# DEVELOPMENT OF INTEGRATED RENEWABLE ENERGY SYSTEM FOR A REMOTE AREA

**Ph.D. THESIS**

**by**

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# ABSTRACT

The utilization of renewable energy resources for the electricity supply in decentralized mode has received considerable attention in recent years due to adverse environmental impacts and high fuel cost associated with conventional energy generation. These resources have enough potential to be the important sources for power generation in the future, because of their environmental, social and economic advantages apart from public support and government incentives. There are, however, several barriers preventing renewable energy resources to be competitive with conventional energy sources in the current power scenario, as the energy supply from these renewable energy resources cannot be regulated as per the demand and their integration with grid network is not easy. The single technology approach, whether it is Solar Photo Voltaic (SPV) home lighting system, wind, biomass, micro hydro power or any other system cannot adequately meet the demands for long period due to high cost of system as well as storage subsystem. To overcome these problems, the concept of Integrated Renewable Energy System (IRES) has been propounded in which the energy demands of an isolated area, which is far away from the utility grid, matches with the energy potential of locally available renewable energy resources.

The extensive review of literature reveals that most of the work concentrates on one or two resources like wind and/or solar. The inclusion of Micro Hydel Power (MHP) and biomass/biogas based electricity production system as the component of IRES has not been tried and the literature is therefore very much scarce and hence rural remote and far-flung areas with MHP, as the major renewable resource, need to be explored with other available renewable energy options also. Further, the electrical load profile of remote area is normally kept fixed for year round application and accordingly, the sizing of renewable energy systems are carried out. The variations of load profiles with seasons are not taken into consideration while calculating the sizing

of renewable energy systems. Also the nature of load profile varies from region to region and therefore, it becomes mandatory for the planners to conduct independent studies for each region instead of generalizing for the whole region encompassing a cluster of sub regions.

The sizing and modeling of renewable energy systems is the most challenging task for the off-grid electrification of cluster of sub regions. Proper sizing of renewable energy systems guarantees proper supply of electricity in feasible manner. The Loss of Load Probability (LOLP), the sizing parameter, mostly used for the sizing and integration of wind-alone, solar photovoltaic (SPV)-alone systems or combination of both with battery bank. The available literature provides the different sizing and modeling approaches considered by researchers for different remote locations. The modeling approach for the optimization and sizing of renewable energy systems through IRES are still quite limited and not concentrated on energy balance approach using Expected Energy not supplied (EENS) reliability. Further, the research focused on sizing of renewable energy system is mainly based on system sizes available in the market. The renewable energy system sizes, that are currently not available in the market, should be considered and need to compare the sizes available in the market to predict the best suitable size among them. Thus, the scope for extension of the IRES concept using MHP along with other renewable energy resources is therefore seems to be very encouraging.

In developing country like India, most of the population lives in remote rural areas and electrification in decentralized mode by locally available renewable energy resources will benefit the overall development of these areas. The locally available renewable energy resources in remote rural areas mainly include MHP, biomass, wind and solar energy. These renewable energy resources available in abundance in the hilly state like Uttarakhand which is one of the richest regions of India as regards the water resources are concerned. The existing small and large hydro power projects are well connected to the utility grid. But the extension of utility grid is quite difficult to isolated and remotely located areas in hilly terrain and dense forest region, due to financial and technical constraints. The best option seems to energize these remote areas in decentralized mode by MHP in combination with other renewable energy resources.

Accordingly, MHP and biomass based electricity generating systems are proposed as the component of the proposed IRES under the present study which aims to develop an IRES system involving MHP, biomass, solar and wind energy systems. The modeling approach for sizing of renewable energy systems is concentrated on energy balance using EENS reliability. The economic parameter like Cost of Energy (COE) is considered to ensure the economically feasible supply of electricity. Based on these parameters, the Integrated Renewable Energy Optimization Model (IREOM) is proposed for the fulfillment of electrical and cooking energy needs of cluster of villages from Uttarakhand state.

In the present study, a cluster of seven unelectrified villages has been selected as the study area on different selection criterion. The study area is located in Tarikhet block of the Almora district of Uttarakhand state in India. The selected cluster of villages considered for the fulfillment of electricity and cooking energy need through IRES. These villages have renewable energy resources such as MHP, biomass, solar and wind energy. Accordingly, the present study proposes decentralized option for the electrification of this cluster of villages. The objective is to find the suitable component sizes and optimal operation strategy for the study area by Integrated Renewable Energy Optimization Model (IREOM). The proposed IREOM model is designed to integrate MHP, biomass (crop residue, forest foliage and energy plantations), biogas (energy used for electrification and cooking), wind energy and solar energy. The biogas produced from bovine animals is first used for cooking and surplus biogas used for electricity generation while energy from other renewable energy resources is used for electricity generation only.

The extensive field survey was conducted for the collection of resource data and load requirement in a questionnaire through site visits. The collected data was analyzed and the standard methods were used for the potential assessment of renewable energy resources. The data indicates that the potential of MHP resource is the maximum (242.14 MWh/yr) followed by biomass including crop residues and forest foliage (198.56 MWh/yr), solar energy (1.84 $MWh/m^2/yr$) and wind potential (0.71 $MWh/m^2/yr$). The additional biomass energy from energy plantation is estimated as 81.39 MWh/yr. Based on the quantity of dung available the estimated potential of 198515 $m^3$ of biogas per year is estimated to be in the study area.

The load estimation includes electrical load and cooking energy need of the study area. The total biogas energy for cooking purposes is estimated as 178332 $m^3$ per year and the surplus biogas of 20183 $m^3$ per year will be utilized for electricity generation. The electricity demand of cluster of villages is classified as domestic, agricultural, community and commercial loads. The domestic load of 190.07 MWh/yr accounts the highest energy demand followed by Agricultural load as 140.53 MWh/yr, commercial load as 18.81 MWh/yr and community load as 13.94 MWh/yr. A year is divided into four seasons of three months each according to the energy requirements and energy consumption pattern and four seasonal load profiles have been considered. Apart from these seasonal loads, the fifth load profile is proposed whose daily load varies as per the seasonal variation. The fifth load profile is termed as yearly load profile.

The study has been focused on the following aspects:

(i) Different resource scenarios have been considered and analyzed. Among these scenarios suitable scenario has been recommended for the study area. The sensitivity analysis of considered scenarios has been carried out for fluctuating biomass fuel prices.

(ii) The developed IREOM model has been applied for optimum sizing of energy systems on the basis of seasonal load profiles as well as yearly load profile. The reliability approach Expected Energy Not Supplied (EENS), represented as Energy Index Ratio (EIR), has been applied to the IREOM model for two reliability values of 1.0 EIR and 0.95 EIR. The model has been considered to find out the optimal sizing of renewable energy resources considering the manufacturer specified and user specified sizes. The minimum cost of energy (COE) with more reliability has been considered as the selection criteria for optimal sizing of renewable energy resources.

The four different resource scenarios as given below have been considered and compared for suitable scenario for the study area.

[i] Scenario 1 : MHP-Biomass-Biogas-SPV

[ii] Scenario 2 : MHP-Biomass-Biogas-Wind-SPV

[iii] Scenario 3 : MHP-Biomass-Biogas-Energy Plantation-SPV and

[iv] Scenario 4 : MHP-Biomass-Biogas-Energy Plantation-Wind-SPV.

The suitable scenario among them has been evaluated using optimum total cost and EENS reliability. It is observed that the system considering scenario 4 (MHP-Biomass-Biogas-Energy Plantation-Wind-SPV) has been found more reliable and cost effective among all the considered scenarios. However, for scenario 4 the optimum total cost has been obtained at EENS reliability value of 0.95 EIR. The sensitivity analysis of the considered scenarios has been carried out for fluctuating biomass fuel prices. The sensitivity analysis of considered scenarios reveals that scenario 4 is more suitable to the study area, even if biomass fuel price fluctuates under the external circumstances like hikes with the wages of salary, shortage of biomass fuel etc.

Further, the IREOM model has been planned and designed to overcome the intermittent behavior of available renewable energy resources. The developed model is capable to give optimized combination of renewable energy system sizes for a given load profile. The study also analyzes the different load profiles and gives different choices to select the best option out of the proposed optimized solutions. The proposed optimization model has three submodels, namely, energy conversion systems, reliability and economic submodel.

The IREOM model considered availability of resources, load demand-supply balance, operational limitation of renewable energy system and available equipment sizes at any time to calculate minimum COE for a required reliability criteria. The hourly energy from resources is calculated by mathematical models and then the demand for that hour, is balanced by these resources. The energy consumption is sequenced from abundantly available and low capital cost renewable energy resources to low availability and high capital cost renewable energy resources.

MHP systems and biogas fuelled engine sizes are fixed while the wood based and rice husk based biomass gasifier system sizes, wind turbine system sizes and SPV system surface area are calculated through simulation. A numerical iterative algorithm is used to size the wood based biomass gasifier system, rice husk based biomass gasifier system and wind energy system. The number of SPV system surface area in $m^2$ is, however, incremented until the system fulfills the criteria. The surface areas of SPV modules are optimized by "Binary Search Optimization Technique" which reduces the iterative time for the selection of SPV module surface area. On the basis of availability and constraints of renewable energy sources, the developed IREOM model has been applied to study area.

Based on the potential of MHP and biogas available the different sets of system sizes have been analyzed to get an optimal solution. The total 12 (5 yearly and 7 seasonal) numbers of MHP systems with total capacity of 41 kW and 4 kW capacity biogas fueled engine system have been considered. The ratings of wood based and rise husk based biomass gasifier systems, wind turbine system and SPV system surface area have been calculated through simulation. The model is simulated for two specified sizes for the sizing of wood based biomass gasifier system, rice husk based biomass gasifier system and wind energy systems. The first one considers the sizes available in the market and those specified by the manufactures while another one considers specifications which may not be available in market and these system sizes termed as user specified sizes. Based on information obtained from manufacturer's catalog, the sizes for wood and rick husk based biomass gasifier system and wind turbine system sizes are considered. Similarly, the same range with different sizes has been considered for user specified systems. Correlations have been developed between the size and capital cost for the user specified sizes of wood based biomass gasifier system, rice husk based biomass gasifier system and wind energy systems. SPV system surface area added linearly for both the manufacturer and user specified sizes and hence the capital cost of these SPV systems also varies linearly.

The two reliability values of 1.0 EIR and 0.95 EIR has been considered separately for sizing and optimization of IREOM model. The results are discussed for three different cases for both values of EENS reliability. In the first case, the manufacturer specified sizes and in the second case, the user specified sizes of the systems have been considered for cost optimization. Further in third case, the model has been simulated for both the manufacturer and user specified sizes of renewable energy systems for yearly load profile.

Based on the results and discussions made for the different cases, the optimum sizes of renewable energy systems for three cases analyzed and the minimum COE has been calculated. The model developed for this purpose has been found to be quite useful in optimizing the renewable energy system sizes of manufacturer and user specified system sizes. It is also observed that the user specified sizes of the wood and rice husk based biomass gasifier system and wind turbine system are more suitable for the study of EENS reliability values than the manufacturer specified sizes.The minimum COE has been found for third case among all considered cases. Accordingly, on the basis of minimum COE criteria, the optimum sizes of renewable energy systems for third case have been considered for the study area. In third case, the percentage increment in COE has been found to be 7% for the systems having EENS reliability value of 1.0 EIR over 0.95 EIR. The percentage increment is found to be less and it will be more benefited to design the system for 1.0 EIR value. It is therefore,, the renewable energy system has been found suitable for EENS reliability value of 1.0 and accordingly, it is recommended for the study area.

Based on the study carried out, it is found that the renewable energy systems having the optimum sizes as 28 kW wood based biomass gasifier system, 35 kW rice husk based biomass gasifier system, 2.5 kW rating wind turbine system and 224 $m^2$ SPV system surface areas along with total 12 (5 yearly and 7 seasonal) numbers of MHP systems with total capacity of 41 kW and 4 kW capacity biogas fueled engine system have been found suitable for study area. The corresponding minimum COE has been obtained as Rs. 6.30 for EENS reliability of 1.0 EIR.