Optimal Economical Analysis and Performance Assessment of Wind-Biomass Hybrid Energy System

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***Abstract*—Recently, due to increase in the environmental issues, fuel prices, energy demand, and the depletion in the fossil fuel reserve, hybrid renewable energy system (HRES) are receiving great attention worldwide. Since many remote regions in our country, off-grid power generation does not have grid connection. Therefore the large interest is taken in the installation of off grid power generation which depends on renewable power sources. The hybrid power system which contains power producers like battery and diesel generation, which can be introduced along with other RESs. Recently, by using suitable load profile techno-economic feasibility analysis for off grid biomass-based HRES is investigated for a remote location. In these remote location the end users do not have an option for the grid extension. Particle swarm optimization (PSO) is utilized for various applications such as financial study, optimization, seizing, and system analysis. In addition, battery profile and wind turbine profile are various profiles of the system. The results which are obtained suggest that the cost of energy (COE) for the considered area is found to be within the acceptable margin in the range of 0.691-1.103 $/kWh.**

Keywords—Energy based on biomass, Cost of energy, Annualized cost of the system, Hybrid energy

I. Introduction

Considering the present conventional energy resources for electricity generation, for rural electrification, renewable energy sources may play an important role. However, weather conditions affect renewable energy resources (RESs) and make them less competitive in general. renewable energy resources (RESs) are uncertainty and irregular in nature.

To provide an economical, reliable and sustained supply of electricity to overcome this intermittent and uncertainty of RESs. The researchers have combined RESs, which yields a hybrid system [1]. Different combinations of energy source such as conventional and renewable that can be operate separate or mode of grid connected [2] are integrated to form Hybrid renewable energy system (HRES).

In a remote location where grid extensions both not possible and not viable because of economic issues, therefore, the use of wind energy alteration system alongside storage devices and PV have found to be very useful [2]. However, both the wind energy resources and PV are stochastic in nature. However, this might influence the consistency of power to the final users. By making the hybrid of both wind energy and PV is one appropriate substitute which increases the viability of these RESs dependent system such that they can balance each other. However, as both the sources are intermittent in nature, therefore this combination depends upon power backup. For such a stand-alone hybrid system, it is necessary to supply a power backup. Instead of using a diesel generator for backing in a hybrid system which increases environmental problems. To alleviate these problems, wind and PV sources along with various RESs options have been integrated. Among these options, a more viable option seems to be biomass, mainly in the agriculture where the developing nations such as India where the economy mostly relies upon agriculture. In India, through biomass electricity generations have been integrated along with other RESs which is found to be a reliable, price-efficient and a best suitable solution for harnessing electricity for people in rural areas where there is no electricity. Also, as it is cost efficient and has a high load factor, nowadays biomass power generation plants are becoming popular.

Around an average of 200 MW per square kilometer of solar radiation is collected in India. Approximately, a 102788 MW of wind energy for the grid extension has been estimated in India. 500 million metric tons of biomass is currently available every year. Biomass provides an average 32% of basic energy requirements of India for rural areas [3]. With optimal usage of these RESs, need for electricity in rural areas can be accomplished.

The important factors which influence such hybrid systems are mainly overall system sizing, existing capacity of the RESs for rural areas and system cost. The hybrid RESs dependent systems need the correct system equipment choice and power conditioning devices capacity, optimal sizing of RESs system and energy system that stores energy which is storage battery bank including the implementation of a competent energy dispatch plan [4]. The selection of the RESs technologies to be utilized basically depends on the availability of RESs where this system has to be developed in a unique site. The presence of solar radiation and wind speed or the local weather conditions also play an important role in taking main decisions. The load necessities such as greenhouse gas release in the expected system life cycle, reliability, energy form change efficiency, economic impacts, and social issues are the other factors which may be taken into account while proper designing. The systems economy and dependability mainly depend on the optimum sizing of a hybrid power system.

In [5] introduced a new way for planning and examining an hyper-hybrid PV-wind power systems for both grids and separately joined uses. The price of electricity is reduced while the load demands are met in a consistent manner by the use of principle called linear programming. With the help of approach, i.e., Genetic Algorithm (GA), a finest energy model that is integrated renewable has been developed in various places of Karnataka [6] which includes wind turbine generator, solar PV, mini hydro and biomass gasifier. The reliability of these models does not depend on optimization power factor (OPF) and served (EENS) rather it depends on the idea of calculated energy. A combined renewable energy system replica to electrify the village areas in Karnataka, India is introduced by Rajanna et al. [7] based on biomass, biogas and solar. This study used HOMER software to compare and determine the various forms of the mixed renewable energy system according to COE, NPC and pollutional realises. Singh et al. [8] present a better method for hybrid energy system based on grid-connected PV-Biomass and a standalone which serves the electricity to rural areas. In this method, the artificial bee colony (ABC) algorithm has been utilized. The authors compared the results of the ABC algorithm and HOMER. The experimental results show that the ABC algorithm gives better results in comparison to HOMER.

In the existing literature, it has been found that maximum works were done to optimize grid attached and standalone PV-Wind dependent hybrid system. Less number of work has been done in the part of literature in which optimization techniques are utilized for a biomass-based hybrid energy system. Therefore, a stand-alone hybrid Wind-Biomass system having device for storing is proposed to supply electricity in a remote location.

II. Problem Formulation

A. Proposed hybrid system

Design of the hybrid system is focutilized in this study to provide electricity in a reliable manner to remote locations. The diagram of the suggested system is shown in Fig. 1. This system contains biomass gasifier and wind turbine with a battery bank which can be utilized for storing. These batteries are utilized without the need for other devices as they compensate the energy lost and store the extra energy. Other parts of the system along with the load are joined to an alternating current (AC) bus. The batteries are joined to the AC bus through a bi-directional converter. To maintain even power flow and inhibit the charge and discharge of batteries power, we use a charge controller.

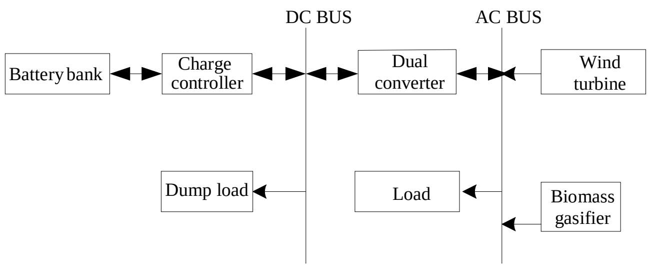

Fig. 1. Depicts the proposed system

B. Wind turbine modeling

The wind turbine produces power $P_{wt}(t)$ per hour is given in [8]:

$$P_{wt} = \begin{cases} 0, & v(t) < v_{cin} \text{ or } v(t) > v_{cout} \\ P_r^w, & v_{rat} \le v(t) \le v_{cout} \\ P_r^w \times k, & v_{cin} \le v(t) \le v_{rat} \end{cases} \quad (1)$$

Where, $k = \left(\frac{v(t) - v_{cin}}{v_{rat} - v_{cin}} \right)$

A single wind turbine has rated power P_r^w cut-in speed is represented as v_{cin}, a rated velocity of the wind is represented as v_{rat}, the cut-off velocity is represented as v_{cout} and the speed of the wind at required height is represented as $v(t)$.

At hub height the speed of wind is given as:

$$v(t) = v_r(t) \times \left(\frac{H_{wt}}{H_r} \right)^{\gamma} \quad (2)$$

In this, $v(t)$ represents speed of the wind at height H_{wt}, $v_r(t)$ represents speed of wind at reference height H_r and γ is the friction coefficient. The magnitude of the friction coefficient is assumed as 1 /7 [8].

C. Modeling of biomass gasifier

The biomass gasifier rating (P_{bmg}) is computed as [8]:

$$P_{bmg} = \frac{E_{bmg}}{8760 \times CUF} \quad (3)$$

where CUF and E_{bmg} is the capacity utilization factor and yearly output electricity of the biomass gasifier system respectively.

The maximum rating of the biomass gasifier installed can be defined as [9]:

$$P_{bmg}^{m} = \frac{Total\ biomass\ available \times CV_{bm} \times \eta_{\text{bmg}}}{365 \times 860 \times Operating\ Hours} \quad (4)$$

In this, CV_{bm} and η_{bmg} is the biomass calorific value and total biomass to electricity conversion efficiency respectively.

D. Battery Bank Modeling

The battery power and the battery condition of charging that is available at an hour of time t is given by the help of equation (5) and (6) as given below:

$$P_b(t) = [-P_W(t) + P_l(t)] \times \eta_{con} \quad (5)$$

$$SOC(t) = SOC(t-1) - \frac{P_b(t) \times \Delta t}{1000 \times C_b} \quad (6)$$

where $P_w(t)$ and $P_l(t)$ represents total output power for wind turbine (kW) and sum of load at time t, respectively. The simulation step time (equated to 1 hour) is Δt and C_b represents the total nominal capacity of the battery in kilowatt-hours.

When a battery is charging, $P_b(t)$ is negative and while discharging, it is positive.

The highest value of SOC for battery bank is equivalent to the overall capacity of the battery bank which can be written by the following equation (7):

$$C_n = \frac{N_{batt} \times C_b}{N^S_{batt}} \tag{7}$$

Where, C_b is the individual battery capacity, N_{batt} and N^s_{batt} denotes the overall number of batteries and the number of batteries joined in series respectively.

Again, the battery bank cannot discharge below a permissible restricted value called the least value of SOC. These two limits can be utilized as system restrictions in accordance with utilization of the battery bank.

The highest charge or discharge power is another important issue for battery modeling as it relies upon the highest charging current and can be calculated as:

$$P_b^{\max} = \frac{N_{batt} \times V_{batt} \times I_{\max}}{1000} \tag{8}$$

In this, I_{max} is the highest charging current of the battery.

E. Power Inverter model

The rating of the converter is chosen using [8]:

$$P_{inv}(t) = \frac{P_l^m(t)}{\eta_{inv}} \tag{9}$$

In this, η_{inv} is the inverter efficiency.

F. Strategy of Operation

A power dispatch plan is required to get good results along with least cost of energy (COE).

Wind turbine and, charge/discharge of the batteries generate time-dependent power. For estimating the sizing of the hybrid energy system (HRES), the wind power is considered to have the maximum priority for meeting the load requirement.

The summary of operation has been discussed as:

a) If a single wind turbine generates the power of P_{wt} (t), then the overall power produced using wind turbines is expressed as:

$$P_W(t) = P_{wt}(t) \times N_{wt} \tag{10}$$

b) The overall power produced using wind turbines is adequate, and the requirement of load may be met via only the wind power. Fulfilling the load, the rest of excess power may be fed to the battery bank that is written as:

$$P_b(t) = [-P_W(t) + P_l(t)] \times \eta_{inv} \tag{11}$$

Where η_{inv} is inverter's efficiency and $P_l(t)$ represents load demand at time t.

c) Excess energy is dumped when battery power surpasses the allowed capacity level of the battery bank. Extra energy is given as:

$$P_{dump}(t) = P_W(t) - P_l(t) + P_b(t) \tag{12}$$

d) If the load demand is not fulfilled by the power generated via wind turbine, then the battery provides the balance power which is calculated as:

$$P_b(t) = [P_l(t) - P_W(t)] \times \eta_{inv} \tag{13}$$

e) When the wind power is not enough and even batteries ($SOC(t)<SOC_{min}$), are not capable in generating the desired power for completing the load demand, in that case, the biomass gasifier gives power to the load which is written as:

$$P_{bmg}(t) = P_l(t) - [P_W(t) + P_b(t)] \tag{14}$$

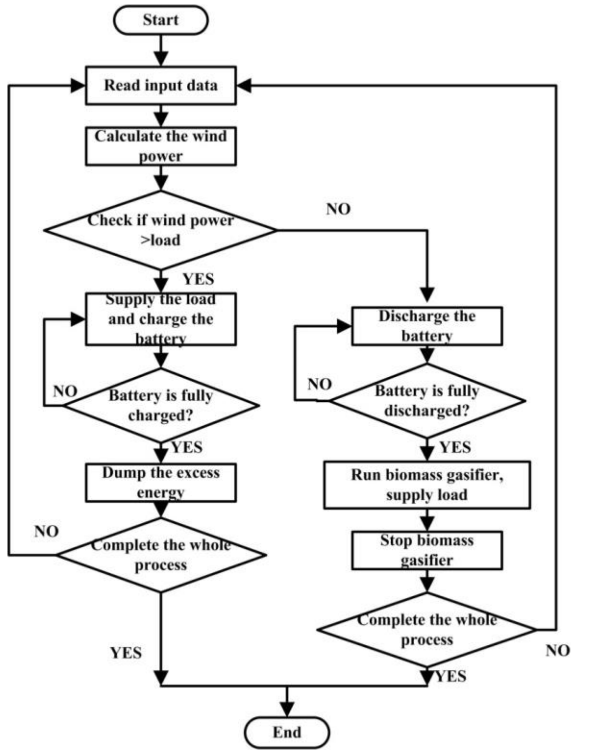

Fig. 2. Proposed Strategy of Operation

A schematic diagram is shown in Fig. 2 to exhibit the strategy of operation of the given HRES.

G. Formulation of Objective Function

The important objective function here is a minimization of the overall system cost, which includes replacement cost, total capital cost, operational and maintenance price of the parts. Capital cost includes installation and other costs.

$$ACS = N_{wt} \times C_{wt} + N_{batt} \times C_{batt} + P_{inv} \times C_{inv} + P_{bmg} \times C_{bmg} \tag{15}$$

It consists constraints such as:

$$N_{wt}^{\min} \le N_{wt} \le N_{wt}^{\max} \tag{16}$$

$$N_{batt}^{\min} \le N_{batt} \le N_{batt}^{\max} \tag{17}$$

$$P_{bmg}^{\min} \le P_{bmg} \le P_{bmg}^{\max} \tag{18}$$

$$SOC_{\min} \le SOC \le SOC_{\max} \tag{19}$$

$$P_W + P_{bmg} + P_b = P_l + P_{dump} \tag{20}$$

Where, C_{wt}, C_{batt}, C_{inv}, and C_{bmg} are the price of the wind turbine, battery, inverter and the biomass gasifier respectively. P_{bmg} and P_{inv} are the ratings of the gasifier of biomass and the rating of the inverter respectively. N_{wt} and N_{batt} stand for the count of wind turbines and batteries respectively.

III. Application of Particle Swarm Optimization

The problems are solved using PSO, the control variables of the objective function, such as the optimal rating of the biomass gasifier, the absolute number of the wind turbines and the complete number of reserved batteries are taken as the position of the particles. Then to solve problems in the same process, which is mentioned in computational steps are utilized. The flow chart representing the implementation of the problem in PSO is shown in Fig. 3.

IV. Result and Discussion

A. *Data collection*

A town which is discovered at a geographical co-ordinate of 30.260 North latitude and 76.120 East longitudes is taken for case study in this work. The total number of people of the above-taken locality is nearly 702 and an entire house in the location is 130 [8].

60 kW is the highest demand of the proposed site. But, the highest demand on the system is taken as 70 kW considering future demand [8].

The load profile hourly of the house area for a sample day is shown in Fig. 4.

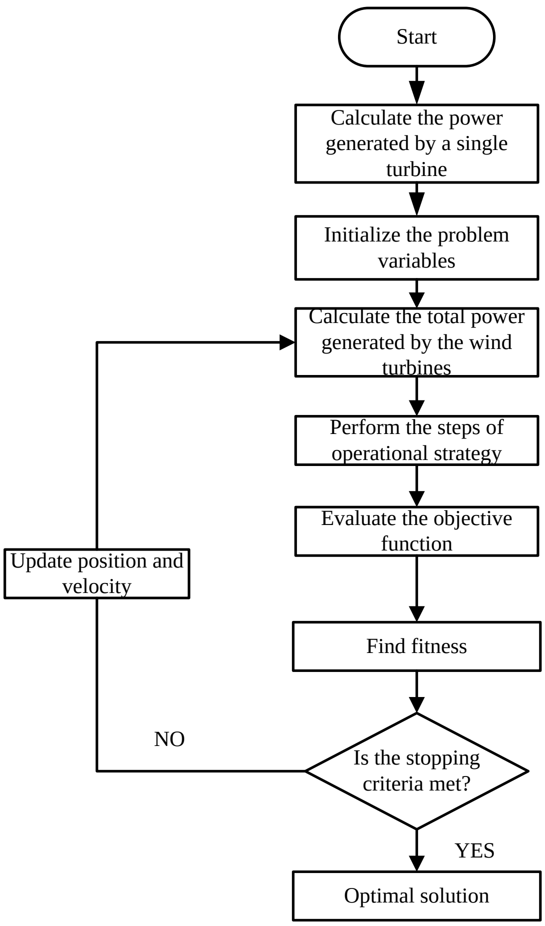

Fig. 3. Implementation of PSO

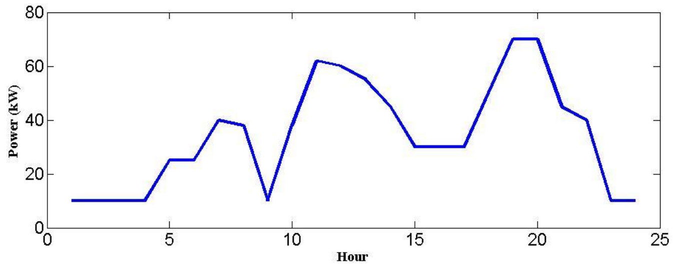

Fig. 4. Load Profile Hourly

B. *Wind Turbine Output Power*

Load demand and wind turbine are compared according to the power they generated are shown in Fig. 5. According to the comparison, we can easily understand that during the peak hours there is some deficiency of wind power in the system. Also in off-peak hours, there is some excess power generated by the wind in the system. The batteries are discharged to meet the shortage power and overload power will assist in getting the batteries charged in peak hours, otherwise, gasifier of biomass will give the necessary power.

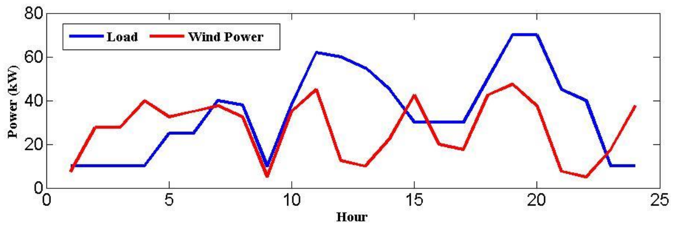

Fig. 5. Hourly Output of Wind Turbine

C. *Battery Specification*

If a load is less than the power produced in the wind turbine then the batteries of the hybrid device are helpful to reserve the excess energy. If there is any power shortage in the system, will be solved by Batteries by supplying the reserved energy to that system. The nonstop changes in discharging or charging the battery power are shown in Fig. 6.

From Fig. 6, it is seen that the batteries are discharged at the peak hours and during the off-peak hours, the batteries are charged.

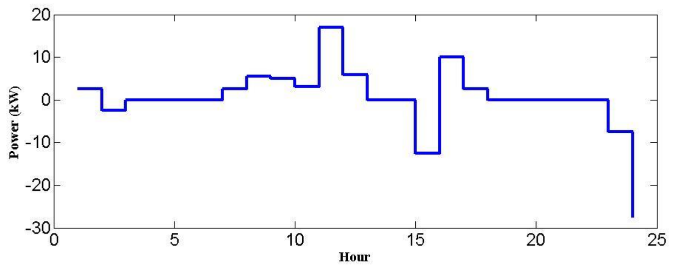

Fig. 6. Discharging and Charging Features of Battery

D. Detailed Description of Gasifier of the Biomass

When there is no sufficient reserve power in a system, the gasifier of biomass will satisfy the excess power. That means power given by gasifier of biomass is helpful in fulfilling the load required when the battery is not able to supply power to a system.

Output power from gasifier of biomass is shown in Fig. 7. As discussed before, the main power source is wind in the proposed hybrid system. If the load is still in demand, next, the batteries discharge and gives the battery power which is stored in it to the system. When stored power is unavailable in the battery then even the batteries are unable to provide power to a system, in that case, power from gasifier of biomass is vital in providing power to the system.

From Fig. 7, we can see that the biomass gasifier supplies power during the peak load hours only as during that hours the power given by battery and wind aren't sufficient to fulfill the load.

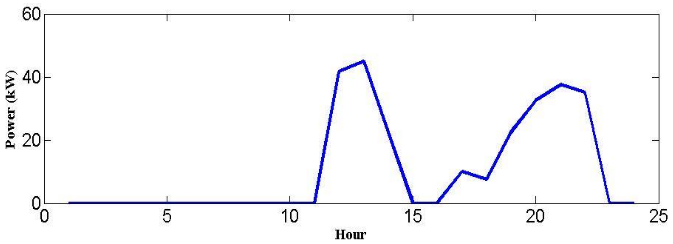

Fig. 7 *Gasifier of Biomass Output*

Fig. 8 demonstrates the power production in twenty-four hours from the sustainable sources alongside the power of the battery.

Using PSO algorithm we got the final optimized results as shown in Table 1. Using PSO algorithm, the rating of the gasifier of biomass and the best possible count of wind turbines, batteries are 45 and 22, 1200 with an ACS of 41664 $/year.

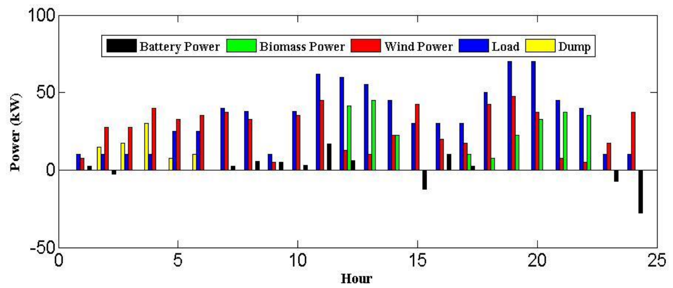

Fig. 8 . *Production from Individual Components*

TABLE I. OPTIMIZED SIZING RESULT ACQUIRED

Algorithm	**Wind Turbine** *(Units)*	**Gasifier of Biomass** *(kW)*	**Battery** *(Units)*	**Converter** *(kW)*	**ACS** *($/year)*
PSO	22	45	1200	115	41664

V. CONCLUSION

Energy supply is the main problem in remote locations in developing countries, the proposed system seems to be the most feasible solution. It requires a high investment at starting, according to the economic analysis the investment for a rural region that stand-alone hybrid energy system can be much cost effective when compared to the conventional grid connection supply. According to this study, the appraisal of the calculation of load demand has been carried out and various resources and the annualized cost of the system (ACS) has been calculated through the optimized result achieved using PSO algorithm for the suggested system configuration. In the present work, exploration of RESs like wind, biomass by considering a rural area is presented. The techno-economic feasibility analyses of RESs are performed with optimization algorithms. In summary, the proposed system with optimal ACS can be considered as a feasible as a feasible option for generation of electricity for the end users.

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