of existing/new high efficiency plants gets enhanced
17)	Since electricity markets will be more and more based on trading/ day ahead, thermal plants must invest in advanced techno commercial modelling software and create specialist groups for harnessing market related dynamics.
18)	Since coal is helping integration of renewable energy in the grid by providing ramp up and ramp down support as needed, it is actually providing ancillary service to Grid. Coal generation should be supported through policy/monitory remuneration for this service.
19)	For all plants that meet minimum environment and efficiency parameters, and are cleared by regulator and grid operator, their fixed cost should be pooled in the country and total fixed cost should be covered by a central dispatcher. All plants, cleared by regulator / grid operator should get this capacity charge, irrespective of fuel source. This cost should be distributed to all the off takers. Competition can be generated through energy charges.
20)	To help and promote greener thermal power, the advanced, supercritical based coal plants with state of the art pollution control and efficiency level above say 41 % (criteria to be decided by regulator), may be categorised under "must run" and may be given status similar to renewable.
21)	For the long term (beyond 30 Years) , an exit plan for thermal power should be prepared and coal plants should be compensated for the exit (A separate policy should be issued by CERC/MOP)
Other Suggestions/Comments	

ANNEXURE F :

LIST OF EXPERTS FOR VALIDATION OF RECOMMENDATIONS- (OBJECTIVE III)

Sl No	Name	Designation/Affiliation
1	Sh R S Sharma	MD Bajaj Energy, Ex CMD NTPC, EX MD Jindal Power,
2	Sh K R C Murthy	Managing Director Chhattisgarh State Power Generating Company Limited
3	Sh Arun Kumar Sharma	Member Chhattisgarh State Regulatory Commission
4	Dr P P Kulkarni	Regional Executive Director NTPC
5	Sh R K Srivastava	Executive Director NTPC Energy Technology Research Alliance
6	Sh Pradip Chanda	Professor, NTPC School of Business
7	Sh A N Sar	Chief Executive Officer & Whole Time Director, Bajaj Energy
8	Sh Aditya Mishra	Chief Operating Officer, Bajaj Energy
9	Sh A K Ahuja	Executive Director, Corporate Planning, NTPC, Consultant
10	Dr. Sarat Kumar Acharya	Ex CMD Neyveli Lignite Corporation
11	Dr Yogendra Saxena	Senior Sustainability Consultant
12	Sh Virendra Singh	Dir (Technical) Haryana DISCOM
13	Sh M G Mue	Superintending Engineer, Gujarat Energy Transmission Corporation Limited
14	Sh Balwant Singh Negi	DGM, Satluj jal Vidyut Nigam Limited
15	Sh Saptarshi Roy	Director (HR), NTPC

ANNEXURE G :

CORRESPONDENCE OF RECOMMENDATIONS / REMEDIAL ACTION WITH THE RESEARCH FINDINGS

Sl No	Recommendation / Remedial Action	Correspondence Reference
1	In-spite of substantial increase in renewable energy sources in the country, coal based thermal generation will remain vital and will contribute significantly of total generation in the country at least for next 20 Years.	Input from Literature Review- Objective -I (Chapter 2, Literature Review, Sub theme - 4) + Objective – III - Global Experience (US and Germany), Chapter 6 and Objective -III Experts Validation through Delphi - (Chapter 7)
2	Since considerable investments have gone into the thermal power plants and they are vital for the operation of grid, these plants must be support through tariff and policy so that they operate with sustainable capacity utilization, remain profitable and survive in business for at least next 20 years and meet the grid requirements.	Input from Literature Review- Objective -I (Chapter 2, Literature Review, Sub theme - 4) + Objective – II – Chapter -4 and Objective -III Experts Validation through Delphi - (Chapter 7)

3	In one of the scenarios –LCARND-Low Coal, Aggressive Renewable and Normal Demand - Growth rate of thermal capacity is considered at 4.04 %, renewable capacity addition at 25.03 % and demand growth is at normal rate of 5.5 % . In this Scenario - National average PLF may drop below 46 % by 22-23 which is a warning signal. This is Business as Usual situation and needs immediate attention of policy makers, power producers and all other stakeholders.	Input from Objective -II, PLS Regression Results, Chapter - 4
4	In the Scenario CEAP - CEA suggested Plan – (Demand Growth @ 6.44 %, Coal Plant Capacity Increase @ 2.66 % and Renewable Capacity Increase @ 17.90 %)- PLF varies between 58.80 % in the year 2020-21 to - 62.03 % in 2024-25 and in Scenario – CEAP+PHOUT- CEA Plan and phasing out of old capacity @5000 MW/Year National PLF (Demand Growth @ 6.44 %, Coal Plant Capacity Increase @ 2.66 % and Renewable Capacity Increase @ 17.90 %)- PLF between 58.80 % in the year 2020-21 to - 62.03 % in 2024-25. These are two recommended paths that should be followed in the best interest of thermal power plants and the country	Input from Objective -II, PLS Regression Results, Chapter - 4
5	Demand of power has emerged as the most important driver of PLF. Sensitivity analysis shows that a 5000 MW increase in demand results in increase of PLF by 2.4 %. While all efforts should be made to spur demand, accurate forecasting of demand is also extremely important. In past, the prediction of demand has not been very robust. This has resulted in demand and supply mismatch rendering some regions to be power surplus.	Input from Objective -II, Financial Impact, Chapter – 5,

6	Since coal-based generation is actually helping the grid by providing ramp up ramp down support as and when needed, it is actually providing ancillary services to Grid. Coal generation may be supported through some policy/monitory support for this extra service.	Global experience study Objective – III (China) Chapter 6 + Objective - III Experts Validation through Delphi - Chapter 7
7	This research shows that lowering of PLF from 90 % to 35 % may result in loss of ROE to the tune of 21% - 28% for unit sizes of 660 MW (28 %), 800MW (21%) and 500 MW (25%). The compensation provided in tariff to thermal power plants, for Heat Rate and Startup Costs may not be not adequate to compensate for the losses because PLFs are dipping. It should be reviewed after a detailed study of actual position in various power plants.	Input from Objective -II, Financial Impact, Chapter -5
8	Top five areas where Coal based power stations must invest immediately are - 1) Water consumption reduction technologies 2) Flexibilization Technologies. 3) Pollution Control Technologies (Sox/Nox/ESP) 4) Ash Utilization 5) Advanced Techno commercial modelling software	Input Literature Review, Chapter 2 + Global Experience, Chapter 7, Objective – III + Validation with experts), Chapter -7, Objective - III
9	All future plants should be ultra-supercritical technology only.	Input from Major Factors identified in Chapter-4, (Objective - I) + Objective – III (Validation with experts), Chapter -7
10	All old and inefficient plants should be shut down with specific timelines so that capacity utilizationof	Input Literature Review, Chapter 2 + Input from

	existing/new high efficiency plants gets enhanced	PLF Projection under different scenarios, Chapter -4, Objective -II + Objective – III (Validation with experts), Chapter -7
11	One of the suggested ways to sustain well performing thermal plants is that for all plants that meet minimum environment and efficiency parameters, and are cleared by regulator and grid operator as system relevant, their fixed cost may be pooled in the country and total fixed cost may be paid/covered by a central dispatcher. All plants, cleared by regulator / grid operator should get the capacity charge, irrespective of fuel source. This cost can be distributed to all the off takers. Competition can be generated through energy charges.	Input from Literature Review Chapter 2 + Financial Impact, Chapter – 5, Objective II + Objective – III (Validation with experts), Chapter -7
12	One of the options to help and promote greener thermal power, is that the advanced, supercritical technology-based coal plants with state-of-the-art pollution control and efficiency level above, say 41 % (criteria to be decided by regulator), and system relevant for Grid, may be categorised under "must run" for next 10 years and may be given status similar to renewable.	Input from Literature Review Chapter 2 + Financial Impact, Chapter – 5, Objective II + Objective – III (Validation with experts), Chapter -7
13	If the coal companies continue to augment the national coal production even at the historical CAGR of 5.66 % (Last five years CAGR) and the new capacity addition of thermal power is reduced to 2.66 % (As suggested in CEA projections), there does not seem to be likelihood of PLF getting affected due to coal in the long run.	Inputs from Objective-I (Major Factors identified, Chapter 4) + PLF Projections Objective -II Chapter 4.

	However, if demand picks up unexpectedly, as is being experienced post Corona in mid-2021, the coal supplies may become a major bottleneck in short term because complacence would have set in in the coal production, power plant stocks and transportation. Also, the Govt is not in favour of importing coal. Low domestic production along with ban on import may result in sudden crunch of coal in the midterm. Coal companies, power producers and Govt must keep a tab about this situation.	
14	Poor financial health of Discoms is a very major concern. Efficiency, transparency, accountability must be enhanced. Programs like UDAY should be implemented well. There is also urgent need of training the entire Discom staff on modern technology, maintenance systems, commercial issues, environment norms, financial skills etc.	Inputs from Objective-I (Major Factors identified Chapter 4)
15	Since electricity markets will be more and more based on trading/ day ahead, thermal plants must invest in advanced techno commercial modelling software and create specialist groups for harnessing market related dynamics.	Input from Objective I (Literature Review, Chapter 2 + Global Experience Objective – III (Global Scenario) Chapter -7 + Experts Validation through Delphi - Chapter 7
16	For the long term (Beyond 30 years) an exit plan for thermal power should be prepared by each producer. Coal plants may also be suitably compensated for the exit (A separate study should be done and policy should be issued by CERC/MOP exclusively for exit).	Indian and Global experience study Objective – III Chapter 7 + Objective -III Experts Validation through Delphi - Chapter 7

17	Learning from other countries should be utilised if decommissioning of thermal plants is required. Learnings from countries like UK, Germany may be utilised. Converting into Natural gas plant, converting into Carnot batteries are some of the options.	Global experience (UK, Germany), Objective – III, Chapter 7 + Objective -III Experts Validation through Delphi - Chapter 7
18	Learning from China, there could be a Govt supported scheme wherein few selected plants in every region in the country are converted into Flexible plants and benefits are demonstrated	Global experience (China) Objective – III, Chapter 7 + + Objective - III Experts Validation through Delphi - Chapter 7
19	Learning from Germany, while preparing scheme for closure of power plants, comprehensive regulatory framework should be in place to guarantee grid security and to ensure that closure of a particular power plant does not endanger the grid. Planned power plant closures (decommissioning) must be intimated to a specified agency, at least 12 months before the shutdown date. The responsible transmission agency should then do simulation studies to verify the system-relevance of the power plant. If the plant is still found system-relevant, then the power plant has to be kept available for power generation, and the costs should be reimbursed to the operator.	Global experience (Germany) Objective – III, Chapter 7 + Objective -III Experts Validation through Delphi - Chapter 7

20	Learning from USA, future plants may be of smaller capacities, with modern technology, thus reducing technological, financial and environmental risks.	Global experience (US) Objective – III Chapter 7 + Objective -III Experts Validation through Delphi - Chapter 7
21	Electricity storage technologies should be supported (along with renewable energy) with intensive R&D, policy push and incentives so that renewable energy can sustain the grid when coal based generation is reduced.	Global experience (US & Germany) Objective – III Chapter 7 + Objective -III Experts Validation through Delphi - Chapter 7
22	If decisive steps are not taken urgently to support the thermal power plants, many of the new, efficient thermal power assets created with large capital investment may face unsustainably low level of utilization and may become unavailable soon.	Input from Objective -II (PLF Projection under different scenarios), Chapter -4, Concluding Remarks

MAJOR FACTORS AFFECTING CAPACITY UTILIZATION OF THERMAL POWER PLANTS IN INDIA

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