EXECUTIVE SUMMARY

Lack of energy is one of the many factors limiting peoples living in remote, inaccessible areas in achieving a dignified life with adequate food, income and employment options. Marginalized and poor, both economically and socially, they continue to suffer from food insecurity and incomes that are inadequate to meeting their basic needs. Access to reliable energy sources is critical for the substantive improvements in their quality of life. Electricity is unarguably the most effective energy source with electricity driven systems being the most user friendly for household use and in production processes. And hence, there is direct link between electrification and rural development.

Given that large parts of rural areas will continue to be un serviced by conventional power, micro - energy solutions based on local resources become significant. They have the potential to effect concrete and sustainable improvements in villages/ community livelihoods and food security – identifiable by a “better quality of life” and “increased dignity” within a broader scope of environmental improvement and the flow on effects this brings.

Access to energy/ electricity offers the potential to develop a wholly integrated approach to village/community development, bringing in issues of environment and resource management, safe water supply, new and greater opportunities for generating additional income and improving food security as well as promoting healthier living environment through the implementation of such energy peripherals watermills.

Based on above identified importance of energy in the context of overall development first chapter (Introduction) highlights the importance of watermill as a source of rural energy in Uttarakhand’s perspective. It also identifies the research methodology to understand the present condition of watermills and the methodology for its renaissance. The chapter also details out the thesis plan and chapters outlay.

Second chapter (Renaissance of Watermills for Sustainable Development In Rural Uttarakhand) focuses on the energy challenges faced the country and its energy position in general and then reviews the position for the state of Uttarakhand in the same perspective.

India is one of the world's emerging economic giants and centre of energy use. India faces formidable challenges in meeting its energy needs and in providing adequate energy of desired quality in various forms in a sustainable manner and at competitive prices. The chapter highlights the huge gap in energy demand and supply in present context and forecasts the power situation for next 25 years keeping pace with economic development.

India needs to sustain an 8% to 10% economic growth rate, over next 25 years. If is to eradicate poverty and meet its human development goals. By 2031-32 power generation capacity must increase to nearly 8,00,000 MW from the current capacity of around 1,50,000 MW. Similarly, as 65% of India's generation is dependent on thermal power generation; energy mix for fossil fuel will need to expand to over 2 billion tonnes per annum. Increasing fossil fuel consumption has serious implications for the environment, in terms of rising concern of green house gases. The nature and dimension of this challenge becomes clear when we look at the energy scene in the country. It also focuses on Electricity Act 2003 which emphasis on power to all with minimum household consumption of 1 unit per day, thereby highlighting the importance of "decentralized distributed power generation" which is supposed to be the most techno economically viable solution for rural and peri rural electrification.

The chapter then pays greater attention to power scenario of Uttarakhand and carries out a detailed analysis of its power generation, transmission and distribution.

Uttarakhand is a Green state of India covering almost 65% of land under forest area. This state carries nine million population in an about 16,000 villages. Only 25 % of the population is residing in the urban areas.

Also, the tremendous Hydro potential of 20,000 MW can be harnessed; presently this state has fulfilling the energy requirement of 3500 MUs from Hydro entirely. Uttarakhand renowned as Energy surplus state aims to develop 10,000 MW by 2018.This chapter also identifies the power supply position of the state as on 2009-10.

Due to system improvement programs and distribution system automation, there is a reduction in AT & C losses of Uttarakhand, but still the percentage is 27. The year wise performance is also identified with some commercial indicators such as, T&D loss, annual per capita consumption etc.

More importantly this chapter identifies the need of energy vis a vis power specifically for rural and peri rural areas. As the state largely has hilly terrain and forest area, taking power to remote rural areas is a very big challenge. Even taking other fossil fuels to those areas is techno economically not very viable and also will cause environmental concern. The absence of energy sources in those areas is causing youth to migrate from their native places to the urban areas in search of livelihood, causing socio - economic disturbance on one hand and let the natural resources of their native places go unutilized on other hand.

Uttarakhand is endowed with rich hydrology and its rivers, streams and springs offer vast hydro power potential. For rural communities located in far off places, watermills or "Gharats" offer a sustainable, economical, reliable and renewable source of energy and livelihood. They are environmentally sustainable and claimed as Green and Clean Energy Mechanism.

The idea of using energy contained in water and converting it into useful energy was known to mankind since long. Traditional watermills for grinding grains are being used in the Himalayan region and approximately 2.5 lac watermills are still in use. In Uttarakhand alone its population is about 15000, however as per the reports of state nodal agency for renewable energy, UREDA, more than 50% of watermills are defunct. The chapter highlights the importance of reviving these mills for generating livelihood in those remote areas and even for generating electricity.

Third chapter (Engineering Analysis & Assessment of Existing Watermills) analyses the existing status of watermills in Uttarakhand. Analysis of existing system is important to understand the deficiency in the system which can be improved upon to make the system efficient and user friendly. This chapter covers the approach to identify such parameters of the existing system and methodology used to gather the information on those parameters. Further, it covers the analysis of those parameters and other observations identified in the process. The outline of this analysis goes with understanding the existing status of water mills.

The existing traditional watermills have wooden blades fixed in a vertical axis called turbine with a heavy wooden stem called runner which is tapered on both ends. Number of blades and their size varies for various gharats. A wooden shaft is fitted on upper end of runner. This shaft passes through a fixed milling stone called lower milling stone through a wooden bush and is fixed with a pin to another milling stone called upper milling stone. These milling stones act as grinding mill. Lower tapered end of runner is supported on hard ground with a piece of stone acting as pivot.

The turbine along with upper grinding stone is rotated by the force of water generated by strike of water falling on turbine blades from a height. The guide of water is called chute or channel which is again made up of wooden plank.

In order to analyze the existing condition of water mills it was imperative to conduct the survey of existing water mills. As per the census of Uttarakhand Renewable Energy Development Agency (UREDA) the numbers of watermills in Uttarakhand are 15449 located all across the state. These watermills are either individually, community or government owned. To manage these water mills, gharat association has been formed in the state which works in co ordination with the district offices of UREDA. Various NGOs are also working in the state for improving the condition of these gharats. Therefore it was found necessary to know the points of concern of all these stake holders of gharat to carry out the true analysis of same. In a meeting organized at the head office of UREDA with all the concerned stake holders of gharat. Following points of relevance were identified:

a. Present Status of watermill
b. Working condition of watermill
c. Current usage (Electrical/mechanical)
d. Potential for upgradation of watermill
e. Distance of watermill from village
f. Distance of watermill from road
g. Status of Electrification
h. Annual average discharge
i. Available head
j. Working duration (annual)
k. Reason for watermill not functioning
l. Willingness for modification of watermill.

10% of watermills were surveyed across the state to cover entire geographical and ecological variance of the region. Some other available relevant information from the stake holders was also included. That covered the information on almost all the watermills.

The survey revealed some interesting facts. In spite of huge efforts made by the UREDA and other NGOs only 3% of total watermills amounting to 499 numbers could be upgraded so far and still 14882 watermills are traditional.

Only 1% of total watermills are used for electricity generation also and rests are used for grinding the grains and other mechanical applications. The water mills work year round as well as seasonal depending on rain, flooding, boulders coming in channel, landslides damaging the channel, mill itself or even damaging the approach to the mill. Maintenance has been identified as the main cause of water mills not functioning. This problem has been identified even in upgraded watermills also. Maintenance problems become even more severe as many of the water mills are very remotely located both from the villages and road head. Some watermills are even beyond 20 kms away from village and 10 kms from road head.

This statistics itself depicts the hard fought life rural habitants have in the hills and the fact that technology up gradation for water mills should be based on local resources and almost maintenance free. This also leads to the fact that successful up gradation water mill in such condition will be that which requires less maintenance even if some efficiency has to be compromised for that.

Other important parameters governing the selection of water mills and improvement criterion for them are identified as the hydrological parameters of the site. Discharge and head have been analyzed for various sites.

At all the total discharge ranges from 0 to 0.6 cumec. However at 90% locations the average annual discharge is only 0 to 0.2 cumec, District wise locations have been identified with respective average annual discharge. Maximum head available is only up to 7 mtrs where as more than 70% locations have head in the range of 2 – 5 mtrs only.

Most importantly all the above data is available location wise and district wise. These data are very important input for upgrading the watermills.

Further to these parameters some other important points are observed which can be crucial for identifying the areas of performance improvement for watermills.

Majority of watermills are defunct due to maintenance problems. The distance of watermill from village and the road head make the owner disinterested in operating and maintaining the watermill. Heavy weight of wooden turbine causes low RPM and hence low output per hour. Mis-match by fabricating heavy turbine vis-a-vis available hydro power potential (head, flow etc). Wooden runner and blades get damaged quite frequently. Blades come out of runner. Use of open channel made up of stones as penstock causing loss of head due to friction, spillage of water. Unavailability of screen at entrance of channel causing trash and boulders to be carried up to turbine. Deposition of elegy and growth of plants in channel causes loss of head. Improper angle of penstock nozzle, causing imperfect strike of water on turbine blade .Damaged penstock nozzle causing water to spill all over.

During rainy seasons the water become violent and carries lots of sediment & boulders with it. These boulders and sediment effect the turbines hence the watermill has to be closed during the seasons of high discharge. Flour dripping in bearing causes its frequent failure/ jamming.

Above points have also been considered while improving the watermill system. Analyzing the existing improved watermills was also important to understand further scope of improvement.

The chapter also analyses the performance of existing improved watermills based on lab testing. Presently cross flow, axial flow and pelton turbines are used. A number of each of these turbines is tested in the lab and their performance is analyzed as effect of flow and load on efficiency. Cross flow turbines are found to be most efficient with efficiency close to 50% for medium and high flow i.e. at more than 100 lps flow while pelton turbine is found to be most efficient in low flow condition i.e. close to 30% at about 20 - 40 lps flow.

As revealed in survey majority of locations have low annual average flow, therefore our design as given in subsequent chapters is based on pelton turbine. Further field testing of existing improved watermill and working traditional watermill was also done to see the impact of practical conditions on the efficiency. It is found that while efficiency of traditional watermill is only 8 – 13% the efficiency of existing improved watermill is 10 – 37% under similar site conditions. This also revealed that under site condition the efficiency of improved watermill has dropped by approx. 25- 30% from controlled lab environment. Further there is huge difference in efficiency for the same type of turbines and for the same hydrological parameters.

Forth chapter (Engineering Redesign & Prototype Development of Watermill System) carries out the design of various parts of watermill. Most importantly the design focuses on overall watermill system rather than only turbine as it was the case in previous design improvements. The design takes care of turbine runner, shaft, penstock, nozzle, bearing and even the material of these components. The design also takes care of site conditions as identified in site survey. Design is based on following points and consideration:

- Based on the test results of existing watermills as per previous chapter and other observations as per the survey finding following considerations have been taken in redesigning the watermill system:
- Low cost, local material, minimum maintenance yet better efficiency, focus on points gathered from survey i.e. penstock, nozzle, trash, water control etc.
- Design is based on low head and discharge as available in most parts of state as evident from survey

Watermill efficiency depends on its hydraulic efficiency, mechanical efficiency and volumetric efficiency which in turn depend on net head, flow, watermill components like bearing, runner, it's material and amount of water striking the runner blades. Nozzle is a component which converts potential energy of water in kinetic energy at outlet of penstock and also helps in properly directing the water stream so that most of the water strikes the runner. Therefore in this chapter penstock, runner and nozzle have been designed to minimize losses and optimizing the overall efficiency keeping economic considerations in mind. Further it is observed to select a turbine of higher specific speed because higher specific speed of a turbine result in reduction of runner diameter as well as the overall size of the runner, due to which weight and cost of runner is reduced. If we are able to change to diameter of nozzle/ jet, we will be able to get almost constant efficiency even at varying discharge.

Nozzles are frequently used to control the rate of flow, speed, direction, mass, shape, and/or the pressure of the stream that emerges from them. In case of hydraulic turbine jet nozzle is mainly used. A hydro jet is a nozzle intended to eject fluid in a coherent stream into a surrounding medium. Nozzle is a device used for converting the pressure energy of jet into kinetic energy of jet. Nozzle is designed for different head and discharge values.

This chapter also deals in calculating specific speed for different head and discharge values also its effect on efficiency. Then a rack and pinion arrangement connected with spear valve to control the jet diameter is designed to maintain the efficiency even at varying discharges. Controlling arrangement to movement of spear is given above the ground so that according to requirement jet diameter can be controlled manually. Efficiency with and without jet control are also compared.

Software is also developed which calculates various design parameters for the given hydrological parameters. It also gives the design drawing for standardization of design thus minimizing the variation in efficiency for turbines from different manufacturers.

Further electricity generation option has also been proposed for the sites with low hydrological parameters.

Fifth chapter (Good Operation & Maintenance Practices) deals with proper installation and commissioning practices of watermill at site. Proper installation and alignment will take care of many maintenance problems which is one of the major barriers in renaissance of watermills. As one of the maintenance problem was identified as dripping of flour on bearing and thus jamming it frequently. To overcome this problem it is proposed to use either sealed self lubricating double "zz" bearing and fit a wooden bush just over the bearing resting on a collar thus eliminating any possibility of friction also due to it. To eliminate another problem of boulders, mud and twigs hitting and damaging the turbine it is proposed to make a small de siltation tank on the channel just before the penstock with different levels for inlet and outlet so that all the boulders etc are trapped in it. It is covered from top with manhole and cover so that it can be cleaned periodically. Further a screen is also provided to take care of small leaves etc. Periodic & breakdown maintenance check sheets are also given for the ease of miller. For generator also, in case it is used, similar maintenance check sheets, earthing details etc. have been provided. Electrical load calculation also has been explained for selecting the proper rating of generator.

In the **Sixth chapter (Conclusion & Future Research)** of results a watermill is designed based on calculations made in previous chapters. Standard watermill thus designed is fabricated and tested in lab for efficiency at various values of discharge for the given head. Testing is also being done with and without nozzle control. It is observed that efficiency of our water mill is higher than that of the other existing improved watermill available for the same hydrological parameter. Efficiency improvement of more than 20% of that of improved watermill is observed. It is also significantly observed that nozzle control has yielded almost constant efficiency whereas the efficiency of improved watermill continued to decrease with the shift from designed hydrological parameters. Average change in efficiency of approximately 30% is observed with and without nozzle control. This improvement is however under lab conditions with proper and regular nozzle control which will not be possible in practical conditions, still under seasonal flow variations it will give significant efficiency improvement compared to the mill without nozzle control. Future scope of work has also been identified.