Modelling of Hybrid Energy System for Off Grid Electrification of Clusters of Villages

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Modelling of Hybrid Energy System for Off Grid Electrification of Clusters of Villages

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***Abstract*-- Hybrid energy systems are increasingly being applied in areas where grid extension is considered uneconomical. Their costs can be minimized through proper equipment sizing and load matching. This paper reports the results of optimization of hybrid energy system model for remote area in India. For this purpose, the Jaunpur block of Uttaranchal state of India has been selected as remote area. The model is developed with the objective of minimizing cost function based on demand and potential constraints. The model has been optimized using LINDO software 6.10 version. From the economic analysis, the capital cost, cost of energy for different types of resources, optimized cost of hybrid energy system are determined. In order to consider the fluctuation in the discharge and power generation from SHP, the EPDF has been varied from 1.0 to 0.0. The EPDF is electric power delivery factor and also called optimizing power factor and is maximum equal to1.**

***Index Terms*—Renewable Energy, Hybrid Energy System (HES), Off-grid Electrification, Stand-Alone Energy System Design, Small Hydro Power, Solar Photovoltaic System, Wind Energy Conversion System, Biogas Usage, Remote Area Power Generation, Power-generation Economics, Optimization Methods, EPDF**

I. Introduction

THERE are only about 7.36% of over 15761 villages in Uttaranchal that are not yet electrified. These villages are either on hill or in remote areas. Jaunpur block, consisting of clusters of villages, a hill-tribe remote area in district Tehri Garhwal, is one of them. The village is accessible by road from the city. There are 8291 households with population of 50,636. The houses are close to each other and most of the households use candles and kerosene lamps for lighting in early morning and in the evening. Peoples are facing the main needs such as good type of food facility & drinking water and electricity. Only primary school is available in some villages. Peoples have not higher education. Only one zone of this block is selected as a case study in this work [1].

A hybrid energy system consists of two or more energy systems, an energy storage system, power conditioning equipment and a controller [2]. A hybrid energy system may or may not be connected to the grid. Examples of energy systems commonly used in hybrid configurations are small wind turbines, photovoltaic systems, micro hydro, biomass, diesel generator, fuel cells and stirling engines. The Hybrid Energy System (HES) has received much attention over the past decade. It is a viable alternative solution as compared to systems, which rely entirely on hydrocarbon fuel. Apart from the mobility of the system, it also has longer life cycle. In particular, the integrated approach [3]-[5]. makes a hybrid system to be the most appropriate for isolated communities such as remote area in Uttaranchal.

For off-grid power supplies, a diesel generator (DG) system is most attractive because of its low capital, although operation and maintenance cost is high and engine emissions can pollute an environment [6]-[7]. In some cases, diesel generator is not cost effective due to high fuel transportation cost to remote area.

For systems employing totally clean renewable energy, high capital cost is an important barrier. However, we can produce green power by adding different renewable energy sources to diesel generator and battery, which is called a hybrid system. This kind of system can compromise investment cost, diesel fuel usage cost and also operation and maintenance costs. Many hybrid systems sizing have been studied and optimized by economic analysis based on system life cycle cost and cost of energy [8]-[10].

Optimization of a hybrid energy system is site specific and it depends upon the resources available and the load demand. The aim of this study is to identify the most economic and appropriate power supply system for a selected remote rural area.

II. Literature Review Conclusions

Literature review reveals that the modeling of hybrid energy system and their application in decentralized mode are quite limited. The models applied, are based on one of the available resources. While the literature has focused on one or two available resources. Further, attempts for developing optimum energy mix of different resources for meeting the energy needs of the rural people are also limited.

Application of models for matching the projected energy demand with mix of sources at decentralized level is limited. The models developed so far mainly focus on rural areas and not individual villages, clusters of villages, blocks, or district. Very limited efforts are reported for block level planning and are not based on any optimization approach [11]-[13].

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III. Problem Formulation

From the literature, it is observed that lot of work has been carried out for modelling of hybrid energy sources. The renewable energy sources considered under these studies are mainly solar, biomass, and wind but a very little work has been reported for the modelling of hybrid renewable energy sources involving small hydro power (SHP)/micro hydropower in combination with conventional system.

The Uttaranchal State is one of the richest states in hydropower having potential of about 254 MW at 47 sites. In addition, thousands of sites in the range of micro hydro also exist.

The main objective of the study is to develop a model of Hybrid Energy System with more emphasis on small hydro power (SHP)/micro hydro for a remote rural area in cost effective manner.

IV. Methodology

A. Study Area

The remote rural area for the study was Jaunpur block of district Tehri Garhwal of Uttaranchal state, India. The area comprises of major hilly and the fertile area under forest with scattered households. The area has been considered by Uttaranchal Renewable Energy Development Agency (UREDA) to be remote and not economically viable for electrification by grid extension. The Jaunpur block (study area) divided into four zones of clusters of villages and only 9% of the total villages are unelectrified, which have been considered for the present study as the best candidate for electrification by decentralized hybrid energy systems consisting of biomass, micro hydro, solar, wind, diesel generator. There is a primary school in every gram sabha, consisting of 6 to 7 villages. The literacy level in Jaunpur block is 16% for women and 62% for men. The total literacy rate of the Jaunpur block is 38.9%.

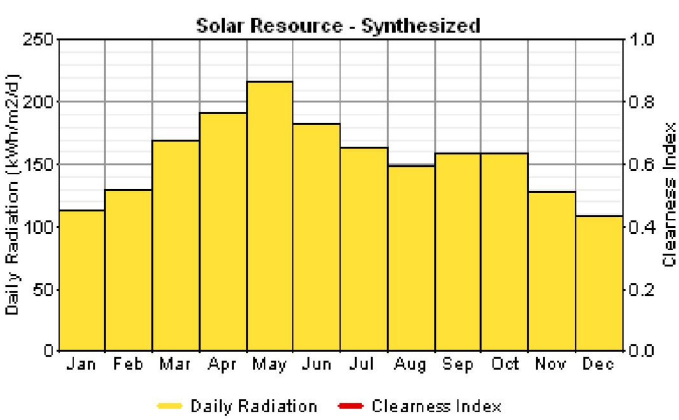

Fig. 1. Monthly average solar radiations in study area.

The study area has adequate sunshine, low to moderate wind speeds, falling water is available 8-10 months in a year frequently, and biomass resource is available in sufficient amount. Monthly average horizontal solar radiations (insolation in kW/m^2) in study area is shown in Fig. 1. Monthly average wind speed distribution at 10m height recorded at study area (30^0 04'-N, 78^0 37'-E) [Details of Bachlikhal Metrological Station] is shown in Fig. 2. During a day wind speed varies from 2.99 m/s to 6.37 m/s.

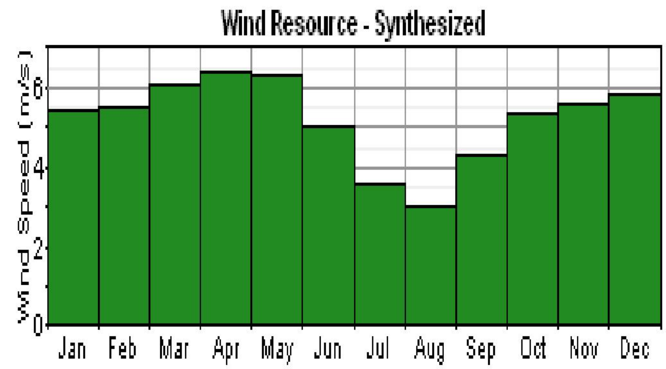

Fig. 2. Monthly average wind speed in study area.

B. Assessment of Energy Potential and Energy Demand

The energy resources data shows that the biomass constitutes maximum potential (641,385 kWh/yr) followed by micro hydro (128,166 kWh/yr), solar (22,363 kWh/yr), and wind energy (15,251 kWh/yr). Though the actual exploitation of potential will depend upon the system configuration. The total potential including all the renewable energy resources considered is about 807,165 kWh/yr. The total estimated demand is 810,000 kWh/yr. This means that the energy demand of the area cannot be fully exploiting the available resources. Therefore diesel-generator option of potential 350,400 kWh/yr is also included.

Therefore, the entire electricity generation will be 1157565 kWh/yr and accordingly the model consisting of micro hydro power (MHP), biomass energy system (BES), solar photovoltaic system (SPV), wind energy system (WES), diesel-generator set (DG) has been considered. The unit costs have been calculated using standard procedures described by [14]-[15] and are based on capital cost of installed capacity, operational & maintenance costs, life of plants etc. used for calculation of each resource.

The energy needs of the area have been identified as domestic, agricultural, transportation, and motive power for small-scale industries [16]-[17]. The energy demands in different sectors calculated on the basis of data collected from survey.

Fig. 3. Indicates the individual load in different sectors of 12-unelectrified villages of the study area with total load 810,000 kWh/yr, out of which lighting load 291,978, cooking load 396,563, other domestic load such as T.V. & fans are 51,786 & 42,964 kWh/yr. Agriculture and motive/industries loads are 135 and 26,576 kWh/yr. Figure 3. Also shows the demand of 12 un-electrified villages, out of which the lighting load is required maximum in the village no. V9 but cooking load needed maximum in all the villages. This graph also shows that the trend of consumption in the study area.

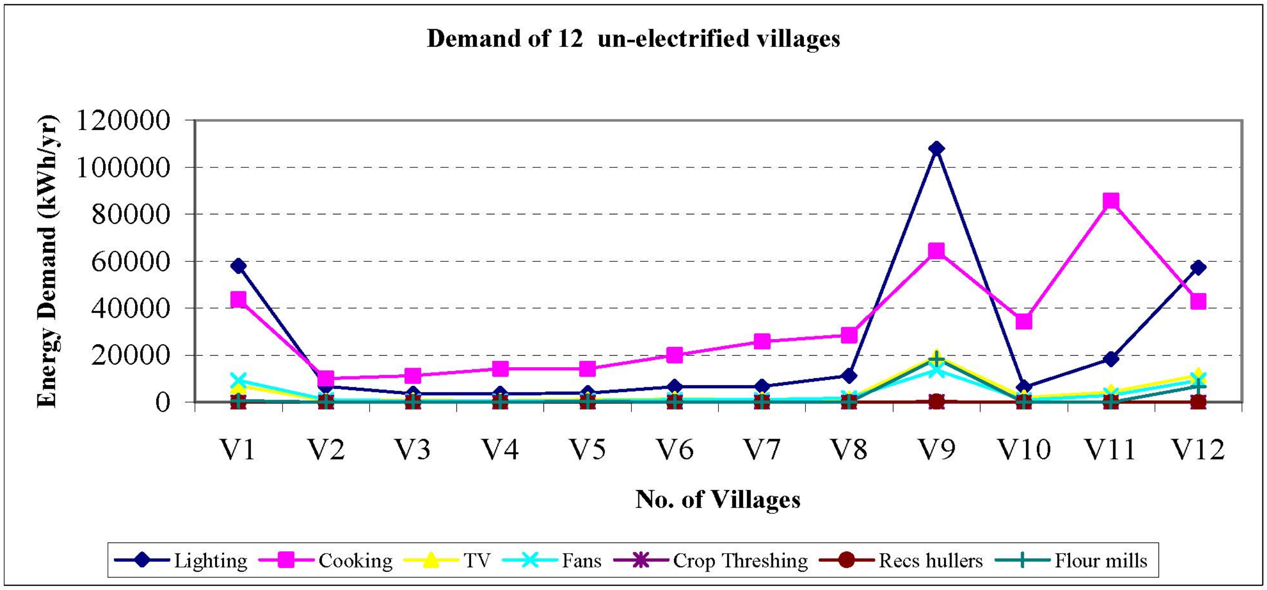

Fig. 3. Monthly load profile of unelectrified villages.

V. Model Formulation

A hybrid energy system model has been constructed for the major end uses lighting mainly and other uses also. The general model can be formulated on the basis of linear programming as [18]-[20]:

$$\begin{aligned} &\text{Minimize:} && TC = \sum C_{ij} \times X_{ij} \\ &\text{Subject to:} && \sum X_{ij} = D_j \\ & && \sum X_{ij}/\eta_{ij} \leq Si \\ & && X_{ij} \geq 0 \end{aligned}$$

Where, TC is the total cost of providing energy for all end uses for operation of the system; $C_{ij,}$ cost/unit of the i_{th} resource option for j_{th} end use (Rs/kWh); $X_{ij,}$ optimal amount of the i_{th} resource option for j_{th} end use (kWh); $D_{j,}$ total energy for j_{th} end use (kWh); S_i, availability of the i_{th} resource option for j_{th} end use (kWh); $\eta_{ij,}$ conversion efficiency for the i_{th} resource option for j_{th} end-use.

The effective cost per unit of energy (C_{ij}) for each of the proposed resource-device combinations (variables) is an important factor in the optimization model. The main objective is to optimize an objective function subject to a set of constraints. The cost function governs the optimal mix in such a manner that resources with lesser-cost function share the greater of the total energy demand in an attempt to optimize (minimize) the objective function.

To account for the fluctuation in the total energy delivered by the SHP, a term known as effective power delivery factor (EPDF) has been introduced, which may be defined as the ratio of the power obtained per year to the maximum power available per year.

VI. Optimization Results and Discussion

The unit cost of energy of different resources and optimized cost for hybrid energy systems (HES) using LINDO software 6.1 version [21] are shown in Table I. and Table II.

TABLE I
UNIT COST OF ENERGY FOR DIFFERENT RESOURCES

SI. No.	Type of Energy Resource	Cost of Energy (Rs/kWh)
1.	Micro Hydro Power (MHP)	1.50
2.	Solar Photovoltaic (SPV)	15.27
3.	Wind Energy System (WES)	3.50
4.	Biomass Energy System (BES)	3.10
5.	Diesel Generator (DG)	15.48

TABLE II
UNIT COST OF HYBRID ENERGY SYSTEM

System Type	Installed capacity (kW)	Resource Fraction (kWh)	Optimal cost of hybrid system (Rs)	COE of Hybrid System (Rs/kWh)
MHP	19.26	115464.87	4045098	4.99
SPV	2	20146.84		
WES	3	12200.79		
BES	70	543546.62		
DG	60	118640.87		

The results shown are for specified parameters, which can vary for individual customers, as well as, from area to area. It can be seen that the least economical system is the stand-alone micro hydro generation system (1.50/kWh) as it has to be run all the time in order to meet the load demand constantly. On the other hand, the most expensive system is the stand-alone diesel generator (15.48/kWh) because it has the highest replacement costs. It needs to replace the generator once every

TABLE III
VARIATION OF UNIT COST WITH EPDF

SI. No.	EPDF	Unit Cost (Rs/kWh)	Load Distribution					Energy Availability
			MHP (kWh)	SPV (kWh)	WES (kWh)	BES (kWh)	DG (kWh)	
1.	1.0	4.99	115464.87	20146.84	12200.79	543546.62	118640.87	MHP: 19.26 kW
2.	0.9	5.19	103918.37	20146.84	12200.79	543546.62	130187.36	SPV: 2 kW
3.	0.8	5.39	92371.89	20146.84	12200.79	543546.62	141733.84	WES: 3 kW
4.	0.7	5.59	80825.40	20146.84	12200.79	543546.62	153280.34	BES: 70 kW
5.	0.6	5.79	69278.921	20146.84	12200.79	543546.62	164826.82	DG: 60 kW
6.	0.5	5.99	57732.40	20146.84	12200.79	543546.62	176373.31	
7.	0.4	6.189	46185.945	20146.84	12200.79	543546.62	187919.79	
8.	0.3	6.38	34639	20146.84	12200.79	543546.62	199466.78	
9.	0.2	6.58	23092.97	20146.84	12200.79	543546.62	211012.76	
10.	0.1	6.78	11546.48	20146.84	12200.79	543546.62	222559	
11.	0.0	6.98	0.0	20146.84	12200.79	543546.62	234105	

three years while the hybrid energy systems needs to replace the generator only once every six years. So the stand-alone system will cost more money than it is necessary.

Regarding the biomass energy it is clear that potential of biomass is sufficient with second lowest cost of energy. In order to fully utilize the biomass resource, one is required to explore the possibility of generating electricity using biomass gasifier engine system in decentralized mode because the cost of generation from the individual resource is Rs 3.10/kWh followed by wind energy system (3.50/kWh), solar photovoltaic system (15.27/kWh).

Table III. Shows the optimization results of hybrid energy model for different values of EPDF from 1.0 to 0.0 and graphically represented in Fig.4. It gives the share of different sources with different EPDF value. It indicates that an EPDF of 1.0, the SHP plant deliver its maximum energy to the load. Similarly, an EPDF of 0.9 gives 10% reduction in the energy delivery capability of the SHP plant. In the present model, it is felt also that the breakdown/nonfunctioning/fluctuation in the discharge of SHP may drastically affect the unit cost of hybrid energy system model. With decrease in EPDF from 1.0 to 0.0, the unit cost of generation increases from 4.99 to 6.98.

VII. CONCLUSIONS

Given the fact that a hybrid energy system consisting two or more energy system has the advantage of stability and supplying the power on sustainable basis. The objective of the electrification at the study area can be achieved by making use of wind, solar, micro hydro and biomass with diesel generator. The information about local wind, solar, micro hydro and biomass indicates that a feasible hybrid energy system can be planned, modeled and designed for the above purpose. The collected data of the various energy sources were analyzed in order to plan for the structure of the system.

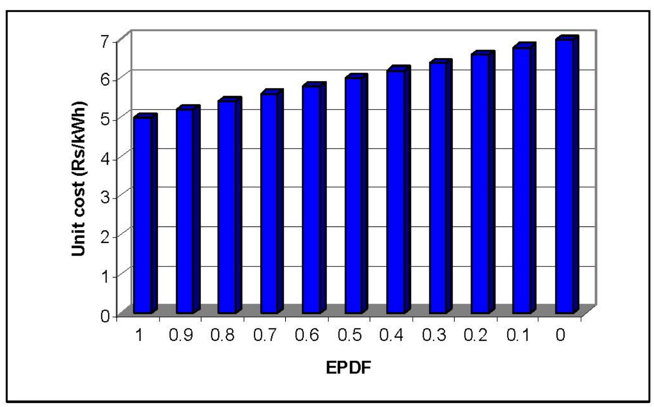

Fig. 4. Variation of Unit cost with EPDF.

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IX. BIOGRAPHIES

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