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Sizing of integrated renewable energy system based on load profiles and reliability index for the state of Uttarakhand in India

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ABSTRACT

In recent years the decentralized rural electrification is becoming cost effective and convenient for areas where grid extension is very difficult. The present paper deals with the electrification of dense forest areas of Uttarakhand state in India by Integrated Renewable Energy Optimization Model (IREOM). The IREOM consists of locally available renewable energy resources such as Micro-Hydropower (MHP), biomass, biogas, wind and solar photovoltaic (SPV) systems have been used to meet electrical energy and cooking energy needs of a cluster of villages. The paper includes the selection of different system components, sizing and development of a general model to find out optimal combination of energy subsystems for the selected study area in order to minimize the cost of energy (COE) generation for a required reliability values. The sizing of different renewable energy system components has been carried out so that they are suitable for four different seasonal load profiles. The two reliability values are considered for the selection of optimum solution of year round application. The model developed for this purpose, has been found to be quite useful in optimizing the renewable energy system sizes that are available in market. The proposed model totally depends on the renewable energy systems and eliminates the use of conventional energy systems.

1. Introduction

The utilization of renewable energy resources such as micro-hydropower (MHP), biomass, biogas, wind and solar energy in decentralized mode for the electricity supply has received considerable attention in recent years due to adverse environmental impacts and fuel cost escalation associated with conventional energy generation. These resources have enough potential to become important sources for power generation in the future because of their environmental, social and economic benefits in addition to public support and government incentives. However, there are several barriers preventing renewable resources to be competitive with conventional energy sources in the current power market as the supply of energy from these renewable resources can not be regulated depending upon the demand and integration of these resources with grid network is not easy. To overcome these problems, the concept of integrated renewable energy system (IRES) has been propounded which matches energy requirements of an isolated area far away from the utility grid having the locally available renewable energy resources [1]. Single technology approach, whether it is SPV home lighting system, wind, biomass, micro-hydropower or any other system is not adequate to meet the demands for long periods due to high cost of system as well as storage subsystem. To meet this challenge, the locally available resources are either integrated or used in combination with the conventional energy systems.

An integrated wind/hydro approach has been used for operational optimization of system components and reduction of electricity cost for a remote island [2–4]. The micro-hydro-wind systems have been found to be the optimal combination for the electrification of the rural villages in Western Ghats (Kerala), India [5]. The biomass gasifier systems in combination with wind parks have been employed to reduce electricity fluctuations of grid network [6]. The hybrid stand-alone PV system has been used to reduce the uncertainty in storage capacity by choosing a combination of large array and smaller storage sizes of batteries [7]. The five different weekly load profiles have been simulated for the reliability parameter and the results were based on two techno-economic parameters, namely, solar to load ratio (SLR) and battery to load ratio (BLR) [8,9]. The wind/diesel hybrid model presents an integrated numerical algorithm to estimate the long term energy autonomy configuration [10,11]. The system has been analyzed to investigate the potential of utilising hybrid (PV/diesel/battery) power system to meet the load

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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 fuelled engine
BioEle electricity generation from biogas fuelled 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

requirements of a typical commercial and residential building in Saudi Arabia [12,13]. The hybrid solar-wind system has been designed to study domestic power generation for a western costal site in India [14]. The literature reveals that the approaches proposed still have limited scope of meeting the energy needs of a residential/commercial building or communication tower.

In Rural Electrification Act 2003 enacted by Government of India, provisions have been made to electrify rural areas by renewable energy resources. The Ministry of New and Renewable Energy, Government of India, has taken major steps to promote renewable energy based decentralized power generation in remote rural areas [15,16]. Some of power units such as stand-alone photovoltaic power plants and hybrid systems integrating wind and Diesel generators, have been installed at Sagar Island region in Sundarbans of West Bengal [17] and in Himalayan region of Ladakh [18], respectively, but not much work has been reported on the electrification of clusters of remote villages by integrated renewable energy system and on the sizing of biomass gasifier, even though biomass is prominent energy source as far as rural India is concerned.

The present study studies the decentralized option for the electrification of a cluster of villages of Ranikhet reserved forest range of Uttarakhand state in India. 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 results obtained have been used to design and plan an optimal system ensuring reliable and economical power supply to the cluster of villages of the study area.

2. IREOM model configuration

Remote clusters of three or more villages are common in developing countries like India. Often such clusters are not electrified because of the low load factors and high capital investment in constructing long distribution lines from exiting utility grids. Such clusters can be energized by establishing an energy center and installing a distribution line connecting all the villages. Depending upon the local conditions, availability and terrain, micro-hydropower units can be integrated with solar energy and/or wind energy and/or with other possible energy conversion units (e.g. agricultural waste and biomass gasifiers) [19]. The proposed IREOM model differs from hybrid system, where all the energy produced from renewable resources is converted to one form of energy which can again be converted to useful energy as needed. This conversion and reconversion increases system cost for hybrid system and requires one or two day's battery backup. On the other hand, IREOM model matches the energy requirements with an appropriate energy resource. These systems do not require large battery backup, however, in case of some renewable energy system such as wind and solar energy battery storage can be added for short duration of 4 to 6 h only.

The proposed system includes micro-hydropower (MHP), biomass (crop residue and forest foliage), biogas (energy used for electrification and cooking) and solar energy with additional energy from wind and 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 based engine and generator is very less and used only for one-two hour per day during peak hours. Fig. 1 shows the line diagram of resources used for electricity generation and cooking purposes.

3. Formulations 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 gasifiers are used continuously for short duration of time and mostly, operate when the load exceeds baseline MHP system capacity while the wind and solar energy are used at the instant of time or stored for short duration of time.

The IREOM model can therefore, be planned and designed to overcome their intermittent behavior. In this model, all the energy systems are interdependent on each other and their size varies when small change occurs in the model. The different sets of system sizes are analyzed to get an optimal solution. The developed model is capable to give optimized combination of renewable energy system sizes for a given load profile. The study 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 brief description of each submodel is given below.

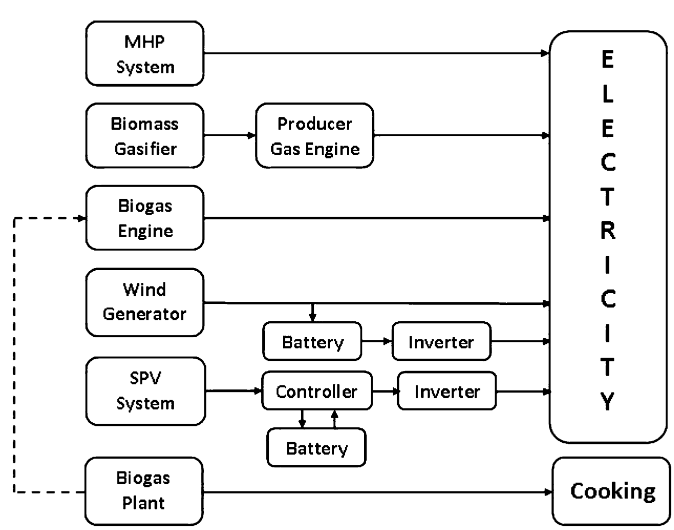

Fig. 1. Configuration of IREOM model.