Modeling and Optimization of Integrated Renewable Energy System for a Rural Site

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***Abstract*— Nowadays, the increasing energy demand and the limited reserves of the conventional sources have raised the concerns of the researchers all around the globe to look for alternative resources. In addition to the rising demand concerns, the environmental concerns have led to the emergence of green power technologies in energy sector. Green power technologies include the power generation from clean and inexhaustible sources like solar energy, wind energy, hydro, biomass, etc. Hybrid renewable energy systems comprising of two or more renewable energy sources have been proposed to overcome the limitations of individual energy sources and make the system more reliable and less costly. The main point of consideration, while designing the hybrid system, is the sizing of different components.**

In this paper, a PV/Wind/Biomass hybrid system has been considered for supplying an electrical load in a remote area. An optimal configuration of different renewable energy system has been obtained. The optimal configuration has been determined by taking the total cost as the objective function. The optimization is then done through optimization software of Hybrid Optimization Model for Electric Renewable (HOMER). The results obtained

Key Words — Green Energy Sources, Hybrid renewable energy system, Modeling, Optimization, HOMER

I. INTRODUCTION

Even with such developments going all around the globe, a big percentage of the world's population residing in the remote rural areas is still not getting the advantages of such developments. Such areas are geographically located in such a manner that the access to these areas is very difficult. These areas are very sparsely populated. In such scenario, connecting these areas to the utility grid is tedious and uneconomical task. This sparsity is the prime impediment in the development of a country. Electrical energy is considered as the most convenient and clean energy and is, therefore, considered as the most viable option for the development of a nation. Nowadays, renewable energy resources are considered as the most suitable option as they are environment friendly, sustainable and inexhaustible. It is a well known fact that the standard of living of any society improves with the provision of resources to that society. Besides being abundant, renewable energy resources have the limitations of intermittency. In addition, these resources are site specific, that is, different sites have different availability in terms of resources as well as their quantum. These limitations of renewable energy resources can either be overcome by creating a renewable based energy generation facility or by the development of integrated renewable energy systems (IRES) [1]. The utilization of two or more resources in tandem to supply different energy needs is termed as IRES [2, 3].

This option has opened new avenues to provide electricity to remote rural areas in decentralized mode.

In this paper, different possible renewable energy resources combinations have been presented and the best combination based on minimum cost of energy (COE) criteria has been suggested.

II. MODELLING OF RESOURCES

A. Photovoltaic system

It is important to have a proper understanding of PV module performance under different operating conditions for appropriate application of PV modules in a stand-alone system. Various parameters that influence the the performance of a crystalline silicon PV module are temperature of module , PV module material and the solar radiance on the PV module surface [4]. Mathematically, from the input solar radiations to PV system, the total solar radiations on an inclined surface is estimated as

$$I_T = I_{Direct} R_{Direct} + I_{Diffuse} R_{Diffuse} + R_{Reflected} (I_{Direct} + I_{Diffuse}) \quad (1)$$

where, I_{Direct} and $I_{Diffuse}$ are direct and diffuse solar radiations, $R_{Diffuse}$ and $R_{Reflected}$ are the tilt factors for the diffuse and reflected part of the solar radiations [4]. Hourly power output from PV system with an area A_{PV} (m^2) on an average day of i_{th} month, when total solar radiation of I_T (kWh/m^2) is incident on PV surface, is given by [5]

$$P_{PV} = I_{Ti}\, \eta\, A_{PV} \quad (2)$$

where, system efficiency [6]

$$\eta = \eta_{mod}\, \eta_{PC}\, P_f \quad (3)$$

and the module efficiency η_{mod} is given by

$$\eta_m = \eta_r [1 - \beta(T_c - T_r)] \quad (4)$$

where, η_r is the module reference efficiency, η_{PC} is the power conditioning efficiency, P_f is the packing factor, β is the array efficiency temperature coefficient, T_r is the reference temperature for the cell efficiency and T_c is the monthly average cell temperature [7]

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A. Wind energy system

A wind turbine follows a typical power output characteristic. Depending upon the manufacturer's specifications, the wind turbine starts generating power at the cut-in speed. The power output increases linearly with the variation of wind speed from cut-in speed to rated speed. At wind speeds greater than cut-out speed, the wind turbine shuts down for safety considerations. The rated power output is obtained at rated wind speed of the turbine [8]. Mathematically, the power output from a wind turbine is given by

$$P_W = ½ . \rho_a. A. Cp. v^3 \quad (5)$$

where, P_w is the power output, ρ_a is the air density, A is the swept area, C_p is the power coefficient and v is the wind speed.

B. Biomass Power Output

The power output from biomass depends upon the volume of gas (V_{BM}) consumed in time, t and is expressed as:

$$PBM = VBM \times CV \times t \quad (6)$$

III. OPTIMIZATION

In general, the optimization problem comprises of an objective function that has either to be minimized or maximized. Classical optimization techniques are based on gradient search approach. A repetitive search has been made in order to get the optimum solution with all its constraints satisfied [9 -11].

A simple resource-load matching based IRES model has been considered in this study with electrical energy as the end-product. Various agricultural, domestic, community based and rural demands are tried to be supplied from the available resources. As the objective function is linear, linear programming approach has been utilized to optimize the function. The formulated model is given below:

Minimize: $C_{Total} = \sum C_{ij} \times S_{ij}$ (9)

Subject to: $\sum S_{ij} = D_J$ (10)

$\sum (S_{ij}/\eta_{ij}) \leq A_J$ (11)

$S_{ij} \geq 0$ (12)

where; C_{Total} is total cost of providing energy for end use (Rs); C_{ij} is cost/unit of i^{th} resource option (Rs/kWh); S_{ij} is optimal share of i^{th} resource option for j^{th} end use (kWh); D_J is total energy for j^{th} end use (kWh); A_i is availability of the i^{th} resource option for j^{th} end use (kWh); η_{ij} is conversion efficiency for the i^{th} resource option for j^{th} end use.

III. CASE STUDY

A hilly remote village is considered for the electrification through IRES. Because of uneven terrain and dense forest, it is difficult and uneconomical to electrify these villages through grid connections. The best option suitable is the locally available renewable energy sources. The population of village is estimated as 1500 in 300 households. Most of the people living in these areas are uneducated with their main business as agriculture. The general electrical energy consumption areas are broadly classified as agricultural, domestic, small scale industries and community. The major electricity consuming appliances that are considered under domestic demands are fan, television and compact fluorescent lamps. Crop threshing machines are the main electricity consuming machines comes under the category of agricultural demands. The community load.includes schools and village panchayat offices. Milk processing plant is considered as load of small scale industry in the area. The daily and seasonal load profile of the area is shown in Fig. 1. It can be clearly seen that the annual peak load of 125 kW is occurred in January. The large demand occurs during the season in between April to August and the lower demand season is in between September to March.

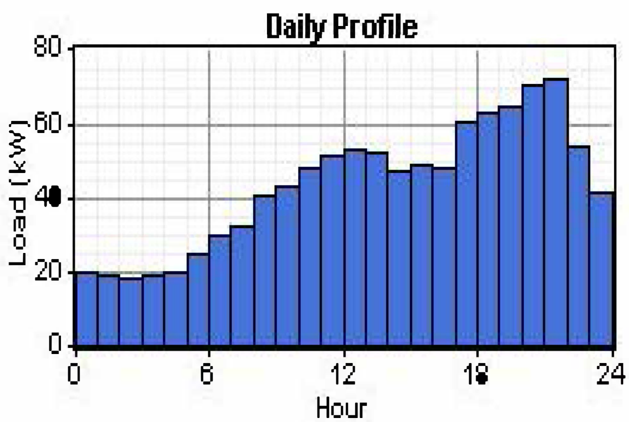

Fig.1a. Daily Load Profile

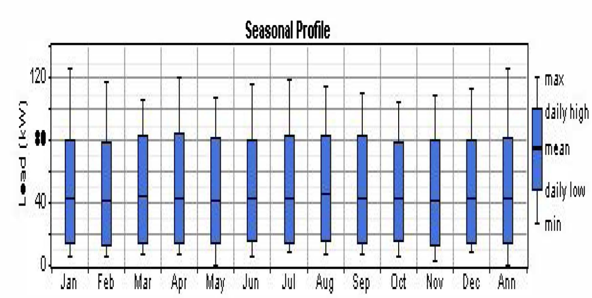

Fig.1b. Seasonal Load Profile

A. Solar energy potential

The clearness index and solar radiation are plotted in Fig. 2. The scaled annual average is 5.09kWh/m^2/day. The plot clearly shows that there is a good potential of solar energy.

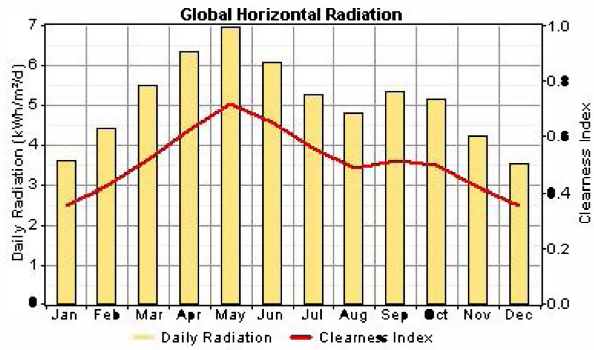

Fig.2. Clearness Index and Daily Radiations

B. Wind energy potential

The wind speed is quite low in the region. The scaled annual average wind speed is 4.77m/s. The wind speeds is presented by Weibull distribution form as shown in Fig. 3. Based on hour to hour variations, the autocorrelation factor is measured as r_1=0.81. The diurnal pattern strength is 0.25 represents as the strength of a wind speed and the windiest time is ø=15.

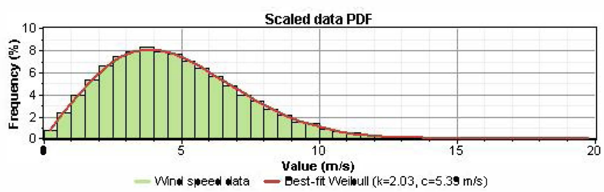

Fig.3. Weilbull Distribution

IV. RESULT AND DISCUSSION

The IRES has been simulated in HOMER. HOMER provides the detailed rigor of chronological simulation and optimization in a model. The simulated model has been shown in Fig. 4. To obtain an optimum size combination of different resources, a range of sizes of all the resources with their capital, replacement and annual maintenance cost has been inputted. The size ranging from 5 – 50 kW of PV system has been considered. Similarly, the number of wind turbines. With this range of ratings, 3744 simulations were done and unit cost of energy has been computed for each simulation.

Out of these simulations, the least cost of energy was found to be Rs. 12.462 per kWh with the PV generator of 5kW, number of wind turbines as 6 of rating 250kW and hydro generator of 10kW.

It was also found that there is a capacity shortage of at most 10%. This capacity shortage can be overcome by exploring other resources like biomass in the region and/or optimal scheduling of resources.

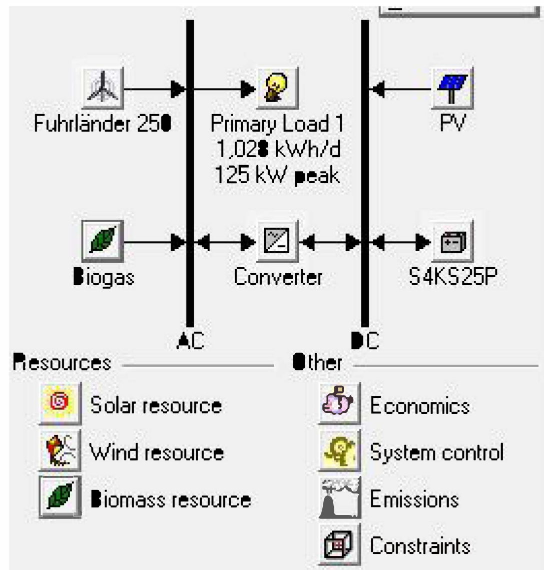

Fig.4. Simulated Model

V. CONCLUSION

It is a challenge to provide reliable and cost effective electrical energy at remote and distant places. Utilization of modelling and optimization techniques to the integrated system paves a way in this direction. In this paper, a method for designing a stand-alone integrated renewable energy system that is capable of supplying the basic energy needs of remote rural areas has been presented. As the first step, the resource and load potential has been estimated. Based on resource-need matching, a model has been simulated for different combinations of sizes of resources. HOMER has been used as simulation tool that can model both the technical and economic factors involved in the project. The least cost of energy was found to be Rs. 12.462 per kWh.

The model developed through HOMER basically is based on the assumption of values of resources which is not realistic. On the contrary, the design needs a proper and realistic estimation of these values. It is, therefore, concluded that there is a need to establish procedures to estimate the values using some statistical techniques.

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