

ABSTRACT

Rural remote area electrification from the main grid leads to large investments and losses and this forms the basis of decentralized Hybrid Energy System. The term 'Hybrid Energy System' describes a stand-alone energy system, which integrates renewable energy sources with fossil fuel powered diesel/petrol generator to provide electric power where the electricity is either fed directly into the grid or to the batteries for energy storage. Hybrid energy systems appear to be viable in locations where electrical grid supply has not yet reached, where commercial fuels are scarce due either to their cost and/or availability and where even small amounts of energy can make a considerable impact on the living environments of the local people.

Hybrid energy system has found much wider dissemination than just as individual stand-alone renewable/conventional systems for rural remote electrification. It is a known fact that the application of hybrid energy system based rural remote area electrification will offer a quick, economic and reliable answer to the rural household's need for power, especially, for those of light duty appliances. However, the planning of rural remote area electrification is not always easy and a proper mix can be arrived at only after a careful technical, economic, and socio-economic study of the region involved. In order to evaluate techno-economics of any hybrid energy system configuration, it is necessary to develop a proper model for optimization and simulation. A range of hybrid configurations are possible, however, the choice must suit the community. Before developing a hybrid energy system for a site-specific, it is essential to know the particular energy demand and the resources available at that site. This will allow them to design the kind of hybrid energy system that meets the demands of the facility at best.

In accordance with the long-term policy objectives of the government of India for rural electrification and guidelines given by *Ministry of New and Renewable Energy*, an off-grid, stand-alone multi-renewable source hybrid energy system consisting of micro-hydro, biomass, biogas solar photovoltaic as a renewable power and diesel and battery bank as a conventional power has been proposed (i.e. abbreviated **MHG-BGG-BMG-PVG-DEG-BATT**) in this study to energize nine un-electrified villages of *Narendra Nagar* block in the district of *Tehri-Garhwal* of Uttarakhand state of India. The study has been focused on the development of model for provision of electricity to rural remote villages through proposed hybrid energy system. It especially looks at sustainability of the plan of the Government of India, to electrify rural remote villages by means of renewable energy.

However, cost effective optimal designing of proposed hybrid energy system is very difficult task due to following prominent problems:

- (a) The core problem of hybrid energy system is its high life-cycle cost (LCC), especially, the LCC of photovoltaic, diesel generator and battery.
- (b) The need for the time-series load to match with intermittent output of PV, while reducing/utilizing the surplus energy.
- (c) The conflict between the desirability of stopping the diesel, while avoiding frequent starts and low partial load operation of diesel engine systems.

Minimization of total life-cycle cost of the system can be achieved through a widely studied approach of optimum resource allocation. It promises to significantly reduce the total life-cost of the system. Also, generating/discharge units need to be controlled according to the well defined operational procedure.

Hence, first problem can be rectified on the basis of minimization of total life-cycle cost by allocating kWh cost for system components of hybrid energy system.

The other two are decision making problem and can be controlled by an intelligent energy management system with detailed analysis. The term “intelligent” refers to the application of fuzzy logic, artificial neural networks, or knowledge based dispatch strategy to optimize the decision making process. Energy dispatch strategy, which is concerned with the allocation of resources and direction of power flow, can be appropriate for analysis.

On the other hand, system configuration should also be based on life-cycle cost analysis, which requires detailed system simulation. It is also noted that the optimal sizing depends on two factors: size of individual components and dispatch strategy. In order to achieve cost effective sizing, simulation analysis needs to be carried out together with the implementation of an efficient energy dispatch strategy.

In order to evaluate the techno-economic performance of proposed hybrid energy system for remote rural area electrification, a mixed integer linear mathematical programming model (time-series), which is a special type of mathematical programming model, has been developed to determine the optimal operation, optimal configuration including the assessment of the economic penetration levels of photovoltaic array area and cost optimization for a proposed hybrid energy generation system. An optimum control algorithm written in C++, based on combined dispatch strategy, allowing easy handling of the models and data of hybrid energy system components has been presented. The main purpose of the solution algorithm proposed here has been to reduce, as much as possible, the participation of the diesel generator in the electricity generation process, taking the maximum advantage of the renewable energy resources available. The overall

load dispatch scenario was controlled by the availability of renewable power, total system load demand, diesel generator operational constraints and the proper management of the battery bank. The incorporation of a battery bank made the control operation more practical and relatively easier.

In order to determine the optimal sizing of system components, a methodology has also been proposed. The proposed methodology was based on the cost optimization approach involving a time-series simulation of the entire system. The sizing result of the components was based on a trade-off between the optimized cost of the system and other techno-economics parameters, as determined by the algorithm in conjunction with a time-series model. The trade-off analysis was carried out due to the fact that objectives (total operating cost, minimization of fuel consumption and frequency of diesel generator starts/stops, minimization of dump and unmet energy etc) were conflicting and incommensurable, i.e. it was not possible to improve them simultaneously.

A special feature of the proposed model is that a cost constant (cost/unit) for each of the proposed resource is introduced in the cost objective function in such a way that resources with lesser unit cost share the greater proportion of the total energy demand in an attempt to optimize the objective function.

To demonstrate the use of model, solution algorithm and sizing methodology, a case study for a rural remote area has been carried out. It has been concluded that the proposed hybrid energy system can supply the entire population of cluster of villages population with 24 h power supply @ Rs 6.23/kWh with annual average daily unmet energy of 0 kWh, dump energy of 0.83%, diesel fuel consumption of 48.63 litres, diesel run-hours of 5.83 and diesel start/stops of only 0.92. Of the total primary energy requirement of the villages, the renewable energy resource based generators produced

72.09%, while the diesel generator and battery produced 17.38% and 10.53% respectively of the energy. The optimum economic penetration level for PV array area has been found 20% i.e. 202 m² with optimum system unit cost. It has also been observed that with the optimum economic penetration level of PV, unmet energy of 0 kWh, dump energy was only 0.35%, diesel fuel saving was about 42.27%, and operating hours of diesel generator decreased by 52.63% as compared to other penetration level/configuration. It is found that the PV, battery, and diesel generator size with 20% PV penetration decreased by 79.99%, 71.58%, and 9.80% respectively as compared to other penetration level/configuration. This implied that adding diesel generator allows the system switches to smaller photovoltaic and battery unit. In contrast, diesel generator size (46 kW) decreases by 9.80% with 21.34% of total energy fraction. It indicated that the introduction of photovoltaic has decreased netload/load demand on the diesel generator considerably.

Further, it has also been observed that the optimum unit cost can be drastically increased by about 72%, if MHG-BGG-BMG-PVG-DEG-BATT hybrid energy system is replaced by PV-DEG-BATT hybrid energy system. It indicated that to make system cost effective, it is better to depend on more than one renewable resource based generators, rather than depending solely on the diesel generator/photovoltaic energy converter.

Taking into account the extensive results obtained, the proposed multi-renewable source hybrid energy system i.e. MHG-BGG-BMG-PVG-DEG-BATT has been found to be cost-effective electrification solution for numerous isolated consumers. The techno-economic feasibility study demonstrated that these systems can theoretically reduce generation costs and increase the reliability of energy supply.