



Development of IREOM model based on seasonally varying load profile for hilly remote areas of Uttarakhand state in India

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ABSTRACT

An Integrated Renewable Energy Optimization Model (IREOM) model has been developed for sizing and optimization of renewable energy systems based on seasonal variation in the load profiles of the study area. An attempt has been made to develop correlations between renewable energy system sizes and their capital cost for the user specified system sizes. The developed correlations were used for the analysis of IREOM model using user specified system sizes and compared with manufacturer specified system sizes. The cluster of seven unelectrified villages having micro-hydro power, biomass, wind and solar energy resources in the state of Uttarakhand, India has been considered for the implementation of IREOM model. Based on the results obtained from the proposed model, suitable sizes of renewable energy systems have been suggested.

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1. Introduction

In developing countries like India, clusters of three or more villages are common in remote location where extension of grid is always uneconomical due to low demand and high capital investment [1]. Further, dense forest and hilly terrain restricts the extension of grid to such remote rural villages in Uttarakhand state of India. The unavailability of electricity is the main barrier in the economic development of these villages which constitute about 0.8% of the total villages in the state [2]. These villages can be energized by establishing an energy center and installing distribution lines to connect all of them. Depending upon the local conditions, type of terrain and availability of renewable energy resources, the energy center can be integrated with micro-hydro power, solar energy and/or wind energy and/or other locally available energy conversion systems [3]. This concept of Integration of Renewable Energy System (IRES) has been widely used by various researchers to energize these remote areas [4–13]. The hybrid energy systems, where conventional energy resources used along with locally available renewable energy resources, have also been studied and reported [14–21]. The literature reveals that most of the work in this area concentrates mainly on the sizes of the system available in the market which may not be appropriate for

particular areas. The effect of different load profiles on the renewable energy system sizing has also been studied and reported [22]. However, work on the effect of seasonally varying load profile on the renewable energy system sizes is very much scarce in the literature. This paper is an extension of author's previous work [23–25] where sizing of renewable energy systems has been calculated for different seasonal load profiles and based on trade-off optimum sizes of renewable energy systems are suggested for year round application.

In view of the above, an IREOM has been developed to meet the electricity and cooking energy needs of cluster of seven unelectrified villages of state of Uttarakhand in India. The present study reports the comparative study of manufacturer specified and user specified sizes of renewable energy systems by considering seasonally varying load profile of the study area. A numerical iterative technique is used for sizing of renewable energy systems and optimum sizes of renewable energy systems have been proposed.

2. Study area

Uttarakhand state is mostly hilly terrain where some of the village population lives in isolated and dense forest locations. The foot or mud road is the only connectivity to such villages. Seven such unelectrified villages are considered which have renewable energy resources like Micro Hydro Power (MHP), biomass, biogas,

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Notations

BatSolar	battery capacity for solar energy storage
BatWind	battery capacity for wind energy storage
BGR	biogas required for 1 h operation of biogas fueled engine
BioEle	electricity generation from biogas fueled engine
BKW1	rating of wood based biomass gasifier system
BKW2	rating of rice husk based biomass gasifier system
CalEIR	calculated EIR value
CostBKW1	capital cost of wood based biomass gasifier system
CostBKW2	capital cost of rice husk based biomass gasifier system
CostWKW	capital cost of wind turbine system
NoSolPnl	number of solar panel
ReqEIR	required/predefined EIR value
Rs	Indian national rupee
sEnergy	solar energy generation at time t
WKW	rating of wind turbine system

wind and solar energy. The study area under consideration is located in Ranikhet reserve forest range of the Almora district of most populated and highly fertile Kumaon region of Uttarakhand state (India). The villages from selected study area are near to each other and majority of population is illiterate and agriculture is the only source of income. Fig. 1 shows the geographical location of the study area on the map. The general information about the study area is given in Table 1 [26].

In order to assess the potential of renewable energy resources, an extensive survey was conducted and information regarding the availability of biomass, intensity of solar radiation (insolation), hydropower and wind speed data was collected. The potential assessment has been carried out as per the methodology adopted and reported in our earlier paper [23]. The data indicate that MHP resource is estimated as the maximum (293040 kWh/yr) followed by biomass including crop residues and forest foliage (198556 kWh/yr), biomass including energy plantation (81395 kWh/yr), solar energy (1837 kWh/m²/yr) and wind potential (1270 kWh/m²/yr).

The electrical energy demands of the area are classified as domestic, agricultural, community and rural industries. The domestic sector needs electricity for electrical appliances such as TV, fan and compact fluorescent lamps. The agricultural load includes fodder cutting and crop threshing machines. The community load includes lighting/fans for schools and village *Panchayat* offices. The rural industries such as milk storage and small-scale milk processing plants were considered for these villages. All these energy requirements vary from month to month. The year is therefore divided into four seasons (months) according to their energy demands and energy consumption pattern. The seasons considered are given in Table 2 along with the duration.

The season III is the lowest energy requirement season while the season II is the highest energy requirement season among all the four seasonal load profiles. The season I and IV are moderate energy requirement seasons. The total energy demand has been calculated and the different seasonal load profiles have been plotted in Fig. 2 that shows the four daily load profiles of each season. The first daily load profile is considered for season I (December to February) and when the month of February ends the second daily load profile is considered for next three months. Same process is repeated for third and fourth load profiles. The developed model automatically shifts from one load profile to another with seasonal change.

3. IREOM model configuration

The Integrated Renewable Energy Optimization Model (IREOM) based on the concept of IRES, uses locally available renewable energy resources for the fulfillment of energy need of the area. The proposed IREOM model differs from hybrid system as the hybrid system former does not require large battery bank as conventional system. However, in case of some renewable energy systems like wind and solar energy, battery storage can be added for short duration of 4–6 h only. The proposed system includes MHP, biomass (crop residue and forest foliage), biogas and solar energy along with additional energy from wind resource and biomass energy plantations. The biogas produced from bovine animals is first used for cooking and then for electricity generation while energy from other renewable energy resources is used for electricity generation only. The electrical energy generated from biogas fueled engine/generator is very less and used only for 1–2 h per day during peak hours. Fig. 3 shows the line diagram of resources used for electricity generation and cooking purposes.

4. Operational strategy of IREOM

The IREOM model takes into account the availability of resources, load demand-supply balance, operating limits of renewable energy system and available equipment sizes at any time to calculate the minimum cost of energy (COE) for a required reliability criteria. The energy from resources is calculated on hourly basis by mathematical models and the demand for the corresponding 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 is the largest energy source of the area followed by biomass, wind and solar energies. The same sequence is followed in the programming code developed using C++ compiler. The flow diagram of the operational flow of the model is shown in Fig. 4. Fig. 5 shows the different modules of the main program.

In IREOM model, MHP system and biogas engine ratings are fixed while wood and rice husk fueled biomass gasifier ratings, wind turbine ratings and PV surface area have been determined through simulation. A numerical iterative algorithm is used to size the wood based, rice husk based biomass gasifier system and wind energy system. However, the surface area (m²) of number of PV modules is incremented until the system fulfills the criteria. The surface areas of PV modules are optimized by “Binary Search Optimization Technique” which reduces the iterative time for the PV module surface area selection. On the basis of availability and constraints of renewable energy sources, the developed IREOM model has been applied to the study area in the state of Uttarakhand in India.

5. Formulation of mathematical model

The proposed IREOM model is designed to integrate locally available different renewable energy systems. Each system has its advantages and limitations. The MHP system supplies continuous energy but is incapable of meeting the peak load demands, biomass gasifier systems are used continuously for short duration of time and mostly operate when the load exceeds the baseline MHP system capacity, while the wind energy and solar energy are used at the instant of time or stored for short duration of time. Hence, the IREOM model has been carefully planned and designed to overcome their intermittent behavior. In this model, all the energy systems are interdependent of each other and their size varies

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