REGULATION MANAGEMENT AND RATIO OPTIMISATION OF HIGH IMPIDANCE POWER TRANSFORMERS FOR A SUSTAINABLE POWER SYSTEM

By

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Subject : **Declaration by the Guide**

This is to certify that Mr Nazeer Ahamed, a student of MBA (Power Management), Roll No 500026393 of UPES has successfully completed this dissertation report on "Regulation Management and Ratio Optimisation of High Impedance Power Transformers for a Sustainable Power System" under my supervision.

Further, I certify that the work is based on the investigation made, data collected and analysed by him and it has not been submitted in any other University or Institution for award of any degree. In my opinion it is fully adequate, in scope and utility, as a dissertation towards partial fulfilment for the award of degree of MBA.

Best Regards,

For **ENERGOPROJEKT-ENTEL CO. LTD.**

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List of Abbreviations
MVA – Mega Volt Ampere.
kV – Kilo Volts.
%Z – Percentage Impedance.
IEC - International Electro technical Commission.
Pf – Power Factor
MW – Mega Watts
GW – Giga Watts

Executive Summary/Abstract

Power transformers are vital equipment in an electrical power system. Bulk transfer of power, import or export, between various networks take place through these expensive equipment whose impedance plays an important role in controlling the magnitude of fault current in the unlikely event of a system fault. This high impedance result in wider regulation, voltage drop and reactive losses. Historically regulation of high impedance transformers is managed through enacting sufficient tapping range and by specifying voltage ratio of the fixed voltage winding higher than that of its connected network.

The mitigation by specifying higher voltage than the network voltage causes an obvious de-rating of the constant voltage winding. This capacity loss is enormous for utilities because usually hundreds of power transformers are connected to their system. This prompted my study of 'Regulation Management and Ratio Optimisation of High Impedance Power Transformers for a Sustainable Power System' which emphasis on how this capacity loss can be saved. Outcome of the study is expected to support utilities for enhancing the specification of new transformers whose power system is in developing stage.

The following questions triggered and inspired while choosing the research topic and vice versa. The objective of my research is to find solution for these questions and prove it systematically and validate it through research. The research questions are:

1. Is the transfer of specified Power 50MVA realized from High Voltage bus to Low Voltage bus that is from 132kV bus to 11kV bus if the voltage ratio of transformer is 132kV/12kV without overloading or without accelerated ageing rate of the transformer?
2. Is the existing tapping range of 132kV ±15% appropriate? Is the step voltage 132kV x 1.67% ±9 ideal?
3. Is the selection of Voltage ratio 132/12kV optimum for power transformers connected to a network of 132kV and 11kV respectively to transfer the rated power without overloading of windings and sacrificing its technical life?

The utility from the Middle East (identity of the utility is kept confidential as requested) whose network is selected for my study have large fleet 132/12kV, 50MVA high impedance power transformers connected to their 132/11kV network. Fixed voltage winding of the transformer is 12kV where as it is connected to the 11kV constant voltage bus. Thu the loading of 12kV winding must be restricted to (11/12) = 91.67% of its capacity. That is each transformer would be de-rated to 45.835MVA instead of 50MVA. Objective of my study is to propose the right solution for saving this capacity loss for future orders by suggesting appropriate specification amendments.

At the planning stage, methodology was devices to collect real time and historical data from the utility. My study concluded with the following recommendations.

Proposal 1 is that the voltage ratio of the 50MVA power transformer for the utility shall be 132/11kV instead of 132/12kV in order to transfer the rated power of 50MVA from 132kV bus bar to 11kV busbar. Otherwise, that if the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

Proposal 2 is that the tapping range of the 50MVA power transformers of the utility shall be 132kV x +5% and 132kV x –15% instead of ±15%. Transformer operates at taps close to one when load is minimum this is because of the ratio of the transformer is 132/12kV implies that to keep the LV bus voltage of 11kV its tap shall be so adjusted. Thus a non-optimum condition of tap position exists. This could have avoided had the transformer voltage ratio been selected as 132/12kV. That is an increased impedance of about 3% is unnecessarily added to the already higher one. This high impedance will cause additional stray losses too which is again contributing more losses of power means loss of precious energy.

Proposal 3 is that the tapping step voltage of the 50MVA power transformers of the utility shall be 132kV x 1.25 x (+ 4 – 12) that is 17 taps instead of 132x 1.67 ± 9 hat is 19 taps. This is to help the utility for much smoother voltage control of the 11kV bus bars helping their strategy to supply quality power to their customers. Also, this will help to optimize the manufacturer for the selection of insulations of tap winding.

Proposal 4 is that the utility shall take action not to load their existing power transformer to its rated full capacity of 50MVA. If the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

Chapter 1

Introduction

This chapter outlines an introduction to the proposed dissertation study starting with an overview followed by objectives of the study, problem definition, limitations, solutions and conclusions. The rational for topic selection and an overview of the upcoming chapters of the report have also been given. The procedure including the literature survey to identify, establish the problem also been presented in this chapter.

Historically regulation of high impedance transformers is managed through enacting sufficient tapping range and by specifying voltage ratio of the fixed voltage winding higher than that of the connected network. The mitigation by specifying higher voltage than the network voltage causes an obvious de-rating of the constant voltage winding. This capacity loss is enormous for utilities because usually hundreds of power transformers are connected to their system.

My study 'Regulation Management and Ratio Optimisation of High Impedance Power Transformers for a Sustainable Power System' emphasis on how this capacity loss can be saved by systematic analysis of the problem to pin point the root cause, validating it scientifically by testing with data collected from transmission network and proposing appropriate solutions. Data collection at actual system operating conditions is required for analyzing, evaluating and proposing the right solution and accomplishing the study. The study is done on the network of a well-known utility in The Middle East. Outcome of the study is expected to support utilities for enhancing the specification of new transformers whose power system is in developing stage. The growth the utility was more than 10% before the global recession however, it is about to catch up the same pace within near future. Hence, outcome of the study would benefit the utility in specifying appropriate rating for power transformers.

1.1 Overview

Power transformers are vital equipment in an electrical power system. Bulk transfer of power, import or export, between various networks take place through these expensive equipment whose impedance plays an important role in controlling the magnitude of fault current in the unlikely event of a system fault. It is a common practice to use high impedance power transformers in the network in order to limit the fault current within the desired level. They in fact have heavy regulation due to the high reactive losses especially when operates at full load and low network lagging power factor.

Purpose of the study is to find answer to the questions and prove the hypothesis through systematic methodology and to appropriately manage the de-rating of power transformer capacity and regulation of high impedance power transformers without compromising the rated power transfer capacity of the winding connected to LV bus bar.

The utility from the Middle East (identity of the utility is kept confidential as requested) whose network is selected for my study has large fleet of 132/12kV, 50MVA high impedance power transformers connected to their 132/11kV network. Fixed voltage winding of the transformer is 12kV where as it is connected to the 11kV constant voltage bus. Thu the loading of 12kV winding must be restricted to (11/12) = 91.67% of its capacity. That is each transformer would be de-rated to 45.835MVA instead of 50MVA.

Objective of my study is to propose the right solution for saving this capacity loss for future orders by suggesting appropriate specification amendments.

When a transformer is loaded with a constant primary voltage, the secondary voltage decreases under lagging power factor and increases under leading power factor because of its internal resistance and leakage reactance. Hence, to keep the output voltage constant the primary voltage must be increased. The rise in primary voltage required to maintain rated output voltage from no-load to full load at a given power factor expressed as percentage of rated primary voltage gives the regulation of the transformer.

Transformers are used widely in our daily life from tiny transformers used for mobile chargers to huge transformers used in power network. My study focuses the transformers used for power transmission. Transformer is a static device which transforms power from one circuit to another without change of frequency but a change in voltage & current through electromagnetic induction.

Transformer copper losses, iron losses, stray losses, impedance voltage, rated voltage, rated current, voltage ration, tapping range, nameplate details, factory test report, type of network parameters like cables or overhead line and availability of reactive power compensation, etc. are required to carry out the proposed study.

The scope of the proposed dissertation study is to cover power transformers connected to the transmission network of selected power utility in the Middle East (name of the utility is kept confidential as per request). Collection of real time readings as per the questionnaire enabled an accurate study. Availability of historical data added the confidence level because I got an effective set of data for comparison and testing the accuracy. I expect that the proposed solutions and outcome of my study would be useful for the implementation in the real life scenario.

Feasibility study is an analysis of the viability of an idea. Accordingly, I have conducted the feasibility study of my dissertation topic and investigated various alternate solutions and finally arrived at conclusion in coordination with my expert guide that the proposed dissertation topic would be feasible to carry out and its proposed solutions and outcome would be useful for the implementation in the real life scenario. The Network where the original study is carried out and primary data is collected was identified and approval obtained during the planning stage.

After discussions I had with my guide, the plan and time frame was prepared for data collection, analysis, report writing, reviewing and printing. Overall schedule has been prepared and then each activity elaborated with action plan on a daily basis. In total the duration of project was set as 45 days including report preparation. Then the 10 days was planned for printing and delivery to the University. Mile stones were identified and constraints assessed. Project management paper studied during the course helped to plan, perform execute the study in a systematic way. Further, various resources required to carry out the dissertation study has been identified and availability ensured. The purpose of feasibility study is to explore the appropriate method from several alternatives for mitigation of the problem. I have taken several paths before reaching the final destination. Just because the initial analysis is negative does not mean that the proposal does not have merit. Sometimes limitations or flaws in the proposal can be corrected.

The purpose of the economic feasibility is to determine the economic aspects of the dissertation project. Quantification and identification of all the economic aspects has been looked into and assessment of a cost/benefit analysis has been done. My study is carried out in coordination with the ENERGOPROJEKT-ENTEL CO. LTD, Dubai with them it has been agreed that the study does not require fund other than that of local travel, telephone charges, e-mail correspondences and of course travel for direct interviews as part of primary data collection.

To conclude, my study concluded with the following proposals:

Proposal 1 is that the voltage ratio of the 50MVA power transformer for the utility shall be 132/11kV instead of 132/12kV in order to transfer the rated power of 50MVA from 132kV bus bar to 11kV busbar. Otherwise, that if the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

Proposal 2 is that the tapping range of the 50MVA power transformers of the utility shall be 132kV x +5% and 132kV x −15% instead of ±15%.

Proposal 3 is that the tapping step voltage of the 50MVA power transformers of the utility shall be 132kV x 1.25 x (+ 4 – 12) that is 17 taps instead of 132x 1.67 ± 9 hat is 19 taps. This is to help the utility for much smoother voltage control of the 11kV bus bars helping their strategy to supply quality power to their customers. Also, this will help to optimize the manufacturer for the selection of insulations of tap winding.

Proposal 4 is that the utility shall take action not to load their existing power transformer to its rated full capacity of 50MVA. If the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

1.2 Background

The utility is one of the leading utilities in the Middle East whose installed capacity of power generation is about 9656MW as on October 2015. They are a fast growing utility well known for its very low T&D losses, values environmental initiatives and supports power generation from renewable energy sources through various initiatives like roof top Solar Photovoltaic power installation thus maintain sustainability development even though major share of power generation is from thermal stations using natural gas.

The utility from the Middle East (identity of the utility is kept confidential as requested) whose network is selected for my study has large fleet of 132/12kV, 50MVA high impedance power transformers connected to their 132/11kV network. Fixed voltage winding of the transformer is 12kV where as it is connected to the 11kV constant voltage bus. Thu the loading of 12kV winding must be restricted to (11/12) = 91.67% of its capacity. That is each transformer would be de-rated to 45.835MVA instead of 50MVA.

Objective of my study is to propose the right solution for saving this capacity loss for future orders by suggesting appropriate specification amendments.

When a transformer is loaded with a constant primary voltage, the secondary voltage decreases under lagging power factor and increases under leading power factor because of its internal resistance and leakage reactance. Hence, to keep the output voltage constant the primary voltage must be increased. The rise in primary voltage required to maintain rated output voltage from no-load to full load at a given power factor expressed as percentage of rated primary voltage gives the regulation of the transformer.

1.3 Purpose of the study

Purpose of the study is to find solution for the following questions raised and to prove the hypothesis by adopting a methodology to appropriately manage the regulation of high impedance power transformers without compromising the rated power transfer capacity of the winding connected to LV bus bar.

1. Is the transfer of specified Power 50MVA realized from High Voltage bus to Low Voltage bus that is from 132kV bus to 11kV bus if the voltage ratio of transformer is 132kV/12kV without overloading or without accelerated ageing rate of the transformer?
2. Is the existing tapping range of plus 132kV ±15% appropriate? Is the step voltage 132kV x 1.67% ±9 ideal?
3. Is the selection of Voltage ratio 132/12kV optimum for power transformers connected to a network of 132kV and 11kV respectively to transfer the rated power without overloading of windings and sacrificing its technical life?

Research Hypotheses:

1. *Hypotheses:* A 50MVA, 132/12kV Power Transformer can transfer only a de-rated 45.83MVA from 132kV bus to 11kV bus without accelerated ageing due to overloading. (When rated parameters of transformers mismatch with that of the connected network then the capacity of transformers either de-rate or the ageing accelerates due to overloading).
2. *Null Hypothesis:* A 50MVA, 132/12kV Power Transformer can transfer full capacity of 50MVA from 132kV bus to 11kV bus without accelerated ageing and overloading.

So that the transformers can be loaded with their full rated capacity as and when required without compromising their expected technical life. Commercial operation of the power transformers is expected to be for about 30years when operated at rated parameters. If these rated parameters are bypassed for the benefit of temporary gain then it would hamper the life expectancy of expensive transforms and commercial losses through replacements costs and losses incurred due to non-availability of the service of the transformers. Hence, it is wise and advisable to operate them within the rated parameters. For example, if the transformer is supposed to deliver 50MVA from primary to secondary then it shall be connected to a network matching with its rated parameters like 132kV primary shall connect to the bus where in the bus voltage is 132kV itself and 12kV secondary shall be connected to a bus whose rated voltage level is 12kV. In case of transformers connected to a network that do not match with its rated parameters like 132kV primary connect to the bus where in the bus voltage is 132kV itself and 12kV secondary connected to a bus whose rated voltage level is 11kV then obviously there will remain a de-rating of one of the winding or overload on the other if the transformer is loaded with its full rated capacity say 50MVA. In both scenarios either the transformer will be running at lower than its capacity with expected technical life as designed, technically say rated ageing rate of one or the transformer would deliver the required load as an overload condition meeting the commercial requirements but of course with a compromised life time. That is in technical terms the transformer would be running at an accelerated ageing rate.

As briefed above, my emphasis to find solution for this accelerated ageing by systematic study of the issues, analyzing them scientifically and providing recommendations for solving or mitigating the highlighted problems above.

The utility from the Middle East (identity of the utility is kept confidential as requested) whose network is selected for my study has large fleet of 132/12kV, 50MVA high impedance power transformers connected to their 132/11kV network. Fixed voltage winding of the transformer is 12kV where as it is connected to the 11kV constant voltage bus. Thu the loading of 12kV winding must be restricted to (11/12) = 91.67% of its capacity. That is each transformer would be de-rated to 45.835MVA instead of 50MVA.

Objective of my study is to propose the right solution for saving this capacity loss for future orders by suggesting appropriate specification amendments.

When a transformer is loaded with a constant primary voltage, the secondary voltage decreases under lagging power factor and increases under leading power factor because of its internal resistance and leakage reactance. Hence, to keep the output voltage constant the primary voltage must be increased. The rise in primary voltage required to maintain rated output voltage from no-load to full load at a given power factor expressed as percentage of rated primary voltage gives the regulation of the transformer.

1.4 Research Hypotheses

A hypothesis is a proposition that is a tentative assumption which a researcher what to test for its logical or empirical consequences. Hypotheses are more useful when stated in precise and clearly defined terms. It may be mentioned that though a hypothesis is useful it is not always necessary, especially in case of exploratory researches. However, in a problem-oriented research, it is necessary to formulate a hypothesis or hypotheses. In such researches, hypotheses are generally concerned with the causes of a certain phenomenon or a relationship between two or more variables under investigation.

The following questions triggered the inspiration to choose the research topic. The objective of my research is to find solution for these questions and prove it systematically and validate it through research. The research questions are:

1. Is the transfer of specified Power 50MVA realized from High Voltage bus to Low Voltage bus that is from 132kV bus to 11kV bus if the voltage ratio of transformer is 132kV/12kV without overloading or without accelerated ageing rate of the transformer?
2. Is the existing tapping range of 132kV ±15% appropriate? Is the step voltage 132kV x 1.67% ±9 ideal?
3. Is the selection of Voltage ratio 132/12kV optimum for power transformers connected to a network of 132kV and 11kV respectively to transfer the rated power without overloading of windings and sacrificing its technical life?

Research Hypotheses:

4. *Hypotheses:* A 50MVA, 132/12kV Power Transformer can transfer only a de-rated 45.83MVA from 132kV bus to 11kV bus without accelerated ageing due to overloading. (When rated parameters of transformers mismatch with that of the connected network then the capacity of transformers either de-rate or the ageing accelerates due to overloading).

5. *Null Hypothesis:* A 50MVA, 132/12kV Power Transformer can transfer full capacity of 50MVA from 132kV bus to 11kV bus without accelerated ageing and overloading.

Significance level: The significance level of 5% that is 0.05 has been taken for testing of the null hypothesis.

A working hypothesis is a hypothesis that is provisionally accepted as a basis for further research in the hope that a tenable theory will be produced, even if the hypothesis ultimately fails. Like all hypotheses, a working hypothesis is constructed as a statement of expectations, which can be linked to the exploratory research purpose in empirical investigation. Working hypotheses and are often used as a conceptual framework in qualitative research. The provisional nature of working hypotheses make them useful as an organizing device in applied research. Here they act like a useful guide to address problems that are still in a formative phase.

Most formal hypotheses connect concepts by specifying the expected relationships between propositions. When a set of hypotheses are grouped together they become a type of conceptual framework. When a conceptual framework is complex and incorporates causality or explanation it is generally referred to as a theory. The hypotheses whose constituent terms have been interpreted become capable of test by reference to observable phenomena. Frequently the interpreted hypothesis will be derivative hypotheses of the theory; but their confirmation or disconfirmation by empirical data will then immediately strengthen or weaken also the primitive hypotheses from which they were derived.

In my study various hypothesis were considered, re-rote and reframed them to arrive at the final research hypothesis.

Hypothesis testing

When a possible correlation or similar relation between phenomena is investigated, such as whether a proposed remedy is effective in treating a disease, the hypothesis that a relation exists cannot be examined the same way one might examine a proposed new law of nature. In such an investigation, if the tested remedy shows no effect in a few cases, these do not necessarily falsify the hypothesis. Instead, statistical tests are used to determine how likely it is that the overall effect would be observed if the hypothesized relation does not exist. If that likelihood is sufficiently small the existence of a relation may be assumed. Otherwise, any observed effect may be due to pure chance.

In statistical hypothesis testing, two hypotheses are compared. These are called the null hypothesis and the alternative hypothesis. The null hypothesis is the hypothesis that states that there is no relation between the phenomena whose relation is under investigation, or at least not of the form given by the alternative hypothesis.

The alternative hypothesis, as the name suggests, is the alternative to the null hypothesis. It states that there is some kind of relation.

Conventional significance levels for testing hypotheses (acceptable probabilities of wrongly rejecting a true null hypothesis) are 0.10, .05, and .01. Whether the null hypothesis is rejected and the alternative hypothesis is accepted, must be determined in advance, before the observations are collected or inspected. If these criteria are determined later, when the data to be tested are already known, the test is invalid.

In the case of my study the significance level of 5% that is 0.05 has been considered for the null hypothesis testing.

Chapter 2

Literature Review

In this chapter I have briefed literature review about the electrical power industry (World Scenario) , about the utility company in the Middle East and also about the sponsoring organization M/s Energoprojekt Entel. I have segregate literature survey into 3 sections chapters, one on the review of industry, review of the utility and the other on the sponsoring organization. The review is done based information gathered from recent publications, books, reports, journals and websites. I have tried to maintain logical direction and flow in the literature survey.

A review of the literature provides the background and context for the research problem. It is required to establish the need for the research and indicate that the research is in the loop. To the extent possible I have avoided statements that indicate little or that too extensive to permit easy summary.

2.1 Review Area Broad: *The Power Industry*:

Electricity is central to our lives at home and at work and to the prosperity of any Nation. Access to sophisticated and extensive electricity systems has given power industries a substantial competitive advantage over the years, a key underlying factor in the growth of the world's most powerful economies. The central role for electricity is as an enabler for every other sector in the economy. It is an essential input for growth in capital investment and in a range of key industries including energy, manufacturing, mining and other emerging clean technology sectors.

It is worth remembering that even today there are millions people around the World have no access to electricity though Governments of developing and undeveloped countries are putting sincere efforts to provide electricity for all.

Information gathered from the website of 'enerdata global energy statistics' is given in the Table 1 which show cases the total quantity of electricity produced for the past 14 years Worldwide (refer to Table 1). It can be observed from the table that the Power Industry was growing at above 4% per annum till the recession period then declined and now picking up the pace. This reveals that my study has relevance from the perspective that it would be applicable for the new fleet of Power Transformers to be inducted to the network of electricity utilities.

The electricity generation shows an increase in trend, which necessitates huge investment and energy efficient use and generation for sustainable growth.

The electric power industry is the generation, transmission, distribution and sale of electric power to the general public. The electrical industry started with introduction of electric lighting in 1882. Throughout the 1880s and 1890s, growing economic and safety concerns lead to the regulation of the industry. Once an expensive novelty limited to the most densely populated areas, reliable and economical electric power has become a requirement for normal operation of all elements of economies.

By the middle of the 20th century, electric power was seen as a "natural monopoly", only efficient if a restricted number of organizations participated in the market; in some areas, vertically-integrated companies provides all stages from generation to retail, and only governmental supervision regulated the rate of return and cost structure.

Since the 1990s, many regions have opened up the generation and distribution of electric power to provide a more competitive electricity market. While such markets can be abusively manipulated with consequent adverse price and reliability impact to consumers, generally competitive production of electrical energy leads to worthwhile improvements in efficiency. However, transmission and distribution are harder problems since returns on investment are not as easy to find.

My research study however is concentrating in supporting enhancements in efficiency improvement in Transmission Network of Power industry.

Year	World electricity Generation in TWh	Percentage increase (%)
2000	15477	-
2001	15594	0.75
2002	16202	3.75
2003	16782	3.45
2004	17571	4.49
2005	18333	4.15
2006	19042	3.72
2007	19878	4.21
2008	20268	1.92
2009	21206	4.42
2010	21526	1.48
2011	22223	3.13
2012	22717	2.17
2013	23276	2.40
2014	23636	1.52

Table 1. Source: 'enerdata global energy statistics'

Host Organization M/s Energoprojekt-Entel

The host organization, 'Energoproejekt Entel' with whom the dissertation is done is a well-known Consultant working in the field of Power industry, especially in Middle East region. They are one of the key players in the design and supervision of major power installation in the Middle East. Their well experienced multinational technocrats possess the knowhow and expertise to support, evaluate and validate my research study.

The reputable American magazine Engineering News Records, which annually publishes lists of the best international engineering companies, has released its Top 2015 lists. Energoprojekt Holding Group is once again listed among the leading 225 international design and 250 international contracting companies based on the turnover achieved in 2015. On the list of Top 225 International Design Firms, Energoprojekt Holding Group ranked 121, which represents a jump of 10 spots when compared to the 2014 position. On the List of Top 250 International Contractors, Energoprojekt Holding Group ranked 232, which represents a jump of 39 spots when compared to the 2014 position.

Following details are collected from their website and their group magazine published quarterly.

Incorporated in 1951, the Energoprojekt Group draws on more than 60 years of experience in the fields of energy, town planning, environmental protection, infrastructure, architecture, industry, information technologies, trade and real estate. For the past six decades of its successful operation, the Energoprojekt Group have developed into an organization able to undertake large and complex projects, ranging from studies and investigations through design and supervision to construction and putting into operation. Today, the Energoprojekt Group has a reputation of the largest contractor in Serbia for complex projects including construction management, full engineering and turn-key jobs. The shares of the Energoprojekt Group are quoted daily at the Belgrade Stock Exchange (BELEX) on the official "A" listing or BELEX BEST (with the symbol ENHL). Relevant projects designed or developed by the Energoprojekt Corporation during the last 60 years in more than 70 countries all over the world include, more than thirty thermal power plants (oil, gas or lignite fired) of various types and capacities (with a unit capacity up to 800 MW). Twenty heating plants and thirty-four district heating systems. More than fifty hydro power plants of various types and capacities including a number of pumped storage plants. Over one hundred and fifty power transmission and distribution substations with a voltage level up to 400 kV. Several thousand kilometers of overhead transmission and cable lines with a voltage level up to 400 kV. Over fifty projects on rural and urban electrification. Fifteen water management plants and basin developments. About fifty municipal and industrial water supply and sewage systems. Heating, cooling and air-conditioning installations for a/m projects. Information systems and technologies for a/m projects.

The name of Energoprojekt can be found on the lists of Top International Design firms and International Contractors published every year by the American professional magazine "Engineering News Record". In 2010 Energoprojekt was listed at No. 118 among 200 International Design firms:

In today's competitive business environment, the Energoprojekt Group adapts its business activities in Serbia to current capital investment requirements, while the center of gravity of its activities is focused abroad. In the countries in which it is operating, the ENERGOPROJEKT Group develops and cultivates business and professional relationships with domestic companies, establishes its own branch offices and joint venture companies and agencies, achieving important cooperation with internationally renowned banks and financial institutions. The Energoprojekt Group is organized around two core businesses – consultancy engineering and construction engineering. The strength of its parent company enable Energoprojekt Entel to expand its leading-edge role in consultancy engineering for energy related projects throughout the EMEA (Europe, Middle East & Africa) region.

2.2 Review area Narrow: ***Electricity in the Middle East***

Demand for electric power in the Middle East region is accelerating rapidly, and is set to continue to grow by seven per cent annually in the coming decade, according to a report published by the Economist Intelligence Unit (EIU). The (Middle East and North Africa (MENA) region has about 57% of the world's proven oil reserves and 41% of proven natural gas resources. MENA is also endowed with unique solar resources. However, great gaps exist between countries rich in natural resources and countries dependent on such resources. Many countries have close to 100% access to electricity, but an estimated 28 million people still lack access to electricity, especially in rural areas, and about 8 million people rely on traditional biomass for all their energy needs.

In many MENA countries, petroleum product prices are distorted, cost recovery in electricity is low, efficiency of supply leaves a lot to be desired and energy intensity is relatively high. Carbon intensity is, on average, higher than in industrialized countries, and the potential for renewable energy is under-explored. The region is lagging behind in implementing reforms in the electricity sector and lack private sector investment.

Population growth, rapid urbanization and economic growth are putting pressure on existing infrastructure and relatively high demand for new investments. Over the next 30 years, the total investment needs in energy in MENA are estimated at over US$ 30 billion a year, or about 3% of the region's total projected GDP (which is three times higher than the world's average). The continued high and volatile prices of fuels are straining the finances of many net importing countries, both at the government and the utility level, and increasing costs of subsidized energy at home for the oil exporters.

There are considerable differences in the situation of the energy sector in the MENA region and solutions have to be tailored to individual countries and situation. There are, however, a number of common issues. In most countries where oil and gas resources are large, price distortions are considerable and cost recovery in electricity is low. In many countries this has led to inefficient use of supply, high energy intensity in energy use, increasing environmental problems, and a rapidly increasing burden on government finances. In countries which are net importers of fossil fuels, price distortions are generally less and cost recovery in the electricity sector has been somewhat better. However, the challenges they face on how to cope with high oil prices while financing the rapidly growing demand for energy in general, and electricity in particular, remain.

The MENA region is highly susceptible to the risk of climate change impact due to water scarcity, concentration of economic activities in coastal areas and reliance on climate-sensitive agriculture. Despite relatively low total greenhouse gas emission as compared to other regions, MENA has the world's third largest growth of carbon emissions compounding the risk of climate change. The high carbon emissions are predominantly from oil-producing countries which make up 74 percent of the region.

Overall in the region, there is much scope for improving the efficiency of energy supply and energy conservation, as well as the development of renewable energy resources. MENA has begun to exploit its renewable energy potential on a large scale and the Bank is fully supportive of this effort.

Information available on the website of 'enerdata energy statistics' shows the details of last decade of electricity generation of Middle East Countries, which given in table below:

Year	Middle East's electricity Generation in one decade in TWh	Percentage increase (%)
2000	472	-
2001	500	5.60
2002	534	6.36
2003	564	5.32
2004	599	5.84
2005	646	7.28
2006	690	6.38
2007	732	5.74
2008	786	6.87
2009	826	4.84
2010	893	7.50
2011	916	2.51
2012	968	5.37
2013	1005	3.68
2014	1051	4.38

Table 2. Electricity generation in the Middle East, source: 'enerdata energy statistics'

The Table 2, above, indicate an increase in trend in the electricity consumption and requirement grow steadily as the population and standard of living improves. The increase in trend is well above the global average, which shows the steep growth in electricity consumption due to population growth, increase in standard of living, etc. especially in the Middle East Countries.

This necessitates fast expansion of the electricity infrastructure in the Middle East countries. Thus, for me it is interesting that there is big scope for efficiency improvements of the equipment installed in the transmission network especially for power transformers and I can contribute successfully for the capacity enhancement without any cost implications. This enhancement of capacity is as high as about 8.34% of the total transformer capacities as whole which is significant to the electrical utilities in the Middle East region that have already realized the importance of environmental friendly approaches and are valuing such initiatives with great pride.

2.3 Factors critical to Success of Study: *Utility in the Middle East*

(Literature Review of My Host Utility whose identity is kept Anonymous upon request)

Next, I would like to brief about the Utility in the Middle East whose network is selected for the dissertation project work. It is worth mentioning that the details of the Utility are kept anonymous upon request of the utility.

The utility is one of the leading utilities in the Middle East whose installed capacity of power generation is about 9656MW as on October 2015. They are a fast growing utility well known for its very low T&D losses, values environmental initiatives and supports power generation from renewable energy sources through various initiatives like roof top Solar Photovoltaic power installation thus maintain sustainability development even though major share of power generation is from thermal stations using natural gas. Their growth story for last 10years as published in the Website is reproduced statistically in Table 3, below:

Year	Installed Capacity in MW	Percentage growth of Generation capacity (%)	Peak Demand in MW	Percentage increase in peak demand (%)
2004	3833	-	3228	-
2005	3833	-	3571	9.61
2006	4599	16.65	4113	13.17
2007	5448	15.58	4736	13.15
2008	6676	18.39	5287	10.42
2009	6997	4.58	5622	5.95
2010	7361	4.94	6161	8.74
2011	8721	15.59	6206	0.725
2012	9646	9.58	6637	6.49
2013	9656	0.10	6857	3.20
2014	9656	0.0	7233	5.19

Table 3. Statistical data of the utility for the last 10years as published in the Website.

The Table 3, above, shows steady growth of generation as well as increase in maximum demand for more than 15% before the recession period which, dropped to slow pace and then picking up the pace. It is evident that the planning of generation always overtakes the peak demand thus ensuring uninterrupted power to their customers.

Thus, for me it is interesting that there is big scope for efficiency improvements of the equipment installed in the transmission network especially for power transformers and I can contribute successfully for the capacity enhancement without any cost implications. This enhancement of capacity is as high as about 8.34% of the total transformer capacities as whole which is significant to the electrical utility that has already realized the importance of environmental friendly approaches and is valuing such initiatives with great pride.

In the Middle East power is utilized mostly for cooling during summer. Hence, major share of load is from Air conditioners of low power factor which consume huge inductive reactive power.

Their 132kV transmission network consists of more than 200numbers of 132kV Gas Insulated Substations (GIS) interconnected by XLPE Cables and overhead lines. Major portion is linked via XPLPE cables. The LV side of the substations varies from 33kV sub transmission system to 11kV distribution network. Majority of their substations are Transforming power from 132kV to 11kV distribution network.

My research study is however limited to the 132/11kV substations. Current design of the 132/11kv substations employs three Power Transformers of 50MVA capacity each connected in parallel at one substation to transfer the power though they had employed various designs in the past. This design necessitates selection of high impedance power transformers in order to limit the fault level within the specified level of LV circuit breakers and network devices.

The high impedance of specified as more than 31.5% has an adverse impact on the regulation of the transformers. To mitigate this high regulation voltage ratio of the transformer is chosen higher than that of the bus bar.

My interest of study is in general concentrated on how to improve the transfer of specified Power 50MVA is realized from High Voltage bus to Low Voltage bus that is from 132kV bus to 11kV bus without overloading of the transformer and without accelerated ageing rate of the transformer in order to help the utility preserve their resources and optimize use of their assets. To explore whether the existing tapping range of 132kV ±15% appropriate or not and to examine the step voltage 132kV x 1.67% ±9 ideal to the application.

Also, I want to ensure that the selection of Voltage ratio 132/12kV is optimum or not for power transformers that connected to a network of 132kV and 11kV respectively to transfer the rated power without overloading of windings and sacrificing its technical life.

All the above want to be done in systematic way that can be reported professionally to the utility.

As stated earlier, electricity in the Middle East is utilized mostly for cooling purpose to ease out from severe hot climate. That means major chunk of power is utilized by residential buildings. Hence, the load pattern varies month by month in a year and hour by hour in day. This change in load brings in voltage fluctuations in the network. To maintain voltage stability and quality of power to the consumers, utility installed on load tap changers for their power transformers.

Monthly load pattern of the utility is shown in the below Graph 1 below. It can be noted that the peak load is experienced in the months of July and August and the load falls to its minimum in December and January months. In the study I concentrated mainly in those four months for the data collection since the tap variation is expected to reach its maximum ranges during those months.

Chapter 3

Research Design, Methodology and Plan

In this chapter research design, research methodology and research plan are explained followed by sections detailing data sources, survey questions, data analysis procedure and interview procedure. As stated earlier, objectives of my study is to find answer for the set of questions defined.. A research question poses a relationship between two or more variables but phrases the relationship as a question. A hypothesis is the groundwork, foundation, supposition or unproved theory about a problem. It is a statement of the relationship between variables (concepts) or empirical events that is in a testable form.

The testing of the stated relationship is the project. The procedure of testing is the methodology. Deciding whether to use questions or hypotheses depends on factors such as the purpose of the study, the nature of the design and methodology and the audience of the research. I have tried to state the questions short and crisp research questions and set the hypothesis accordingly

Problem has been well defined as given under in the purpose of the study under first chapter of introduction. A hypothesis formulation is also done under the same chapter. The next step of the research process calls for determining the information needed, developing a plan for gathering it efficiently. The plan outlines source of data and spells out the specific approaches, contact methods, sampling plan and instrument that used to gather the primary data. I have implemented the research plan into action by collecting, processing and analyzing the collected information.

A research design or model indicates a plan of action to be carried out in connection with a proposed research work. It is the arrangement of conditions for collection and analysis of data in a manner that aims to combine the relevance to the research purpose with the economy in procedure. Broadly, it is a plan that specifies the sources and types of information relevant to the research problem. It is a strategy specifying which approach will be used for gathering and analyzing the data. It also includes the time and cost budgets since most studies are done under these two constraints. The methods or procedures section is really the core of any of the research study.

In this chapter I have included the methodological steps that have taken to answer every question or to test every question or hypothesis defined under my study. Clear and careful distinction between the dependent and independent variables are done.

Methodology adopted is to gather data from the utility by questionnaire prepared in advance after the literature review. The questionnaire was prepared based on the relationship of the variables I wish to prove in my study. Short interviews were also planned to communicate the objective of my study, its requirement, advantages and disadvantages, methods of testing expected time duration and budget requirements. Then analyzing of the collected primary data statically and interpret the result scientifically.

In the design section I have indicated the variables I propose to control and how these are controlled them. In my study I am proposing to control the variables and prove it statistically. Variables I propose to randomize and the nature of the randomizing unit have also been mentioned under this chapter. The possible sources of error to which my research design exposes my shortcomings are also detailed there. Because, it is obvious that I will not be able to produce a perfect, error free design as no human being can. However, I am anticipating possible sources of error and attempt to overcome them or took them into account in my analysis to the extent possible. Moreover, I have disclosed the sources I have identified and efforts made to account for such possible sources of errors. The relationship of individual questions, group or set of questions and trigger questions and other related aspects are elaborated with the relevant hypothesis because the primary data has been gathered using a questionnaire.

My research projects involve sampling. Hence, a cautious approach has been taken for validation that is the extent to which the interpretations of the results of the study follow from the study itself and the extent to which results may be generalized. I have learnt that sampling is critical to external validity too as external validity is the degree to which the findings of a study can be generalized to units other than those observed in the study. To generalize validly the findings from a sample to some defined population requires that the sample has been drawn from that population according to one of several probability sampling plans.

In my research experimentation, random assignment sampling is adopted. In general, two distinct sampling steps are involved. They are random selection, wherein, participants to be included in the sample have been chosen at random from the same population. It is required to define the population and indicate the sampling plan in detail. Random assignment sampling, wherein, participant for the sample is assigned at random to one of the experimental conditions. Another aspect of sampling is that while designing the sampling procedure is to check on the extent to which the outcomes of a study result from the variables that were manipulated, measured, or selected rather than from other variables not systematically treated. Without internal validation, the sampling design may be flawed. I have questioned myself on the representativeness of the sample and explained why the sample has been so chosen out of the population from the obtained data. The survey population is the group from which the sample is selected. It is important that how representative is the survey population out of the target population (the larger group to which we wish to generalize. Perhaps the key word in sampling is representative.

In the case of my study the transformers are manufactured and delivered by their approved suppliers conforming to the utilities standard specification. Hence, the target population that is the 132/12 kV 50MVA transformers connected to the network of the utility is purely homogenous in nature. Accordingly, sample obviously a representative of the total population. Therefore it can very well be concluded that the research finding would be applicable to the entire population of the power transformers which are expected to be installed to the utility's network in future.

After discussions I had with my guide, the plan and time frame was prepared for data collection, analysis, report writing, reviewing and printing. Overall schedule has been prepared and then each activity elaborated with action plan on a daily basis. In total the duration of project was set as 45 days including report preparation. Then the 10 days was planned for printing and delivery to the University. Mile stones were identified and constraints assessed. Project management paper studied during the course helped to plan, perform execute the study in a systematic way. Further, various resources required to carry out the dissertation study has been identified and availability ensured. The purpose of feasibility study is to explore the appropriate method from several alternatives for mitigation of the problem. I have taken several paths before reaching the final destination. Just because the initial analysis is negative does not mean that the proposal does not have merit. Sometimes limitations or flaws in the proposal can be corrected.

The purpose of the economic feasibility is to determine the economic aspects of the dissertation project. Quantification and identification of all the economic aspects has been looked into and assessment of a cost/benefit analysis has been done. My study is carried out in coordination with the ENERGOPROJEKT-ENTEL CO. LTD, Dubai with them it has been agreed that the study does not require fund other than that of local travel, telephone charges, e-mail correspondences and of course travel for direct interviews as part of primary data collection.

3.1 Data Sources

The Table 4, below, shows the monthly load pattern of the utility for the past 5 years, primary data collected from the utility by using questionnaire. This load details is taken to consider only the months when load is maximum and also those months when load is minimum so that I will be able to filter out remaining months as part of narrowing the problem area. Because, these months might have witnessed the operation range of the OLTC to their highest or lowest ranges in line with the load.

Year / Month	2010 MW	2011 MW	2012 MW	2013 MW	2014 MW
January	3000	3250	3400	3500	3450
February	3200	3350	3500	3450	3500
March	3600	3500	3600	3950	4000
April	4500	4500	4600	4500	4700
May	5400	5500	5800	5700	6200
June	5800	5800	6000	6200	6500
July	6000	6000	6637	6400	7000
August	6161	6206	6300	6857	7233
September	5850	6000	6100	6300	6600
October	5400	5500	6200	6000	6500
November	3950	4000	4050	5000	5100
December	3550	3600	3700	4000	4050

Table 4, shows the monthly load pattern of the utility. Source: primary data collected through questionnaire.

Table 5, below, shows primary data collected to analyze the load at substations for sample collection and to limit the data to a presentable form. Following table showcases the substations where the load shows more than 50% of the firm capacity in the year 2014. Nine of such stations are shown in the table and remaining stations not included because of lower load at those stations and also have handy data. Because, as said in the preceding chapter the samples are homogeneous so the behavior of remaining parameters of the transformer would change proportionately with respect to load condition irrespective of the substation. Out of the overall substations considered as universe few of them are listed here as examples. These stations have the maximum load which is taken for study as the sample characteristic is homogeneous.

Station	Date/Time	MW	MVAR	MVA	Commissioned capacity of Transformers (MVA)		Firm Capacity (MVA)
1	23-Aug-14 12:22:52	73.47	7.18	73.82	3 x 50	150	120
2	23-Aug-14 14:17:13	72.17	3.22	72.24	3 X 50	150	120
3	04-Aug-14 22:17:11	75.01	9.51	75.61	3 x 50	150	120
4	23-Aug-14 14:16:18	77.76	4.12	77.87	3 x 50	150	120
5	17-Aug-14 12:30:28	71.00	9.26	71.60	3 x 50	150	120
6	16-Aug-14 14:08:11	74.13	4.11	74.24	3 x 50	150	120
7	17-Aug-14 14:29:35	76.42	4.56	76.56	3 x 50	150	120
8	17-Aug-14 14:20:28	74.64	0.79	74.64	3 x 50	150	120
9	17-Aug-14 12:43:29	87.41	27.01	91.49	3 x 50	150	120

Table 5. Load data collected from substations. Source: Primary data collection.

From the Table4, above, it can be inferred that the Maximum load observed during the month of August for all past 5years. And, that from the Table 5, we can find that the substation numbered as '9' has the maximum load on 17 of August 2014. So, the primary data collected such as tap position of OLTC, substation number, transformer number, active power, reactive power, power factor of each transformer on hourly basis in order to track the tap variation at maximum load is narrowed to the day 17 of the month of August 2014 in order to optimize the handling of huge size of data and shown in Table 7, below. From the same OLTC position can be seen along with active power, reactive power and power factor for all the three power transformers at the so called substation '9'. Kindly note that due to huge size of table the hourly reading of the full month is given in Annexure 1 from which tap variations and other parameters can be inferred on an hourly basis. I have included only one day's primary data for August 17 2014 in Table 7. In this table hourly reading shows the tap variation from tap position '10' to tap position '9' and back along with other parameters.

Table 7, Hourly reading of load with OLTC position. Source: Primary data collected through questionnaire.

Date/Time	Tap position of Transformers 1, 2 and 3 at station 9			Load		P.F
	1	2	3	Active Power (P)	Reactive Power (Q)	
17-Aug-14 00:09:03	10	10	10	67.44	21.48	0.96
17-Aug-14 01:07:05	9	9	9	65.23	19.53	0.96
17-Aug-14 02:06:10	9	9	9	64.17	19.26	0.96
17-Aug-14 03:05:43	9	9	9	62.41	18.83	0.96
17-Aug-14 04:03:09	9	9	9	61.24	18.44	0.96
17-Aug-14 05:06:31	9	9	9	60.27	18.47	0.96
17-Aug-14 06:10:16	9	9	9	59.94	18.39	0.96
17-Aug-14 07:13:14	9	9	9	65.54	19.93	0.96
17-Aug-14 08:07:35	10	10	10	72.66	24.07	0.96
17-Aug-14 09:06:28	10	10	10	79.03	25.12	0.95
17-Aug-14 10:11:55	10	10	10	82.79	25.96	0.96
17-Aug-14 11:03:00	10	10	10	85.98	26.41	0.96
17-Aug-14 12:09:21	10	10	10	87.41	27.35	0.96
17-Aug-14 13:04:21	10	10	10	86.02	27.71	0.95
17-Aug-14 14:07:55	10	10	10	85.80	33.54	0.97
17-Aug-14 15:48:34	10	10	10	84.23	26.07	0.96
17-Aug-14 16:24:50	10	10	10	84.64	26.06	0.96
17-Aug-14 17:08:52	10	10	10	81.32	25.52	0.95
17-Aug-14 18:22:02	10	10	10	77.80	25.56	0.95
17-Aug-14 19:11:55	10	10	10	76.81	25.45	0.95
17-Aug-14 20:13:09	10	10	10	74.05	24.00	0.95
17-Aug-14 21:03:00	10	10	10	71.79	22.88	0.95
17-Aug-14 22:03:00	10	10	10	67.92	21.91	0.95
17-Aug-14 23:05:33	10	10	10	64.80	20.65	0.95

Table 6, Hourly reading of load with OLTC position. Source: Primary data collected through questionnaire.

From Table 4, it can be seen that the substation load is the lowest during the month of January 2014. Primary data Collection of data for the month of lowest load in order to investigate the position variation of tap changer while load is at its low. Data to be collected include tap position of OLTC, active power, reactive power, power factor (pf), substation number, transformer number. The collected data of hourly reading are shown for one day that is 26. 1. 2014 in Table 8 below. However, hourly reading for the full month of January 2014 is given in Annxure2 for reference. It can be inferred that the tap position is stable at position say 6.

Date/Time	Tap position of transformers 1, 2 and 3			Load		P.F
	1	2	3	Active Power (P)	Reactive Power (Q)	
26-Jan-15 00:11:29	6	6	6	22.57	0.00	0.96
26-Jan-15 01:14:19	6	6	6	21.32	6.09	0.96
26-Jan-15 02:39:03	6	6	6	20.81	6.04	0.95
26-Jan-15 03:07:09	6	6	6	20.37	6.09	0.95
26-Jan-15 04:21:47	6	6	6	20.07	5.92	0.95
26-Jan-15 05:13:09	6	6	6	20.73	6.05	0.96
26-Jan-15 06:13:02	6	6	6	23.00	6.47	0.96
26-Jan-15 07:07:57	6	6	6	25.71	1.41	0.97
26-Jan-15 08:19:10	6	6	6	25.94	1.60	1
26-Jan-15 09:09:37	6	6	6	26.11	1.86	0.99
26-Jan-15 10:09:21	6	6	6	27.01	2.50	0.94
26-Jan-15 11:07:58	6	6	6	27.23	2.66	0.94
26-Jan-15 12:13:39	6	6	6	26.93	2.98	0.99
26-Jan-15 13:35:31	6	6	6	26.65	2.68	0.99
26-Jan-15 14:46:36	6	6	6	25.76	2.34	0.99
26-Jan-15 15:16:04	6	6	6	26.35	2.61	0.99
26-Jan-15 16:03:00	6	6	6	26.78	2.68	0.99
26-Jan-15 17:04:39	6	6	6	27.26	2.74	0.99
26-Jan-15 18:14:26	6	6	6	30.69	3.16	0.99
26-Jan-15 19:03:00	6	6	6	31.80	3.73	0.99
26-Jan-15 20:50:53	6	6	6	30.89	3.22	0.99
26-Jan-15 21:03:58	6	6	6	29.34	2.82	0.99
26-Jan-15 22:05:49	6	6	6	27.13	2.43	0.99
26-Jan-15 23:03:00	6	6	6	24.89	0.00	0.96

Table 7, Hourly reading of load with OLTC position for 26. 1. 2014 . Source: Primary data collected through questionnaire.

Table 9, Collection of data for the transformers:

Tap No	HV Volts in kV	HV Current in Amps	Imp Voltage in kV	LV Voltage in kV	Turn Ratio
1	151.8	190	57922	12	7.303695
2	149.6	193	56710	12	7.197844
3	147.4	196	55315	12	7.091994
4	145.2	199	53966	12	6.986143
5	143	202	52418	12	6.880293
6	140.8	205	51100	12	6.774442
7	138.6	208	49689	12	6.668591
8	136.4	212	48564	12	6.562741
9	134.2	215	47202	12	6.45689
10	132	219	45898	12	6.351039
11	129.8	222	45463	12	6.245189
12	127.6	226	44200	12	6.139338
13	125.4	230	42957	12	6.033487
14	123.2	234	41717	12	5.927637
15	120.9	239	40586	12	5.816975
16	118.8	243	39338	12	5.715935
17	116.6	248	38276	12	5.610085
18	114.4	252	37048	12	5.504234
19	112.2	257	35888	12	5.398383

Table 8, Collection of data for the transformers:

Calculated data of transformer after collecting the details in Table 10. Below table shows calculated voltage at LV side at various tap positions while 132kV is available at the HV side of transformer.

Tap No	HV in kV	Turn Ratio	LV volts in kV when 132kV is applied at HV
1	132	7.30	10.4
2	132	7.19	10.5
3	132	7.09	10.7
4	132	6.98	10.9
5	132	6.88	11.0
6	132	6.77	11.2
7	132	6.66	11.4
8	132	6.56	11.6
9	132	6.45	11.8
10	132	6.35	12.0
11	132	6.24	12.2
12	132	6.13	12.4
13	132	6.03	12.6
14	132	5.92	12.8
15	132	5.81	13.1
16	132	5.71	13.3
17	132	5.61	13.5
18	132	5.50	13.8
19	132	5.39	14.1

Table 9, calculated data of transforms from the primary data obtained

Impedance voltage data collected for all taps at 50MVA base. Impedance voltage for remaining taps has been calculated and the values are shown in table below.

Transformer impedance calculated based on factory test data collected									
MVA / Tap No	20	25	30	35	40	45	50	55	60
1	15.27	19.09	22.91	26.73	30.55	34.37	38.191	42.01	45.82
2	15.16	18.95	22.74	26.53	30.32	34.11	37.90	41.69	45.48
3	14.99	18.74	22.49	26.24	29.99	33.74	37.49	41.24	44.99
4	14.85	18.56	22.27	25.99	29.70	33.41	37.13	40.84	44.55
5	14.65	18.31	21.98	25.64	29.30	32.97	36.63	40.29	43.96
6	14.51	18.14	21.77	25.40	29.03	32.66	36.29	39.92	43.55
7	14.35	17.94	21.53	25.12	28.71	32.30	35.89	39.48	43.07
8	14.21	17.77	21.32	24.88	28.43	31.99	35.54	39.09	42.65
9	14.07	17.59	21.11	24.63	28.15	31.67	35.19	38.71	42.22
10	13.88	17.36	20.83	24.30	27.77	31.25	34.72	38.19	41.66
11	14.03	17.54	21.05	24.56	28.07	31.58	35.08	38.59	42.1
12	13.87	17.33	20.80	24.27	27.74	31.20	34.67	38.14	41.61
13	13.71	17.14	20.57	24.00	27.42	30.85	34.28	37.71	41.14
14	13.56	16.95	20.34	23.73	27.12	30.51	33.90	37.29	40.68
15	13.41	16.76	20.12	23.47	26.83	30.18	33.53	36.89	40.24
16	13.24	16.55	19.86	23.17	26.49	29.80	33.11	36.42	39.73
17	13.10	16.38	19.66	22.94	26.21	29.49	32.77	36.04	39.32
18	12.97	16.21	19.45	22.70	25.94	29.18	32.42	35.67	38.91
19	12.80	16.01	19.21	22.41	25.61	28.82	32.02	35.22	38.42

Table 10, Impedance voltage of transformers at various loads and tap positions. Information gathered as part of primary data collection.

Table 12, Collection data for the Load losses, Impedance voltage %z from primary data collection

Tap no	Load loss in kW at 50MVA	Impedance Voltage in %
1	248.9	38.16
2	243.2	37.91
3	243.8	37.53
4	243.8	37.17
5	244.2	36.71
6	244.1	36.29
7	244.1	35.85
8	245.7	35.60
9	245.6	35.17
10	251.1	34.77
11	248.0	35.03
12	248.0	34.64
13	248.0	34.26
14	248.1	33.86
15	250.1	33.54
16	249.0	33.11
17	250.2	32.83
18	249.6	32.39
19	252.8	31.99

Table 11, Collection data for the Load losses, Impedance voltage %z from primary data collection

Serial no.	Parameter	Value
1	Rated HV Voltage	132kV
2	Rated LV Voltage	12kV
3	Rated Power	50MVA (60MVA for 6 hours)
4	Tapping range	+15% - 15% of 132kV
6	Tapping steps	1.67 x ± 9
7	Impedance voltage	Minimum 31.5% at tap 19
8	Connection symbol	YNd1
9	Number of Transformers per 132kV substation	3
10	Impedance Voltage	Minimum 31.5% at tap 19 and 50MVA base

Table 12, Data collection of Transformer rating

3.2 Research Design

A research design or model indicates a plan of action to be carried out in connection with a proposed research work. It is the arrangement of conditions for collection and analysis of data in a manner that aims to combine the relevance to the research purpose with the economy in procedure.

Accordingly, for my research study the collection of primary data is planned to be done through enacting questionnaires. In the case of my study the transformers are manufactured and delivered by their approved suppliers conforming to the utilities standard specification. Hence, the target population that is the 132/12 kV 50MVA transformers connected to the network of the utility is purely homogenous in nature. Accordingly, sample obviously a representative of the total population. Therefore it can very well be concluded that the research finding would be applicable to the entire population of the power transformers which are expected to be installed to the utility's network in future.

After discussions I had with my guide, the plan and time frame was prepared for data collection, analysis, report writing, reviewing and printing. Overall schedule has been prepared and then each activity elaborated with action plan on a daily basis. In total the duration of project was set as 45 days including report preparation. Then the 10 days was planned for printing and delivery to the University. Mile stones were identified and constraints assessed. Project management paper studied during the course helped to plan, perform execute the study in a systematic way. Further, various resources required to carry out the dissertation study has been identified and availability ensured. The purpose of feasibility study is to explore the appropriate method from several alternatives for mitigation of the problem. I have taken several paths before reaching the final destination. Just because the initial analysis is negative does not mean that the proposal does not have merit. Sometimes limitations or flaws in the proposal can be corrected.

The purpose of the economic feasibility is to determine the economic aspects of the dissertation project. Quantification and identification of all the economic aspects has been looked into and assessment of a cost/benefit analysis has been done. My study is carried out in coordination with the ENERGOPROJEKT-ENTEL CO. LTD, Dubai with them it has been agreed that the study does not require fund other than that of local travel, telephone charges, e-mail correspondences and of course travel for direct interviews as part of primary data collection.

Percentage Regulation of Transformers can be found out by the following formula for network where the lagging power factor. (For a leading power factor the equation would be same but the first plus sign would become minus sign and the minus sign inside the bracket would become plus sign). However, for the network of our study the power factor (pf) is lagging. Hence, the equation below is used throughout for the calculation and analysis of the data.

$$\%\,Regulation = v_r \cos\emptyset + v_x \sin\emptyset + \frac{(v_x \cos\emptyset - v_r \sin\emptyset)^2}{200}$$

Here, $v_r = \%\,copper\ loss\ of\,the\ Transformer.$

v_x is the Reactance of the transformer expressed in percentage.

%Z is the impedance of the transformer expressed in percentage of either Primary Voltage or Secondary Voltage.

$$\%Z = \frac{I_1 Z_{01}}{V_1} \times 100 = \frac{I_2 Z_{02}}{V_2} \times 100$$

Therefore $\%X = v_x = \sqrt{\%Z^2 - v_r^2}$

Cos $\emptyset$ is the Power factor (pf) of the system to which the transformer is connected.

It is clear from the equation that here I have 3 variables controlling the above equation while computing the percentage regulation. They are Power factor (pf) of the system, Reactive drop v_x of the transformer and resistive drop v_r which is controlled by copper loss of the transformer. Out of these v_r and v_x are contribute to the impedance of the transformer which is represented by Z. The transformers under study are having high impedance which contribute to the higher voltage drop or high regulation due to this high impedance.

Broadly, research design is a plan that specifies the sources and types of information relevant to the research problem. It is a strategy specifying which approach will be used for gathering and analyzing the data. It also includes the time and cost budgets since most studies are done under these two constraints. The methods or procedures section is really the core of any of the research study.

In this chapter I have included the methodological steps that have taken to answer every question or to test every question or hypothesis defined under my study. Clear and careful distinction between the dependent and independent variables are done.

Methodology adopted is to gather data from the utility by questionnaire prepared in advance after the literature review. The questionnaire was prepared based on the relationship of the variables I wish to prove in my study. Short interviews were also planned to communicate the objective of my study, its requirement, advantages and disadvantages, methods of testing expected time duration and budget requirements. Then analyzing of the collected primary data statically and interpret the result scientifically.

In the design section I have indicated the variables I propose to control and how these are controlled them. In my study I am proposing to control the variables and prove it statistically. Variables I propose to randomize and the nature of the randomizing unit have also been mentioned under this chapter. The possible sources of error to which my research design exposes my shortcomings are also detailed there. Because, it is obvious that I will not be able to produce a perfect, error free design as no human being can. However, I am anticipating possible sources of error and attempt to overcome them or took them into account in my analysis to the extent possible. Moreover, I have disclosed the sources I have identified and efforts made to account for such possible sources of errors. The relationship of individual questions, group or set of questions and trigger questions and other related aspects are elaborated with the relevant hypothesis because the primary data has been gathered using a questionnaire.

My research projects involve sampling. Hence, a cautious approach has been taken for validation that is the extent to which the interpretations of the results of the study follow from the study itself and the extent to which results may be generalized. I have learnt that sampling is critical to external validity too as external validity is the degree to which the findings of a study can be generalized to units other than those observed in the study. To generalize validly the findings from a sample to some defined population requires that the sample has been drawn from that population according to one of several probability sampling plans.

In my research experimentation, random assignment sampling is adopted. In general, two distinct sampling steps are involved. They are random selection, wherein, participants to be included in the sample have been chosen at random from the same population. It is required to define the population and indicate the sampling plan in detail. Random assignment sampling, wherein, participant for the sample is assigned at random to one of the experimental conditions. Another aspect of sampling is that while designing the sampling procedure is to check on the extent to which the outcomes of a study result from the variables that were manipulated, measured, or selected rather than from other variables not systematically treated. Without internal validation, the sampling design may be flawed. I have questioned myself on the representativeness of the sample and explained why the sample has been so chosen out of the population from the obtained data. The survey population is the group from which the sample is selected. It is important that how representative is the survey population out of the target population (the larger group to which we wish to generalize. Perhaps the key word in sampling is representative.

The type of research selected for my study is the Quantitative research on the basis of data collection and conclusion required in terms of quantity. Causal research design is adopted in order to establish the effect of change in ratio with the power transformation from HV to LV bus if the voltage ratio of transformer is different from that of bus bar.

3.3 Survey Questions

In this chapter I shall introduce the survey questions and questionnaire. There different types of questions in a survey. In general, a survey is a quantitative research method for data collection where questions are used to describe a specific survey subject. To design the questionnaire for my survey effectively I recognized the types of questions and their specifics.

Open-ended questions are mainly those that offer answers only in a form of text. They are intended for examination of the specific responses from respondents, which are not possible to express otherwise than by word description. For example, is there something specific you would want to change in our transformer design?

Semi close-ended questions are suitable to use in cases where we need to get a particular and textual response. The textual answer is usually defined as a separate answer at the end. Respondents choose it if they cannot choose from one of the suggested answers. Data can be collected by phone, in person, via e-mail, etc.

In my study I have used both open ended as well as semi clos ended questions in order to collect the required data. I have gathered those via collecting the answer in person and also via e-mail.

Table 13, Survey Questionnaire used to gather the primary data

Questionnaire to collect primary data for the research study titled, as 'Regulation Management and Ratio Optimisation of High Impedance Power Transformers for a Sustainable Power System'		
Serial No.	Questions	Answer in descriptive manner
1.	Kind of transformer, e.g. separate winding transformer, auto-transformer	
2.	Single or three phase units	
3.	Operating Frequency	
4.	Dry type or oil-immersed type. If oil-immersed type, whether mineral oil or synthetic insulating liquid	
5.	Indoor or outdoor type	
6.	Type of cooling	
7.	Rated power	
8.	Rated voltages (for each winding)	
9.	Type and range of voltage variation	
10.	Highest voltage for equipment (for	

	each winding)	
11.	Connection symbol	
12.	Impedance voltage HV/LV at 75^0C	
	Base of MVA for specified impedance	
13.	Design maximum ambient temperature	
14.	Design maximum average ambient temperature over one year	
15.	Whether unbalanced loading is anticipated and if so, the details.	
16.	Details of intended loading beyond name plate rating	
17.	Temperature rise limits at continuous duty at rated power	
	Windings rise	
	Top oil rise	
	Hot spot rise at relative thermal aging rate of '1'.	
18.	Maximum Values of load and no load losses, if specific values are required.	
19.	Type termination connection at HV and LV, whether cables or GIS.	
20.	Monthly load of the substation including OLTC tap and P.F.	
21.	Historical load data for the past 5 years.	
22.	Is the specification same for all substations? If no kindly mention the standard.	
23.	Share copy of the Factory type test report of one Transformer	
24.	State the Reactive power compensation method, its capacity per substation, HV side or LV side.	

Table 13, Survey Questionnaire used to gather the primary data

3.4 Interview Procedures

In this chapter I am discussing about the interview patterns adopted to gather the primary data. I have collected the data through direct and indirect interviews in line with the research design. In the first instant questionnaires have been forwarded via e-mail clearly specifying the objective of the survey. Then a meeting has been requested by the utility to clarify their answers to the questions. Few of the requested data were collected from the Factory type test report.

Specifically to research the primary data collection can be based on direct or indirect interview methods where respondents answer standardized questions. The survey techniques include primary data collection in person or through e-mail. The physical design of a survey can affect response quality and cause bias through the question-order effect in which previous questions affect the answers to subsequent questions, or affect the likelihood of completing the survey.

Interviewing often involves a face-to-face interaction but may also take place through other direct communication like over the phone. Interviews may consist of a predetermined set of questions, a spontaneous conversation, or both. Interview material should be recorded during the interview or as soon as possible thereafter to capture as much relevant data as possible.

The universe or population is the total number of Power Transformer under 132/11kV Substations of the host Utility. All transformers under study are considered to be identical and homogenous because they are built under same specification. Hence, the universe is homogeneous. So, one sample from the universe will have all the characteristics of the universe. Sampling on assigned random basis and Evaluation is based on Multivariate analysis.

3.5 Data Analysis Procedures

Several methods are available for data analysis. For example univariate statistics (single variable), bivariate associations (correlations), graphical techniques (scatter plots). In my study bivariate correlation analysis is used as the procedure for analyzing the data.

Analysis of data is a process of inspecting, cleaning, transforming and modeling data with the goal of discovering useful information, suggesting conclusions and supporting decision-making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains. Analysis refers to breaking a whole into its separate components for individual examination. Data analysis is a process for obtaining raw data and converting it into information useful for decision-making by users. Data is collected and analyzed to answer questions, test hypotheses or disprove theories.

Percentage Regulation of Transformers can be found out by the following formula for network where the lagging power factor. (For a leading power factor the equation would be same but the first plus sign would become minus sign and the minus sign inside the bracket would become plus sign). However, for the network of our study the power factor (pf) is lagging. Hence, the equation below is used throughout for the calculation and analysis of the data.

$$\%\,Regulation = v_r \cos\emptyset + v_x \sin\emptyset + \frac{(v_x \cos\emptyset - v_r \sin\emptyset)^2}{200}$$

Here, $v_r = \%\, copper\ loss\ of\ the\ Transformer.$

v_x is the Reactance of the transformer expressed in percentage.

%Z is the impedance of the transformer expressed in percentage of either Primary Voltage or Secondary Voltage.

$$\%Z = \frac{I_1 Z_{01}}{V_1} \times 100 = \frac{I_2 Z_{02}}{V_2} \times 100$$

Therefore $\%X = v_x = \sqrt{\%Z^2 - v_r^2}$

Cos $\emptyset$ is the Power factor (pf) of the system to which the transformer is connected.

It is clear from the equation that here I have 3 variables controlling the above equation while computing the percentage regulation. They are Power factor (pf) of the system, Reactive drop v_x of the transformer and resistive drop v_r which is controlled by copper loss of the transformer. Out of these v_r and v_x are contribute to the impedance of the transformer.

Chapter 4
Findings and Analysis

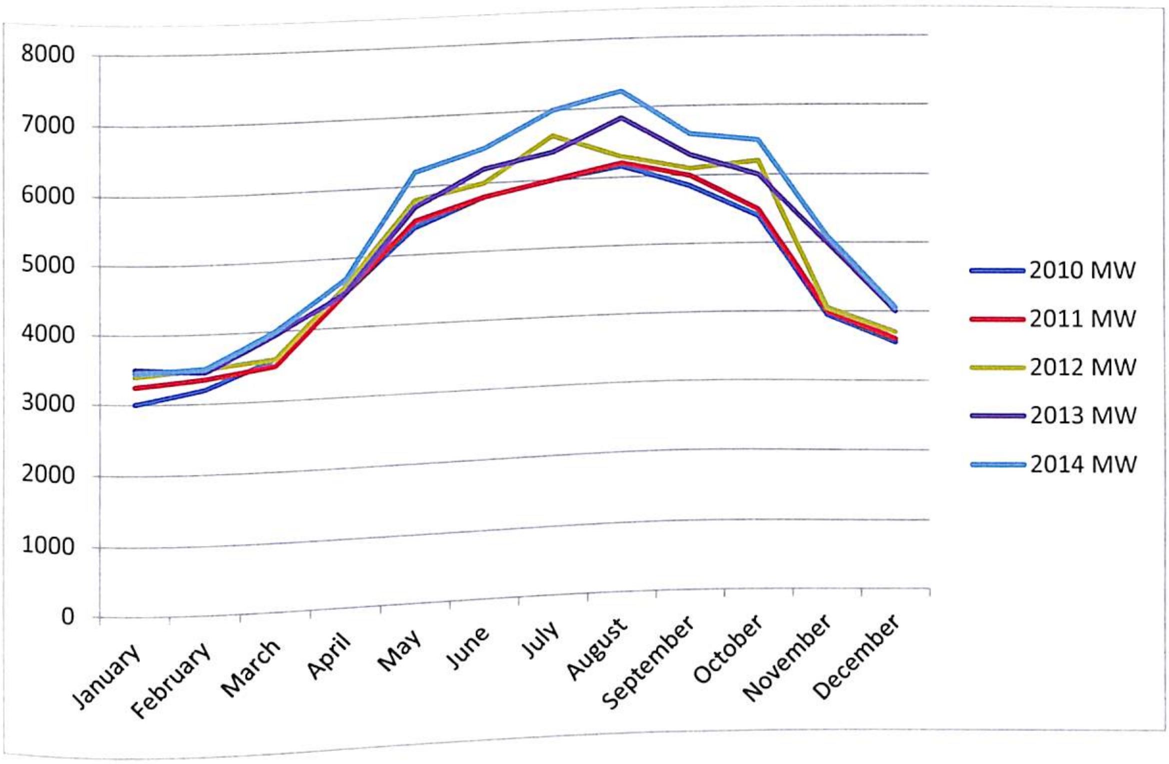
In this chapter the findings and analysis of my study are explained. Analysis of data is a process of inspecting, cleaning, transforming and modeling data with the goal of discovering useful information, suggesting conclusions and supporting decision-making. Data analysis has multiple facets and approaches, encompassing diverse techniques under a variety of names, in different business, science, and social science domains. Analysis refers to breaking a whole into its separate components for individual examination. Data analysis is a process for obtaining raw data and converting it into information useful for decision-making by users. Data is collected and analyzed to answer questions, test hypotheses or disprove theories.

4.1 Descriptive Statistics

Descriptive statistics are very important because if we simply present our raw data it would be hard to visualize what the data was showing, especially if there was a lot of it. Descriptive statistics therefore enables us to present the data in a more meaningful way, which allows simpler interpretation of the data. For example, the effect of power factor and load on the terminal voltage of transformer is shown in a graphical manner which is very simple to understand. My study I am interested in the overall performance of the system and also interested in the distribution or spread of the variables. Descriptive statistics allow us to do this. How to properly describe data through statistics and graphs is an important topic.

In general, descriptive statistics uses the data to provide descriptions of the population, either through numerical calculations or graphs or tables. Descriptive statistics is the term given to the analysis of data that helps describe, show or summarize data in a meaningful way such that, for example, patterns might emerge from the data. Descriptive statistics do not, however, allow us to make conclusions beyond the data we have analyzed or reach conclusions regarding any hypotheses we have made. They are a way to describe the data.

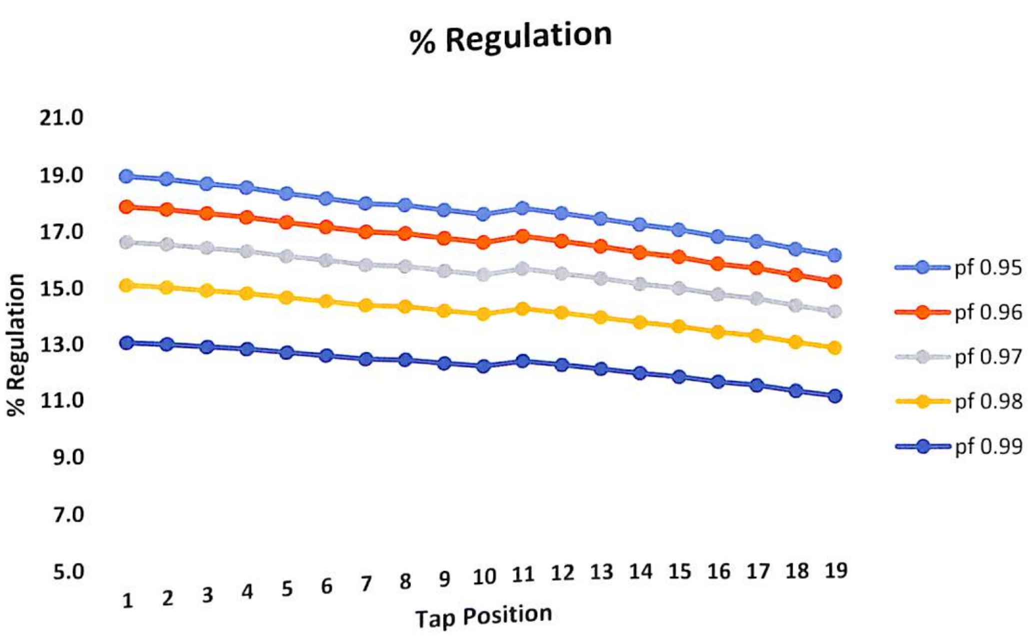
As per Table 4, the monthly load pattern of the utility for the past 5 years is analyzed in the Graph 1, below. This load details is taken to consider only the months when load is maximum and also those months when load is minimum so that I will be able to filter out remaining months as part of narrowing the problem area. Because, these months might have witnessed the operation range of the OLTC to their highest or lowest ranges in line with the load.



Picture 1, Analysis of monthly load pattern of the utility for the past 5 years

TAP	Regulation at PF....				
	0.95	0.96	0.97	0.98	0.99
1	18.90	17.82	16.56	15.04	12.98
2	18.73	17.65	16.40	14.88	12.84
3	18.48	17.42	16.18	14.67	12.65
4	18.25	17.19	15.96	14.47	12.47
5	17.95	16.91	15.69	14.22	12.24
6	17.68	16.65	15.45	13.99	12.03
7	17.40	16.38	15.19	13.75	11.81
8	17.25	16.23	15.05	13.62	11.69
9	16.98	15.97	14.80	13.38	11.48
10	16.74	15.74	14.58	13.18	11.30
11	16.89	15.89	14.73	13.31	11.42
12	16.65	15.66	14.50	13.11	11.23
13	16.41	15.43	14.29	12.91	11.05
14	16.17	15.19	14.06	12.70	10.86
15	15.97	15.01	13.89	12.53	10.71
16	15.71	14.75	13.65	12.31	10.51
17	15.54	14.59	13.50	12.17	10.38
18	15.27	14.34	13.25	11.94	10.18

Table 14, Transformer regulation at each tap position against various power factors (p.f.)



Picture 2, percentage regulation analysis

Rated parameters of Transformer as per specification which are tested and proven by tests at Factory						
	Rated Values of HV Winding			Rated Values of LV Winding		
Tap position	Volts in kV	Current in Amps	Capacity in MVA	Volts in kV	Current in Amps	Capacity in MVA
1	151.8	190	50	12	2405.7	50
2	149.6	193	50	12	2405.7	50
3	147.4	196	50	12	2405.7	50
4	145.2	199	50	12	2405.7	50
5	143	202	50	12	2405.7	50
6	140.8	205	50	12	2405.7	50
7	138.6	208	50	12	2405.7	50
8	136.4	212	50	12	2405.7	50
9	134.2	215	50	12	2405.7	50
10	132	219	50	12	2405.7	50
11	129.8	222	50	12	2405.7	50
12	127.6	226	50	12	2405.7	50
13	125.4	230	50	12	2405.7	50
14	123.2	234	50	12	2405.7	50
15	120.9	239	50	12	2405.7	50
16	118.8	243	50	12	2405.7	50
17	116.6	248	50	12	2405.7	50
18	114.4	252	50	12	2405.7	50
19	112.2	257	50	12	2405.7	50

Table 15, Analysis of Transformer rated values

Change in parameters of Transformer under load while operating at site when connected to a network							
	Terminal Values of HV Winding			Terminal Values of LV Winding			Loss of Capacity at site for LV Winding in MVA
HV Tap position	Volts in kV	Current in Amps	Capacity in MVA	Desired Volts in kV	Rated Current in Amps	Capacity in MVA	
1	151.8	190	50	11	2405.7	45.595	4.405
2	149.6	193	50	11	2405.7	45.595	4.405
3	147.4	196	50	11	2405.7	45.595	4.405
4	145.2	199	50	11	2405.7	45.595	4.405
5	143	202	50	11	2405.7	45.595	4.405
6	140.8	205	50	11	2405.7	45.595	4.405
7	138.6	208	50	11	2405.7	45.595	4.405
8	136.4	212	50	11	2405.7	45.595	4.405
9	134.2	215	50	11	2405.7	45.595	4.405
10	132	219	50	11	2405.7	45.595	4.405
11	129.8	222	50	11	2405.7	45.595	4.405
12	127.6	226	50	11	2405.7	45.595	4.405
13	125.4	230	50	11	2405.7	45.595	4.405
14	123.2	234	50	11	2405.7	45.595	4.405
15	120.9	239	50	11	2405.7	45.595	4.405
16	118.8	243	50	11	2405.7	45.595	4.405
17	116.6	248	50	11	2405.7	45.595	4.405
18	114.4	252	50	11	2405.7	45.595	4.405
19	112.2	257	50	11	2405.7	45.595	4.405

Table 16, Analysis of Transformer rated values Vs site values.

	Terminal Values of LV Winding			50MVA base Loss of Capacity at site for LV Winding in MVA	Required LV Current for 50MVA in Amps	Expected increase in LV Current for 50MVA in Amps	Percentage increase in LV Current for 50MVA in %
HV Tap position	Desired Volts in kV	Rated Current in Amps	Capacity in MVA				
1	11	2405.7	45.595	4.405	2638.1	232.4	9.66
2	11	2405.7	45.595	4.405	2638.1	232.4	9.66
3	11	2405.7	45.595	4.405	2638.1	232.4	9.66
4	11	2405.7	45.595	4.405	2638.1	232.4	9.66
5	11	2405.7	45.595	4.405	2638.1	232.4	9.66
6	11	2405.7	45.595	4.405	2638.1	232.4	9.66
7	11	2405.7	45.595	4.405	2638.1	232.4	9.66
8	11	2405.7	45.595	4.405	2638.1	232.4	9.66
9	11	2405.7	45.595	4.405	2638.1	232.4	9.66
10	11	2405.7	45.595	4.405	2638.1	232.4	9.66
11	11	2405.7	45.595	4.405	2638.1	232.4	9.66
12	11	2405.7	45.595	4.405	2638.1	232.4	9.66
13	11	2405.7	45.595	4.405	2638.1	232.4	9.66
14	11	2405.7	45.595	4.405	2638.1	232.4	9.66
15	11	2405.7	45.595	4.405	2638.1	232.4	9.66
16	11	2405.7	45.595	4.405	2638.1	232.4	9.66
17	11	2405.7	45.595	4.405	2638.1	232.4	9.66
18	11	2405.7	45.595	4.405	2638.1	232.4	9.66
19	11	2405.7	45.595	4.405	2638.1	232.4	9.66

Table 17, Analysis of Transformer LV site values Vs required current for 50MVA.

HV Tap position	HV Voltage at site in service in kV	Ratio	No load LV Volts in kV	Required (actual) LV terminal Volts at service load in kV	Expected Variation in LV Voltage due to load (regulation) in Volts
1	132	7.30	10.43	11	-565.2
2	132	7.19	10.58	11	-411.7
3	132	7.09	10.74	11	-253.7
4	132	6.98	10.90	11	-90.9
5	132	6.88	11.07	11	76.9
6	132	6.77	11.25	11	250.0
7	132	6.66	11.42	11	428.5
8	132	6.56	11.61	11	612.9
9	132	6.45	11.80	11	803.2
10	132	6.35	12	11	1000.0
11	132	6.24	12.20	11	1203.3
12	132	6.13	12.41	11	1413.7
13	132	6.03	12.63	11	1631.5
14	132	5.92	12.85	11	1857.1
15	132	5.81	13.10	11	2101.7
16	132	5.71	13.33	11	2333.3
17	132	5.61	13.58	11	2584.9
18	132	5.50	13.84	11	2846.1
19	132	5.39	14.11	11	3117.6

Table 18 Analysis of Transformer Voltage variation under load, base 50MVA.

Serial No.	Questions	Answer in descriptive manner
1.	Kind of transformer, e.g. separate winding transformer, auto-transformer	separate
2.	Single or three phase units	3 phase
3.	Operating Frequency	50Hz
4.	Dry type or oil-immersed type. If oil-immersed type, whether mineral oil or synthetic insulating liquid	Oil
5.	Indoor or outdoor type	Outdoor
6.	Type of cooling	ONAN/ONAF
7.	Rated power	50MVA
8.	Rated voltages (for each winding)	132/12kV
9.	Type and range of voltage variation	OLTC±5%
10.	Highest voltage for each winding	145/12kV
11.	Connection symbol	YNd1
12.	Impedance voltage HV/LV at 75^0C	31.5%
	Base of MVA for specified impedance	50MVA
13.	Design maximum ambient temperature	55C
14.	Design maximum average ambient temperature over one year	35C
15.	Whether unbalanced loading is anticipated and if so, the details.	No
16.	Details of intended loading beyond name plate rating	1.2p.u.(for 6 hours)
17.	Temperature rise limits at continuous duty at rated power	
	Windings rise	50K
	Top oil rise	45K
	Hot spot rise at relative thermal aging rate of '1'.	63K
18.	Maximum Values of load and no load losses, if specific values are required.	260kW 14kW
19.	Type termination connection at HV and LV, whether cables or GIS.	XLPE Cables
20.	Monthly load of the substation including OLTC tap and P.F.	Furnished
21.	Historical load data for the past 5 years.	Furnished
22.	Is the specification same for all substations? If no kindly mention the standard.	Same for all
23.	Share copy of the Factory type test report of one Transformer	Furnished
24.	State the Reactive power compensation method, its capacity per substation, HV side or LV side.	LV side. 6 x 5 MVAr capacitors

Table 19, filled in questionnaire, reproduced.

4.2 Correlation/Regression Analysis

Regression analysis involves identifying the relationship between a dependent variable and one or more independent variables. A model of the relationship is hypothesized, and estimates of the parameter values are used to develop an estimated regression equation. Various tests are then employed to determine if the model is satisfactory. If the model is deemed satisfactory, the estimated regression equation can be used to predict the value of the dependent variable given values for the independent variables.

In my study regression Analysis is not adopted.

Chapter 5.

Interpretation of Results

This chapter is dedicated to the interpretation of results as obtained in light of the analysis contained in the previous section. I have made comparisons of the results with the original set of assumptions.

From Table 4, it can be seen that the substation load is the lowest during the month of January 2014. Primary data Collection of data for the month of lowest load in order to investigate the position variation of tap changer while load is at its low. Data to be collected include tap position of OLTC, active power, reactive power, power factor (pf), substation number, transformer number. The collected data of hourly reading are shown for one day that is 26. 1. 2014 in Table 8 below. However, hourly reading for the full month of January 2014 is given in Annxure2 for reference. It can be inferred that the tap position is stable at position say 6.

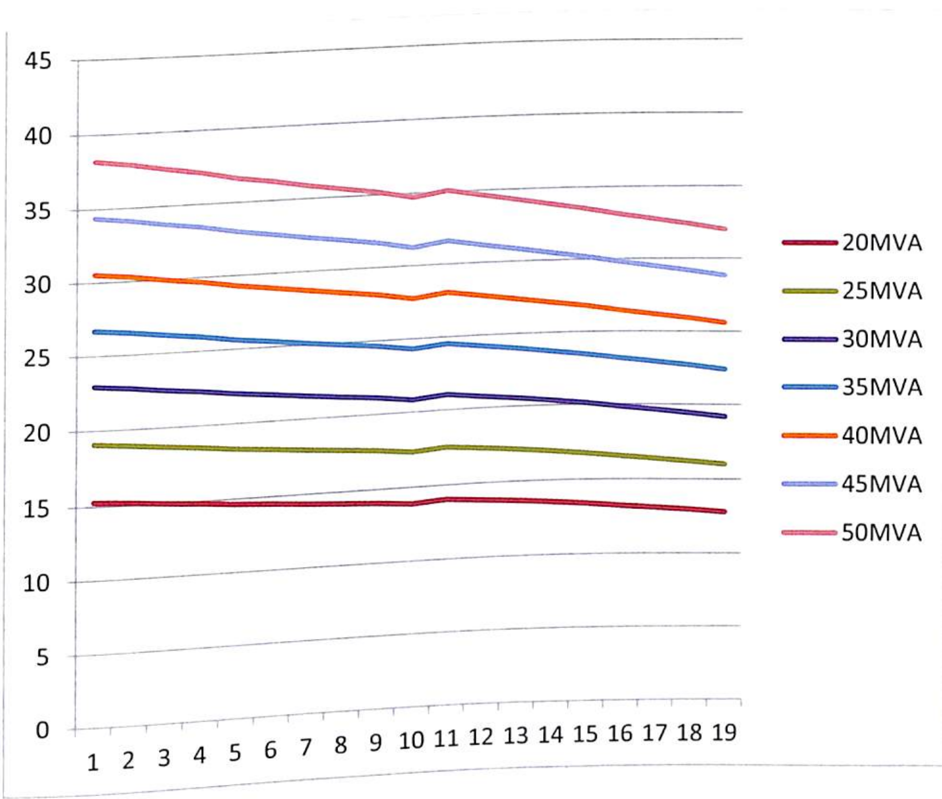
Table 5 showed the primary data collected to analyze the load at substations for sample collection and to limit the data to a presentable form. It showcases the substations where the load shows more than 50% of the firm capacity in the year 2014. Nine of such stations were shown in the table and remaining stations not included because of lower load at those stations and also have handy data. Because, as said in the preceding chapter the samples are homogeneous so the behavior of remaining parameters of the transformer would change proportionately with respect to load condition irrespective of the substation. Out of the overall substations considered as universe few of them are listed here as examples. These stations have the maximum load which is taken for study as the sample characteristic is homogeneous

From the Table4, it can be inferred that the Maximum load observed during the month of August for all past 5years. And, that from the Table 5, we can find that the substation numbered as '9' has the maximum load on 17 of August 2014. So, the primary data collected such as tap position of OLTC, substation number, transformer number, active power, reactive power, power factor of each transformer on hourly basis in order to track the tap variation at maximum load is narrowed to the day 17 of the month of August 2014 in order to optimize the handling of huge size of data and shown in Table 7, below. From the same OLTC position can be seen along with active power, reactive power and power factor for all the three power transformers at the so called substation '9'. Kindly note that due to huge size of table the hourly reading of the full month is given in Annexure 1 from which tap variations and other parameters can be inferred on an hourly basis. I have included only one day's primary data for August 17 2014 in Table 7. In this table hourly reading shows the tap variation from tap position '10' to tap position '9' and back along with other parameters.

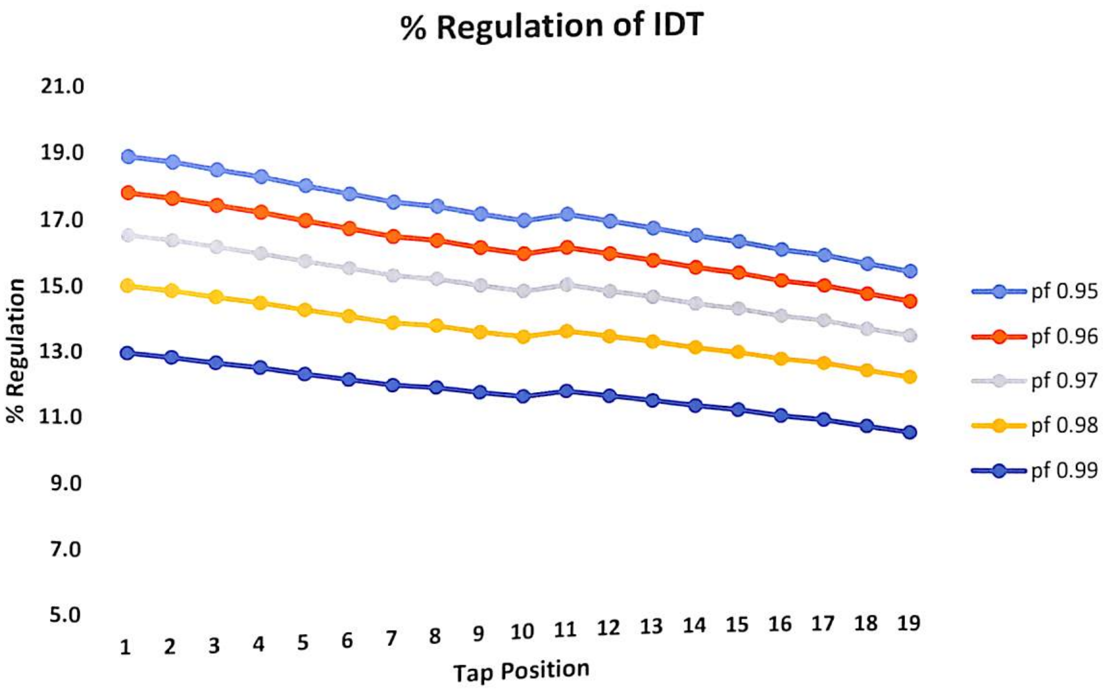
Calculated data of transformer after collecting the details are given in Table 10. The table shows calculated voltage at LV side at various tap positions while 132kV is available at the HV side of transformer. Impedance voltage data collected for all taps at 50MVA base. Impedance voltage for remaining taps has been calculated and the values are shown in table.

5.1. Interpretation of Results

From table 11, we can interpret the behavior of Impedance voltage with respect to the load on the transformer. As the load increases the impedance voltage increases and the voltage drop of the winding also increases. Thus regulation is high at high impedance transformers. From picture 3, below, it is very well interpret that as the load goes high impedance also goes high. One important interpretation is that while the tap ratio is high that is towards tap number 1 the impedance is high. From table 8 above it is evident that the Transformer operates at taps close to one when load is minimum this is because of the ratio of the transformer is 132/12kV implies that to keep the LV bus voltage of 11kV its tap shall be so adjusted. Thus a non optimum condition of tap position exists. This could have avoided had the transformer voltage ratio been selected as 132/12kV. Thus the corresponding position would have been around 10 instead of position 6. That is an increased impedance of about 3% is unnecessarily added to the already higher drop.



Picture 3, Interpretation of increase in Impedance voltage with respect to Load



Picture 4, Interpretation of Regulation with respect to the power Factor.

Similarly, from picture 4 above, we can very well interpret that the regulation is high when the power factor value goes down. Hence, it is important for the utility to keep the power factor of the network as far as possible close to one.

It can be interpreted from the tables 7 and 8 given above that the power factor of the network is kept well close to one throughout the year irrespective of load. The minimum power factor recorded is not during maximum load. In the direct interview it was clarified that they have capacitor banks 6 X 5 MVAr for catering to the Reactive power requirements and thus improving the power factor. This also clarified through the questionnaire.

It is simple to interpret from Tables 16 and 17 that the Capacity de-rating. Table 16 showed the actual specified capacity of 50MVA for both HV and LV windings. This capacity has already been proven by the manufacturer of the transformer before being delivered to the utility. The tests at factory have confirmed the design validation for its current carrying and temperature limiting parameters at 50MVA as given under item 18 of Table 20.

Whereas, Table 17 shows the parameters at actual operating conditions of the transformer in which as per the last column the rated capacity has de-rated by 4.405MVA. That means, the same transformer could only be able to deliver a much de-rated capacity of 45.595MVA instead of 50MVA to the LV busbar. This is a huge loss as far as the network reliability and sustainability are concerned.

Also, from Table 18 it is clear that the current of LV winding is 2405A at 50MVA 12kV. Whereas the current is about 9.66% higher than the rated LV current that is 2638A is required to flow through LV winding to transfer the same power of 50MVA from 132kV to 11kV bus bar. Higher current through LV windings will lead to higher losses in the LV windings means the LV winding will run at overload. The higher the losses inside the winding the higher the temperature rise of the winging, which exceeds the temperature rise limits specified and factory test values of the transformer. Because the transformer was designed, manufactured and tested at factory for the rated LV current of 2405A only not 2638A. This higher temperature causes premature death of insulation paper of the winding leading to its failure. This proves that the transformer will have an accelerated ageing.

Interpretation of tap position at actual operating condition of transformer can be interpreted from Tables 7 & 8 that the OLTC never moved below tap 6 that is never to 5, 4, 3, or 1 even though the power factor is 1 at occasions. From the tables 7 and 8 the OLTC position can be seen varying from tap position '10' to tap position '6' and back along with other parameters. This observation well interprets that the transformer will remain at tap 6 even when there is no load in order to match with the 11kV bus bar voltage. This observation proves that the transformer does not require the tapping range corresponds to +15% in full even at 12kV. It requires only +7.5% maximum even at 12kV of LV ratio. Also, this positive range is required only if the network power factor goes towards a leading power factor which does not exists due to the inductive reactance of transformer and that of the load pattern of the utility as mentioned under literature review their load is mainly inductive due to air conditioners. Whereas from the Tables 7 & 8 it can be inferred that full load of 50MVA has not been attained. Also in case of possible power factor poorer than 0.95 the ratio towards -15% would be required. So the -15% can remain as such and plus side it can be +7.5% for 132kV/12kV ratio.

5.2 Comparison of Results with Assumptions (Hypothesis)

My research questions and hypotheses are reproduced below for easy comparison of results with that of assumptions.

1. Is the transfer of specified Power 50MVA realized from High Voltage bus to Low Voltage bus that is from 132kV bus to 11kV bus if the voltage ratio of transformer is 132kV/12kV without overloading or without accelerated ageing rate of the transformer?
2. Is the existing tapping range of plus 132kV ±15% appropriate? Is the step voltage 132kV x 1.67% ±9 ideal?
3. Is the selection of Voltage ratio 132/12kV optimum for power transformers connected to a network of 132kV and 11kV respectively to transfer the rated power without overloading of windings and sacrificing its technical life?

Research Hypotheses:

Hypotheses (H): A 50MVA, 132/12kV Power Transformer can transfer only a de-rated 45.83MVA from 132kV bus to 11kV bus without accelerated ageing due to overloading. (When rated parameters of transformers mismatch with that of the connected network then the capacity of transformers either de-rate or the ageing accelerates due to overloading).

Null Hypothesis (H_0): A 50MVA, 132/12kV Power Transformer can transfer full capacity of 50MVA from 132kV bus to 11kV bus without accelerated ageing and overloading.

Comparison of results for my research question 1 can be taken from the interpretation above that it is simple to interpret from Tables 16 and 17 that the Capacity de-rating. Table 16 showed the actual specified capacity of 50MVA for both HV and LV windings. This capacity has already been proven by the manufacturer of the transformer before being delivered to the utility. The tests at factory have confirmed the design validation for its current carrying and temperature limiting parameters at 50MVA as given under item 18 of Table 20.

Whereas, Table 17 shows the parameters at actual operating conditions of the transformer in which as per the last column the rated capacity has de-rated by 4.405MVA. That means, the same transformer could only be able to deliver a much de-rated capacity of 45.595MVA instead of 50MVA to the LV busbar. This is a huge loss as far as the network reliability and sustainability are concerned.

The above comparison proves that the assumptions made under my research question 1 and its related hypothesis is correct.

Comparison of results for my research question 2 can be taken from the interpretation above that it is simple to compare from Tables 7 & 8. Interpretation of tap position at actual operating condition of transformer can be interpreted from Tables 7 & 8 that the OLTC never moved below tap 6 that is never to 5, 4, 3, or 1 even though the power factor is 1 at occasions. From the tables 7 and 8 the OLTC position can be seen varying from tap position '10' to tap position '6' and back along with other parameters. This observation well interprets that the transformer will remain at tap 6 even when there is no load in order to match with the 11kV bus bar voltage. This observation proves that the transformer does not require the tapping range corresponds to +15% in full even at 12kV. It requires only +7.5% maximum even at 12kV of LV ratio. Also, this positive range is required only if the network power factor goes towards a leading power factor which does not exists due to the inductive reactance of transformer and that of the load pattern of the utility as mentioned under literature review their load is mainly inductive due to air conditioners. Whereas from the Tables 7 & 8 it can be inferred that full load of 50MVA has not been attained. Also in case of possible power factor poorer than 0.95 the ratio towards -15% would be required. So the -15% can remain as such and plus side it can be +7.5% for 132kV/12kV ratio.

The above comparison proves that the assumptions made under my research question 2 and its related hypothesis is correct.

Comparison of results for my research question 3 can be taken from the interpretation above that from Table 18 it is clear that the current of LV winding is 2405A at 50MVA 12kV. Whereas the current is about 9.66% higher than the rated LV current that is 2638A is required to flow through LV winding to transfer the same power of 50MVA from 132kV to 11kV bus bar. Higher current through LV windings will lead to higher losses in the LV windings means the LV winding will run at overload. The higher the losses inside the winding the higher the temperature rise of the winging, which exceeds the temperature rise limits specified and factory test values of the transformer. Because, the transformer was designed, manufactured and tested at factory for the rated LV current of 2405A only not 2638A. This higher temperature causes premature death of insulation paper of the winding leading to its failure. This proves that the transformer will have an accelerated ageing.

The above comparison proves that the assumptions made under my research question 3 and its related hypothesis is correct.

Hypothesis testing

Testing hypotheses is part of the statistical inference. In order to formulate such a test the null hypothesis proved to be not true. The null hypothesis denoted H_0, against the alternative hypothesis, denoted H_1. These two competing claims / hypotheses are not however treated on an equal basis, special consideration is given to the null hypothesis. The study has been carried out in an attempt to disprove or reject the null H_0 hypothesis. Thus we give that one priority so it cannot be rejected unless the evidence against it is sufficiently strong.

Accordingly we have to prove that the null Hypothesis (H_0), A 50MVA, 132/12kV Power Transformer can transfer full capacity of 50MVA from 132kV bus to 11kV bus without accelerated ageing and overloading.

The final conclusion once the test has been carried out is always given in terms of the null hypothesis. We either reject H0 in favour of H1 or do not reject H0 we never conclude reject H1 or even accept H1. If we conclude do not reject H0, this does not necessarily mean that the null hypothesis is true. It only suggests that there is not sufficient evidence against H0 in favour of H1. Rejecting the null hypothesis then, suggests that the alternative hypothesis may be true. If one of the two hypotheses is simpler we give it priority so that a more complicated theory is not adopted unless there is sufficient evidence against the simpler one.

The significance level: The significance level of a statistical hypothesis test is a fixed probability of wrongly rejecting the null hypothesis H0, if it is in fact true. It is the probability of a type I error and is set by the investigator in relation to the consequences of such an error. That is, we want to make the significance level as small as possible in order to protect the null hypothesis and to prevent, as far as possible, the investigator from inadvertently making false claims.

For my study, the significance level is chosen as 0.05 (or equivalently to 5%) as stated under the chapter of introduction to this report.

Accordingly, comparison of results for my research question 1 can be taken from the interpretation above that it is simple to interpret from Tables 16 and 17 that the Capacity de-rating. Table 16 showed the actual specified capacity of 50MVA for both HV and LV windings. This capacity has already been proven by the manufacturer of the transformer before being delivered to the utility. The tests at factory have confirmed the design validation for its current carrying and temperature limiting parameters at 50MVA as given under item 18 of Table 20.

Whereas, Table 17 shows the parameters at actual operating conditions of the transformer in which as per the last column the rated capacity has de-rated by 4.405MVA. That means, the same transformer could only be able to deliver a much de-rated capacity of 45.595MVA instead of 50MVA to the LV busbar. This is a huge loss as far as the network reliability and sustainability are concerned.

The above comparison proves that the loss of capacity is 4.405MVA that is 8.81% of the rated 50MVA which is more than 5% of what is considered as the significance level. Hence, it is proved that the assumptions made under the null hypothesis is, A 50MVA, 132/12kV Power Transformer can transfer full capacity of 50MVA from 132kV bus to 11kV bus without accelerated ageing and overloading, is not true.

Thus, I decided accepting the alternate hypothesis which is, a 50MVA, 132/12kV Power Transformer can transfer only a de-rated 45.83MVA from 132kV bus to 11kV bus without accelerated ageing and overloading. (When rated parameters of transformers mismatch with that of the connected network then the capacity of transformers either de-rate or the ageing accelerates due to overloading).

Chapter 6

Conclusion and Scope for Future Work

In this chapter, conclusions of my study and my proposals for future scope of work are stated based on the study conducted as explained in the preceding chapters.

Proposal 1 is that the voltage ratio of the 50MVA power transformer for the utility shall be 132/11kV instead of 132/12kV in order to transfer the rated power of 50MVA from 132kV bus bar to 11kV busbar. Otherwise, that if the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

Proposal 2 is that the tapping range of the 50MVA power transformers of the utility shall be 132kV x +5% and 132kV x –15% instead of ±15%.

From table 11, I have interpreted and proved that the behavior of Impedance voltage with respect to the load on the transformer. As the load increases the impedance voltage increases and the voltage drop of the winding also increases. Thus regulation is high at high impedance transformers. From picture 3 it is very well interpret that as the load goes high impedance also goes high. One important interpretation is that while the tap ratio is high that is towards tap number 1 the impedance is high. From table 8 above it is evident that the Transformer operates at taps close to one when load is minimum this is because of the ratio of the transformer is 132/12kV implies that to keep the LV bus voltage of 11kV its tap shall be so adjusted. Thus a non-optimum condition of tap position exists. This could have avoided had the transformer voltage ratio been selected as 132/12kV. Thus the corresponding position would have been around 10 instead of position 6. That is an increased impedance of about 3% is unnecessarily added to the already higher drop. This high impedance will cause additional stray losses too which is again attracting more losses of power means loss of precious energy.

The above explained condition of existing undesirable excess 3% of impedance and related high and excess stray losses and solutions for mitigating it. My study reveals that if the transformer ratio is 132/11kV then it would work in the tapping range of around nominal tap under light load conditions thus eliminate possible excess impedance due to undesirable tap position.

Proposal 3 is that the tapping step voltage of the 50MVA power transformers of the utility shall be 132kV x 1.25 x (+ 4 – 12) that is 17 taps instead of 132x 1.67 ± 9 hat is 19 taps. This is to help the utility for much smoother voltage control of the 11kV bus bars helping their strategy to supply quality power to their customers. Also, this will help to optimize the manufacturer for the selection of insulations of tap winding.

Proposal 4 is that the utility shall take action not to load their existing power transformer to its rated full capacity of 50MVA. If the ratio of 132/12kV is still used then the rated capacity will de-rate to 45.595MVA instead of 50MVA for the LV winding which will limit the utility from loading their transformers continuously for the rated capacity of 50MVA. This means that the utility is losing precious 4.405MVA capacity per transformer throughout the transformer's life time.

My proposal for the rated parameters of new transformer is given in table 21 below, which may be done as amendment to the existing specification.

Serial no.	Parameter	Proposed Value
1	Rated HV Voltage	132kV (keep as existing)
2	Rated LV Voltage	11kV (changed from 12kV)
3	Rated Power	50MVA (60MVA for 6 hours)
4	Tapping range for HV winding	+5% - 15% of 132kV (instead of ±15%)
6	Tapping steps for HV winding	1.25 x (+ 4 – 12) instead of 1.67 x ± 9. Total 17 Taps instead of 19.
7	Impedance voltage	Minimum 31.5% at maximum rated current tap that is at tap 17
8	Connection symbol	YNd1
9	Number of Transformers per 132kV substation	3
10	Impedance Voltage	Minimum 31.5% at tap 17 and 50MVA base

Table 21, Proposed new parameters of transformer inferred from my study. Kindly refer to Table 13 for existing parameters.

Scope for Future Work

The utility may review their existing specification for the 132/12 50MVA Power transformers in light of the findings prosed based on this study report upon they getting convinced of the proposals.

The specification of the transformer can be so revised as to help the utility to use the power transformer as contingency spare in case of emergencies. If required, the tapping step voltage can remain as 132kV x 1.67 for +5% -15%. Thus there will be total of 13 taps only.

The utility may study alternate means to reduce the high impedance voltage of the transformers. Options like 2 transformers out of 3 in service while the third one maintaining as stand by connecting it to the network but keeping its LV open etc. may open room for further research studies.

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Annexure 1, Hourly load pattern of the transformer in August 2014

Date/Time	Tap position of Transformers 1, 2 and 3 at station 9			Load		P.F
	1	2	3	Active Power (P)	Reactive Power (Q)	
15-Aug-14 00:08:27	10	10	10	64.35	21.20	0.96
15-Aug-14 01:22:58	9	9	9	62.23	19.58	0.96
15-Aug-14 02:03:00	9	9	9	61.48	19.15	0.96
15-Aug-14 03:12:05	9	9	9	60.11	18.79	0.96
15-Aug-14 04:03:00	9	9	9	58.84	18.35	0.96
15-Aug-14 05:03:22	9	9	9	57.65	18.08	0.96
15-Aug-14 06:34:54	9	9	9	55.99	17.53	0.96
15-Aug-14 07:06:36	9	9	9	59.96	18.18	0.96
15-Aug-14 08:07:39	9	9	9	65.45	20.35	0.96
15-Aug-14 09:05:21	9	9	9	70.89	21.25	0.96
15-Aug-14 10:09:24	9	9	9	73.11	22.65	0.96
15-Aug-14 11:37:47	9	9	9	75.42	23.45	0.96
15-Aug-14 12:03:00	9	9	9	75.85	23.60	0.96
15-Aug-14 13:58:45	10	10	10	76.58	25.45	0.96
15-Aug-14 14:48:33	10	10	10	77.37	25.88	0.95
15-Aug-14 15:18:30	10	10	10	76.04	25.67	0.95
15-Aug-14 16:15:31	10	10	10	75.31	25.58	0.95
15-Aug-14 17:17:25	10	10	10	73.97	25.27	0.95
15-Aug-14 18:03:13	10	10	10	71.76	24.15	0.95
15-Aug-14 19:03:00	10	10	10	72.65	24.25	0.95
15-Aug-14 20:04:39	10	10	10	72.55	24.07	0.95
15-Aug-14 21:03:47	10	10	10	71.05	24.13	0.95
15-Aug-14 22:03:00	10	10	10	69.71	23.68	0.95
15-Aug-14 23:03:00	10	10	10	68.14	23.00	0.95
16-Aug-14 00:03:50	10	10	10	65.83	21.85	0.95
16-Aug-14 01:04:36	10	10	10	63.98	21.07	0.96
16-Aug-14 02:07:47	9	9	9	61.55	19.08	0.96
16-Aug-14 03:11:02	9	9	9	60.31	19.07	0.96
16-Aug-14 04:06:25	9	9	9	58.32	18.23	0.96
16-Aug-14 05:24:05	9	9	9	57.74	18.18	0.96
16-Aug-14 06:05:00	9	9	9	56.90	17.71	0.96
16-Aug-14 07:09:47	9	9	9	61.29	19.12	0.96
16-Aug-14 08:15:11	9	9	9	68.20	21.15	0.96
16-Aug-14 09:22:56	10	10	10	74.99	24.39	0.96
16-Aug-14 10:04:49	10	10	10	78.62	25.90	0.95
16-Aug-14 11:13:17	10	10	10	80.06	26.06	0.95

16-Aug-14 12:06:13	10	10	10	81.99	26.39	0.95
16-Aug-14 13:16:06	10	10	10	82.95	26.91	0.95
16-Aug-14 14:17:19	10	10	10	83.00	27.16	0.95
16-Aug-14 15:06:23	10	10	10	82.75	26.90	0.95
16-Aug-14 16:03:00	10	10	10	80.70	26.36	0.95
16-Aug-14 17:19:22	10	10	10	78.98	26.17	0.95
16-Aug-14 18:10:43	10	10	10	77.37	25.89	0.95
16-Aug-14 19:13:30	10	10	10	78.03	25.99	0.95
16-Aug-14 20:24:46	10	10	10	78.09	25.86	0.95
16-Aug-14 21:17:44	10	10	10	76.21	24.88	0.95
16-Aug-14 22:12:33	10	10	10	72.89	23.81	0.95
16-Aug-14 23:17:35	10	10	10	69.44	21.91	0.95
17-Aug-14 00:09:03	10	10	10	67.44	21.48	0.96
17-Aug-14 01:07:05	9	9	9	65.23	19.53	0.96
17-Aug-14 02:06:10	9	9	9	64.17	19.26	0.96
17-Aug-14 03:05:43	9	9	9	62.41	18.83	0.96
17-Aug-14 04:03:09	9	9	9	61.24	18.44	0.96
17-Aug-14 05:06:31	9	9	9	60.27	18.47	0.96
17-Aug-14 06:10:16	9	9	9	59.94	18.39	0.96
17-Aug-14 07:13:14	9	9	9	65.54	19.93	0.96
17-Aug-14 08:07:35	10	10	10	72.66	24.07	0.96
17-Aug-14 09:06:28	10	10	10	79.03	25.12	0.95
17-Aug-14 10:11:55	10	10	10	82.79	25.96	0.96
17-Aug-14 11:03:00	10	10	10	85.98	26.41	0.96
17-Aug-14 12:09:21	10	10	10	87.41	27.35	0.96
17-Aug-14 13:04:21	10	10	10	86.02	27.71	0.95
17-Aug-14 14:07:55	10	10	10	85.80	33.54	0.97
17-Aug-14 15:48:34	10	10	10	84.23	26.07	0.96
17-Aug-14 16:24:50	10	10	10	84.64	26.06	0.96
17-Aug-14 17:08:52	10	10	10	81.32	25.52	0.95
17-Aug-14 18:22:02	10	10	10	77.80	25.56	0.95
17-Aug-14 19:11:55	10	10	10	76.81	25.45	0.95
17-Aug-14 20:13:09	10	10	10	74.05	24.00	0.95
17-Aug-14 21:03:00	10	10	10	71.79	22.88	0.95
17-Aug-14 22:03:00	10	10	10	67.92	21.91	0.95
17-Aug-14 23:05:33	10	10	10	64.80	20.65	0.95
18-Aug-14 00:06:10	10	10	10	63.51	20.99	0.96
18-Aug-14 01:05:55	10	10	10	64.14	21.23	0.95
18-Aug-14 02:13:30	10	10	10	62.74	20.80	0.95
18-Aug-14 03:03:00	10	10	10	61.35	20.31	0.96
18-Aug-14 04:13:22	9	9	9	59.28	18.57	0.96
18-Aug-14 05:04:36	9	9	9	58.69	18.37	0.96
18-Aug-14 06:14:03	9	9	9	58.65	18.54	0.96
18-Aug-14 07:08:24	9	9	9	62.51	19.69	0.96

18-Aug-14 08:03:36	10	10	10	68.04	22.73	0.96
18-Aug-14 09:03:00	10	10	10	73.89	24.95	0.95
18-Aug-14 10:03:00	10	10	10	76.82	25.34	0.95
18-Aug-14 11:03:00	10	10	10	80.13	25.87	0.95
18-Aug-14 12:12:55	10	10	10	82.04	26.25	0.95
18-Aug-14 13:10:36	10	10	10	83.64	27.19	0.95
18-Aug-14 14:12:45	10	10	10	83.92	26.62	0.97
18-Aug-14 15:19:19	10	10	10	83.05	26.50	0.95
18-Aug-14 16:04:21	10	10	10	81.46	26.51	0.95
18-Aug-14 18:02:32	10	10	10	79.07	26.43	0.95
18-Aug-14 18:03:00	10	10	10	78.80	26.23	0.95
18-Aug-14 19:43:21	10	10	10	80.32	26.58	0.95
18-Aug-14 20:03:00	10	10	10	80.13	26.55	0.95
18-Aug-14 21:04:45	10	10	10	78.50	26.25	0.95
18-Aug-14 22:17:34	10	10	10	75.11	25.21	0.95
18-Aug-14 23:03:48	10	10	10	71.49	24.14	0.95
19-Aug-14 00:03:00	10	10	10	68.64	23.10	0.95
19-Aug-14 01:12:21	9	9	9	64.77	20.15	0.96
19-Aug-14 02:27:11	9	9	9	63.08	20.03	0.96
19-Aug-14 03:11:05	9	9	9	60.50	18.77	0.96
19-Aug-14 04:03:36	9	9	9	59.20	18.33	0.98
19-Aug-14 05:03:02	9	9	9	58.65	18.45	0.96
19-Aug-14 06:07:43	9	9	9	58.43	18.29	0.96
19-Aug-14 07:10:21	9	9	9	61.96	20.04	0.96
19-Aug-14 08:33:14	10	10	10	67.18	22.89	0.95
19-Aug-14 09:06:22	10	10	10	71.47	23.98	0.95
19-Aug-14 10:04:34	10	10	10	75.55	25.00	0.95
19-Aug-14 11:03:00	10	10	10	78.01	25.93	0.95
19-Aug-14 12:10:33	10	10	10	78.33	26.13	0.95
19-Aug-14 13:03:00	10	10	10	78.97	26.44	0.95
19-Aug-14 14:03:00	10	10	10	78.71	26.08	0.95
19-Aug-14 15:03:42	10	10	10	77.96	25.74	0.95
19-Aug-14 16:05:03	10	10	10	77.02	25.62	0.95
19-Aug-14 17:23:20	10	10	10	75.09	25.13	0.95
19-Aug-14 18:03:39	10	10	10	73.72	24.64	0.95
19-Aug-14 19:05:27	10	10	10	74.93	24.85	0.95
19-Aug-14 20:04:36	10	10	10	74.30	24.50	0.95
19-Aug-14 21:03:39	10	10	10	72.04	23.97	0.95
19-Aug-14 22:04:20	10	10	10	70.71	23.39	0.95
19-Aug-14 23:17:38	10	10	10	68.33	22.55	0.95
20-Aug-14 00:48:52	10	10	10	65.61	21.76	0.95
20-Aug-14 01:03:00	10	10	10	63.66	21.43	0.95
20-Aug-14 02:03:00	10	10	10	61.87	20.28	0.96
20-Aug-14 03:08:12	8	8	8	58.66	16.96	0.96

20-Aug-14 04:07:07	8	8	8	56.86	16.31	0.96
20-Aug-14 05:04:31	8	8	8	56.60	16.46	0.96
20-Aug-14 06:06:30	8	8	8	56.39	16.42	0.96
20-Aug-14 07:03:00	8	8	8	60.04	17.01	0.96
20-Aug-14 08:08:42	9	9	9	64.70	20.79	0.96
20-Aug-14 09:03:00	9	9	9	69.82	22.08	0.96
20-Aug-14 10:04:34	9	9	9	73.28	22.78	0.96
20-Aug-14 11:21:05	10	10	10	76.16	25.47	0.96
20-Aug-14 12:03:00	10	10	10	77.26	25.72	0.95
20-Aug-14 13:03:04	10	10	10	78.41	25.69	0.95
20-Aug-14 14:05:53	10	10	10	78.64	25.86	0.95
20-Aug-14 15:09:58	10	10	10	77.86	26.29	0.95
20-Aug-14 16:03:00	10	10	10	76.95	25.63	0.95
20-Aug-14 17:03:00	10	10	10	74.88	25.23	0.95
20-Aug-14 18:05:39	10	10	10	73.82	25.20	0.95
20-Aug-14 19:03:00	10	10	10	75.13	25.32	0.95
20-Aug-14 20:03:00	10	10	10	74.58	25.19	0.95
20-Aug-14 21:03:00	10	10	10	72.50	24.23	0.95
20-Aug-14 22:03:00	10	10	10	70.72	23.85	0.95
20-Aug-14 23:05:42	10	10	10	68.37	22.89	0.95
21-Aug-14 00:03:00	10	10	10	65.87	22.12	0.95
21-Aug-14 01:15:16	10	10	10	63.93	20.68	0.95
21-Aug-14 02:23:58	10	10	10	61.02	20.04	0.95
21-Aug-14 03:03:00	10	10	10	58.55	19.59	0.96
21-Aug-14 04:04:54	9	9	9	57.75	17.74	0.96
21-Aug-14 05:03:00	9	9	9	56.83	17.74	0.96
21-Aug-14 06:04:16	9	9	9	56.10	17.31	0.96
21-Aug-14 07:10:45	9	9	9	60.55	19.02	0.96
21-Aug-14 08:12:36	9	9	9	65.92	21.22	0.96
21-Aug-14 09:03:00	9	9	9	71.08	22.70	0.95
21-Aug-14 10:46:02	10	10	10	74.89	25.23	0.95
21-Aug-14 11:04:23	10	10	10	76.77	25.70	0.95
21-Aug-14 12:03:00	10	10	10	78.45	26.24	0.95
21-Aug-14 13:03:00	10	10	10	79.16	26.45	0.95
21-Aug-14 14:03:57	10	10	10	79.63	26.08	0.95
21-Aug-14 15:22:56	10	10	10	79.16	26.11	0.95
21-Aug-14 16:03:09	10	10	10	77.99	26.08	0.95
21-Aug-14 17:13:06	10	10	10	76.85	26.09	0.95
21-Aug-14 18:04:03	10	10	10	74.83	24.87	0.95
21-Aug-14 19:03:00	10	10	10	75.80	25.12	0.95
21-Aug-14 20:44:41	10	10	10	75.05	24.93	0.95
21-Aug-14 21:38:32	10	10	10	72.74	24.36	0.95
21-Aug-14 22:09:42	10	10	10	70.77	23.87	0.95
21-Aug-14 23:07:19	10	10	10	69.09	23.16	0.95

22-Aug-14 00:24:25	10	10	10	66.53	22.90	0.95
22-Aug-14 01:22:08	10	10	10	63.73	21.08	0.95
22-Aug-14 02:17:24	10	10	10	62.16	20.42	0.95
22-Aug-14 03:42:24	10	10	10	60.70	20.60	0.95
22-Aug-14 04:03:00	10	10	10	60.24	20.08	0.95
22-Aug-14 05:39:32	10	10	10	59.65	20.12	0.95
22-Aug-14 06:10:21	10	10	10	58.85	19.57	0.95
22-Aug-14 07:03:00	10	10	10	63.06	20.94	0.95
22-Aug-14 08:32:44	10	10	10	67.71	22.87	0.95
22-Aug-14 09:03:37	10	10	10	71.20	23.75	0.95
22-Aug-14 10:03:00	10	10	10	73.45	24.60	0.95
22-Aug-14 11:03:00	10	10	10	75.42	24.97	0.95
22-Aug-14 12:06:14	10	10	10	76.51	25.17	0.95
22-Aug-14 13:04:39	10	10	10	77.41	25.96	0.95
22-Aug-14 14:03:00	10	10	10	77.41	26.04	0.95
22-Aug-14 15:24:52	10	10	10	76.11	25.95	0.95
22-Aug-14 16:23:57	10	10	10	75.21	25.61	0.95
22-Aug-14 17:03:00	10	10	10	72.99	25.11	0.95
22-Aug-14 18:03:00	10	10	10	72.86	24.77	0.95
22-Aug-14 19:12:51	10	10	10	73.82	24.91	0.95
22-Aug-14 20:51:40	10	10	10	72.74	24.56	0.95
22-Aug-14 21:04:31	10	10	10	71.52	24.22	0.95
22-Aug-14 22:03:00	10	10	10	69.69	23.42	0.95
22-Aug-14 23:20:35	10	10	10	68.30	22.93	0.95
23-Aug-14 00:03:54	10	10	10	66.98	22.35	0.95
23-Aug-14 01:19:28	10	10	10	65.35	21.92	0.95
23-Aug-14 02:03:00	10	10	10	64.05	21.62	0.95
23-Aug-14 03:03:00	10	10	10	61.88	20.33	0.96
23-Aug-14 04:34:30	9	9	9	58.95	18.32	0.96
23-Aug-14 05:19:31	9	9	9	57.71	18.33	0.96
23-Aug-14 06:09:29	9	9	9	57.48	18.10	0.96
23-Aug-14 07:05:36	9	9	9	62.43	19.07	0.96
23-Aug-14 08:57:21	10	10	10	69.10	23.17	0.96
23-Aug-14 09:06:33	10	10	10	74.84	24.83	0.95
23-Aug-14 10:08:13	10	10	10	78.83	25.46	0.95
23-Aug-14 11:03:00	10	10	10	81.79	26.06	0.95
23-Aug-14 12:03:00	10	10	10	84.29	26.65	0.95
23-Aug-14 13:17:53	10	10	10	86.34	26.82	0.96
23-Aug-14 14:21:47	10	10	10	86.24	27.07	0.96
23-Aug-14 15:10:31	10	10	10	85.06	27.21	0.95
23-Aug-14 16:04:31	10	10	10	84.27	27.29	0.95
23-Aug-14 17:03:00	10	10	10	82.44	26.86	0.95
23-Aug-14 18:16:35	10	10	10	79.07	26.11	0.95
23-Aug-14 19:03:00	10	10	10	79.18	25.74	0.95

23-Aug-14 20:05:04	10	10	10	77.69	25.45	0.95
23-Aug-14 21:20:12	10	10	10	75.57	25.09	0.95
23-Aug-14 22:09:14	10	10	10	72.18	24.50	0.95
23-Aug-14 23:48:52	10	10	10	68.34	23.42	0.95
24-Aug-14 00:18:29	10	10	10	65.30	21.99	0.95
24-Aug-14 01:03:00	10	10	10	63.28	21.12	0.96
24-Aug-14 02:18:02	9	9	9	60.96	19.08	0.96
24-Aug-14 03:18:24	9	9	9	60.12	19.00	0.96
24-Aug-14 04:03:00	9	9	9	58.55	18.55	0.96
24-Aug-14 05:05:41	9	9	9	58.02	18.67	0.96
24-Aug-14 06:11:48	9	9	9	57.32	18.28	0.95
24-Aug-14 07:06:03	9	9	9	61.62	19.06	0.96
24-Aug-14 08:03:00	9	9	9	66.52	20.99	0.96
24-Aug-14 09:10:20	10	10	10	72.04	24.74	0.95
24-Aug-14 10:03:45	10	10	10	75.42	25.33	0.95
24-Aug-14 11:03:00	10	10	10	77.73	25.58	0.95
24-Aug-14 12:04:57	10	10	10	79.45	26.00	0.95
24-Aug-14 13:19:53	10	10	10	79.46	26.07	0.95
24-Aug-14 14:25:27	10	10	10	79.44	26.27	0.95
24-Aug-14 15:03:00	10	10	10	78.72	26.30	0.95
24-Aug-14 16:20:08	10	10	10	77.08	25.90	0.95
24-Aug-14 17:09:22	10	10	10	75.35	25.66	0.95
24-Aug-14 18:22:01	10	10	10	73.59	25.09	0.95
24-Aug-14 19:04:54	10	10	10	75.09	24.92	0.95
24-Aug-14 20:19:53	10	10	10	74.21	24.60	0.95
24-Aug-14 21:08:11	10	10	10	72.60	24.36	0.95
24-Aug-14 22:07:33	10	10	10	70.67	23.47	0.95
24-Aug-14 23:03:00	10	10	10	68.23	22.63	0.95
25-Aug-14 00:03:00	10	10	10	64.58	21.97	0.95
25-Aug-14 01:03:47	10	10	10	61.89	20.36	0.95
25-Aug-14 02:03:00	10	10	10	59.84	20.03	0.96
25-Aug-14 03:03:00	9	9	9	58.31	18.08	0.96
25-Aug-14 04:04:14	9	9	9	55.66	17.54	0.96
25-Aug-14 05:03:58	9	9	9	55.40	17.58	0.96
25-Aug-14 06:14:10	9	9	9	55.25	17.27	0.96
25-Aug-14 07:03:10	9	9	9	58.26	18.12	0.96
25-Aug-14 08:09:57	9	9	9	62.90	19.88	0.96
25-Aug-14 09:06:21	9	9	9	68.16	20.87	0.96
25-Aug-14 10:23:12	10	10	10	71.27	23.25	0.96
25-Aug-14 11:03:00	10	10	10	73.19	23.80	0.95
25-Aug-14 12:03:00	10	10	10	74.33	23.89	0.95
25-Aug-14 13:03:00	10	10	10	75.29	24.21	0.95
25-Aug-14 14:03:00	10	10	10	75.60	24.56	0.95
25-Aug-14 15:09:23	10	10	10	75.36	24.56	0.95

Annexure 2, Hourly load pattern of the transformer in January 2014

Date/Time	Tap position of transformers 1, 2 and 3			Load		P.F
	1	2	3	Active Power (P)	Reactive Power (Q)	
26-Jan-15 00:11:29	6	6	6	22.57	0.00	0.96
26-Jan-15 01:14:19	6	6	6	21.32	6.09	0.96
26-Jan-15 02:39:03	6	6	6	20.81	6.04	0.95
26-Jan-15 03:07:09	6	6	6	20.37	6.09	0.95
26-Jan-15 04:21:47	6	6	6	20.07	5.92	0.95
26-Jan-15 05:13:09	6	6	6	20.73	6.05	0.96
26-Jan-15 06:13:02	6	6	6	23.00	6.47	0.96
26-Jan-15 07:07:57	6	6	6	25.71	1.41	0.97
26-Jan-15 08:19:10	6	6	6	25.94	1.60	1
26-Jan-15 09:09:37	6	6	6	26.11	1.86	0.99
26-Jan-15 10:09:21	6	6	6	27.01	2.50	0.94
26-Jan-15 11:07:58	6	6	6	27.23	2.66	0.94
26-Jan-15 12:13:39	6	6	6	26.93	2.98	0.99
26-Jan-15 13:35:31	6	6	6	26.65	2.68	0.99
26-Jan-15 14:46:36	6	6	6	25.76	2.34	0.99
26-Jan-15 15:16:04	6	6	6	26.35	2.61	0.99
26-Jan-15 16:03:00	6	6	6	26.78	2.68	0.99
26-Jan-15 17:04:39	6	6	6	27.26	2.74	0.99
26-Jan-15 18:14:26	6	6	6	30.69	3.16	0.99
26-Jan-15 19:03:00	6	6	6	31.80	3.73	0.99
26-Jan-15 20:50:53	6	6	6	30.89	3.22	0.99
26-Jan-15 21:03:58	6	6	6	29.34	2.82	0.99
26-Jan-15 22:05:49	6	6	6	27.13	2.43	0.99
26-Jan-15 23:03:00	6	6	6	24.89	0.00	0.96
27-Jan-15 00:03:45	6	6	6	23.22	6.39	0.96
27-Jan-15 01:53:28	6	6	6	21.31	6.01	0.96
27-Jan-15 02:03:00	6	6	6	20.83	5.97	0.95
27-Jan-15 03:25:36	6	6	6	20.46	5.80	0.96
27-Jan-15 04:03:00	6	6	6	20.34	5.73	0.95
27-Jan-15 05:05:52	6	6	6	20.84	5.60	0.96
27-Jan-15 06:03:00	6	6	6	23.10	1.48	0.96
27-Jan-15 07:30:05	6	6	6	25.59	0.00	1
27-Jan-15 08:10:58	6	6	6	25.87	0.00	1
27-Jan-15 09:08:13	6	6	6	26.87	1.97	1
27-Jan-15 10:07:18	6	6	6	27.08	2.16	0.99
27-Jan-15 11:09:48	6	6	6	27.31	2.45	0.99
27-Jan-15 12:03:00	6	6	6	27.26	2.73	0.99
27-Jan-15 13:29:56	6	6	6	26.92	2.63	0.99

27-Jan-15 14:30:19	6	6	6	26.55	2.49	0.99
27-Jan-15 15:38:22	6	6	6	26.60	2.43	0.99
27-Jan-15 16:03:54	6	6	6	26.43	0.00	0.99
27-Jan-15 17:05:18	6	6	6	27.80	2.86	0.99
27-Jan-15 18:03:00	6	6	6	30.42	3.44	0.99
27-Jan-15 19:05:24	6	6	6	32.83	3.99	0.99
27-Jan-15 20:03:00	6	6	6	31.50	3.75	0.99
27-Jan-15 21:22:05	6	6	6	29.67	3.09	0.99
27-Jan-15 22:11:30	6	6	6	26.86	2.56	0.99
27-Jan-15 23:03:00	6	6	6	24.85	0.00	0.99
28-Jan-15 00:08:27	6	6	6	22.75	0.00	0.96
28-Jan-15 01:03:00	6	6	6	22.13	6.38	0.95
28-Jan-15 02:03:00	6	6	6	21.18	5.97	0.96
28-Jan-15 03:09:35	6	6	6	20.80	6.09	0.96
28-Jan-15 04:03:00	6	6	6	20.64	5.87	0.96
28-Jan-15 05:15:48	6	6	6	21.21	5.89	0.95
28-Jan-15 06:03:00	6	6	6	23.52	6.38	0.96
28-Jan-15 07:19:16	6	6	6	25.99	0.00	0.97
28-Jan-15 08:05:16	6	6	6	26.21	0.00	1
28-Jan-15 09:22:53	6	6	6	27.42	2.15	0.99
28-Jan-15 10:28:16	6	6	6	27.64	2.65	0.99
28-Jan-15 11:03:00	6	6	6	27.86	2.82	0.99
28-Jan-15 12:03:00	6	6	6	27.39	2.75	0.99
28-Jan-15 13:17:13	6	6	6	26.72	2.81	0.99
28-Jan-15 14:09:44	6	6	6	26.91	2.79	0.99
28-Jan-15 15:48:27	6	6	6	27.07	2.77	0.99
28-Jan-15 16:23:29	6	6	6	27.59	2.97	0.99
28-Jan-15 17:05:29	6	6	6	27.93	3.14	0.99
28-Jan-15 18:41:10	6	6	6	30.87	3.93	0.99
28-Jan-15 19:09:37	6	6	6	33.01	4.32	0.99
28-Jan-15 20:07:53	6	6	6	31.51	3.92	0.99
28-Jan-15 21:03:00	6	6	6	29.34	3.27	0.99
28-Jan-15 22:20:25	6	6	6	27.37	2.70	0.99
28-Jan-15 23:03:38	6	6	6	25.11	0.00	1
29-Jan-15 00:22:57	6	6	6	23.31	0.00	0.99
29-Jan-15 01:03:00	6	6	6	22.25	0.00	0.96
29-Jan-15 02:21:52	6	6	6	21.52	6.23	0.96
29-Jan-15 03:05:14	6	6	6	20.83	6.03	0.95
29-Jan-15 04:20:25	6	6	6	20.95	5.86	0.96
29-Jan-15 05:38:35	6	6	6	21.23	5.96	0.96
29-Jan-15 06:27:59	6	6	6	24.12	6.43	0.97
29-Jan-15 07:11:34	6	6	6	25.62	6.57	0.96
29-Jan-15 08:03:29	6	6	6	26.20	6.65	0.96
29-Jan-15 09:10:43	6	6	6	26.98	7.24	0.96

29-Jan-15 10:04:45	6	6	6	27.83	3.09	0.96
29-Jan-15 11:03:04	6	6	6	28.29	3.10	0.99
29-Jan-15 12:08:47	6	6	6	28.07	2.86	0.99
29-Jan-15 13:11:08	6	6	6	27.75	3.52	0.8
29-Jan-15 14:34:28	6	6	6	27.77	3.30	0.99
29-Jan-15 15:04:10	6	6	6	28.10	3.34	0.99
29-Jan-15 16:24:45	6	6	6	28.03	3.00	0.99
29-Jan-15 17:03:00	6	6	6	28.56	3.32	0.99
29-Jan-15 18:03:00	6	6	6	31.09	4.35	0.99
29-Jan-15 19:16:19	6	6	6	33.17	4.67	0.99
29-Jan-15 20:20:42	6	6	6	31.34	4.16	0.99
29-Jan-15 21:55:09	6	6	6	29.82	3.46	0.99
29-Jan-15 22:29:27	6	6	6	27.89	2.75	0.99
29-Jan-15 23:29:55	6	6	6	25.93	2.19	0.99
30-Jan-15 00:03:00	6	6	6	24.53	0.00	0.99
30-Jan-15 01:17:18	6	6	6	23.52	0.00	0.99
30-Jan-15 02:14:46	6	6	6	22.46	0.00	0.95
30-Jan-15 03:16:20	6	6	6	21.92	6.31	0.96
30-Jan-15 04:23:18	6	6	6	21.83	6.31	0.95
30-Jan-15 05:05:52	6	6	6	21.88	6.44	0.95
30-Jan-15 06:03:00	6	6	6	22.60	6.35	0.96
30-Jan-15 07:03:00	6	6	6	22.91	6.35	0.74
30-Jan-15 08:05:36	6	6	6	24.31	5.90	0.96
30-Jan-15 09:08:39	6	6	6	26.36	6.86	0.96
30-Jan-15 10:12:05	6	6	6	27.45	7.56	0.96
30-Jan-15 11:08:20	6	6	6	27.71	7.52	0.92
30-Jan-15 12:09:52	6	6	6	28.14	7.95	0.96
30-Jan-15 13:03:00	6	6	6	27.79	7.92	0.96
30-Jan-15 14:03:00	6	6	6	27.09	8.17	0.96
30-Jan-15 15:04:42	6	6	6	26.80	8.07	0.95
30-Jan-15 16:03:00	6	6	6	26.57	7.91	0.95
30-Jan-15 17:24:06	6	6	6	26.99	8.10	0.76
30-Jan-15 18:03:00	6	6	6	29.09	8.86	0.95
30-Jan-15 19:03:00	6	6	6	31.42	9.47	0.96
30-Jan-15 20:53:58	6	6	6	30.22	9.11	0.78
30-Jan-15 21:03:04	6	6	6	29.11	8.76	0.96
30-Jan-15 22:03:00	6	6	6	27.33	3.00	0.96
30-Jan-15 23:03:57	6	6	6	26.20	2.60	0.99
31-Jan-15 00:25:23	6	6	6	24.35	2.23	0.99
31-Jan-15 01:07:01	6	6	6	23.32	0.63	0.99
31-Jan-15 02:03:00	6	6	6	22.82	0.00	0.99
31-Jan-15 03:03:00	6	6	6	21.94	0.00	0.95
31-Jan-15 04:10:11	6	6	6	21.78	6.44	0.95