Economic Feasibility of Stand-Alone Wind Energy Hybrid with Bioenergy from Anaerobic Digestion for Electrification of Remote Area of Pakistan

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Abstract: Hybrid Renewable Energy systems (HRES) are gaining importance throughout the world because of the finite sources of oil and gas reservoirs. These have the great ability in the production of electrical energy and cleaning the environment. It is difficult to get grid electricity in the remote areas where no infrastructure exists. The utilization of renewable sources is the ultimate solution for the generation of electricity. In this paper, the economic modeling of Hybrid system consisting of Wind/biomass is explored for the remote area 'Jangiah' of Balochistan province, Pakistan. Anaerobic Digestion of biomass is used to get biogas. This source is used to complement the uncertainties in the wind production. Homer is used to simulate the hybrid model. Economic analysis is performed to get the net present value (NPV) and cost of energy. It is observed that wind/biomass alone is capable to meet the demand of community which consumes 60 kW peak daily along with the storage backup. This system is the most economical with COE equal to 0.118 US$/kWh following the hybrid biomass/wind/diesel system with COE 0.202 US$/kWh. The sensitivity analysis is carried out and shows that the proposed system is sensitive to the prices of fossil fuel and project lifespan. The net present value increases as the lifetime of the project increases from 15 years to 30 years. It can also be concluded that if the price of the diesel drops below 0.8 US$/liter, the traditional system using fossil fuels will become the most suitable system for the generation of electricity in remote areas.
Keywords – Bioenergy, Hybrid Renewable Energy system, Homer, Wind turbine, Pakistan, Cost of energy

1. Introduction

Hybrid renewable energy systems (HRES) are gaining importance for remote areas for power generation applications because of advancements in renewable energy technologies and subsequent fluctuations in the prices of fossil fuels. Economic aspects of these technologies are sufficiently capable to include them in developing power generation capacity for developing countries. Research and development efforts in biomass, wind, solar and other renewable energy technologies are prerequisite to continue improving their performance, launching techniques for precise measurement of output and reliably integrating them with other conventional generating sources.

It is interesting to build hybrid renewable energy systems in remote areas, where grid extension is neither practical nor excessively economical and where the cost of fuel considerably rises with the remoteness of the locality [1]. The term "hybrid" energy system is often used to describe a power system with more than one type of source input whether renewable or conventional such as a photovoltaic (PV), wind, biomass or hydroelectric power generator. In recent years, the utilization of these sources to meet the power demand of different regions, especially villages and towns appealed some researchers' attention. Electrical demand of the biggest island of Turkey was evaluated to catch out how it could be supplied with renewable energy sources [2]. The practicality of addition of wind turbines to an existing diesel plant for a remote area in Saudi Arabia was planned [3].

A number of researchers are working now a days on hybrid energy systems [4-11]. Balamurugan et al. [12] investigated the operation viability of hybrid systems using different hybrid sources. They performed optimization on Biomass/wind/PV hybrid system for the three remote areas of India. A system comprising of PV/biomass for the rice mill was analyzed and found that the system conserved 90 % of grid electricity when used as grid-connected [13]. They also reported the economic adaptability for the system. Another study suggested that wind, hydro and biomass can displace 32 % of fossil fuelled thermal generations [14]. An analytical method used was found to be good not only for the New Zealand

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but also for other countries with dissimilar RES mix. The hybrid biomass/solar plants are more economical for mid-scale applications as compared to biomass-only in terms of economic feasibility [15]. A hybrid system consisting of biomass-gasifiers, gas storage and wind park was proposed by Perez-Navarro et al. [16]. They evaluated the system with real-time data and concluded that this kind of system could assure the reliability of power even in peak hours. They used the biomass as a complementary element for wind power plant and hence capable to mitigate the prediction error for wind data. Stand-alone PV/biomass hybrid system was proposed by [17].

This paper proposes a hybrid system of wind/Biomass for the community of a remote area of Pakistan in a standalone use. Economic feasibility with certain sensitivities is carried out using the software. An economic model for biomass/wind hybrid system is being proposed in this paper. The objective of this research is to find the hybrid system with minimum NPV as well as minimum COE.

2. Modeling of Hybrid system

A wind/Biomass power system, which is a combination of a number of wind turbines integrated with a biomass generator, is a good choice for a remote located area of Pakistan [18], which is not connected to the grid and is a best solution for electrification of remote areas, where extension of national grid is not a cost effective option. The system analyzed consists of wind turbines, a battery, a biomass generator, a diesel generator and a DC/AC converter. In the design and modeling of the system, the system should be assumed to be an autonomous system. Such a consideration leads to the many numbers of possible system combinations.

2.1 Location

Pakistan, being an agricultural country with a population of 180 million people, has four seasons in a year. It has coastal areas in Karachi city and Balochistan province. The air blow in these coastal areas is good enough for wind energy projects [19]. It has also been estimated that Pakistan has 40 million animals including camels, mules, horses and cattle [20]. The annual growth rate of animals in Pakistan is about 8 %. Hence Pakistan is capable to manage hybrid renewable energy projects throughout the country. The project site is selected where the wind blow is quite good for the renewable energy production. The site selected is located at latitude 28.97 degrees and longitude 63.13 degrees, Jangiah, one of the remote sites in Balochistan.

2.2 Load

The load is supplied to the community of daily consumption of 500kWh with a peak of 60 kW. The community comprises of 50 households in the village. Each household consists of five family members. The load mainly consists of providing electricity for fan running and lighting. The probability density function (PDF) describes the relative likelihood of a random variable to take on the given value.

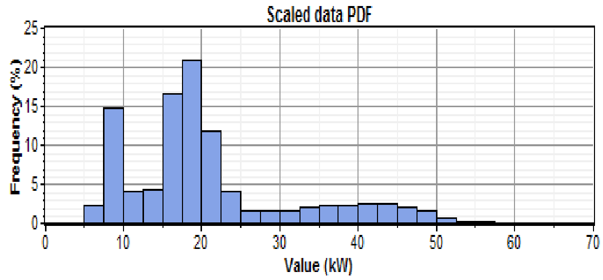

Fig. 1 PDF of Load

Fig. 1 shows the integral of the load density and moving between highest and lowest value over one day. The variation in load, depending on the location, gives the fact that it is high during peak hour time.

2.3 Wind Energy

The query is run with wind power density of 200W/m^2 to 800 W/m^2 on Pakistan map at 50 m elevation. This results many sites with 600 to 800 W/m^2 wind power density in Balochistan and Sindh province and one in Punjab province. Therefore it is decided to include the wind turbine in the system to calculate the overall cost since the speed of wind is almost above 12 m/sec. The type of wind turbine used depends on the rated power. For the community of 60 kW peak, the wind turbines used is of Furhlander FL 100/21. The specifications are given below in Table 1:

Table 1. FL 100/21 Specification.

Wind Turbine Spec.	
Model	FL 100/21
Diameter	21 m
Hub height	30 m
Tower height	35 m
Rated Power	100 kW
Lifetime	25 years

The power extracted from the wind turbine depends on wind speed and diameter of the turbine and it is given as:

$$p = 0.3v^3 \quad (1)$$

Where v = free-stream velocity of the wind

The power curve of a wind turbine can be drawn which describes the amount of power turbine produces versus the wind speed at specific hub height as shown in Fig 2.

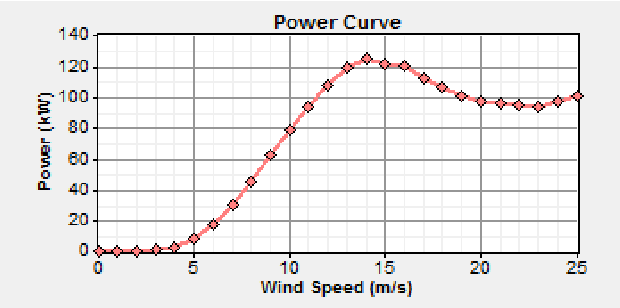

Fig. 2 Power curve of FL 100/21

The efficiency of the turbine cannot be more than 59 %, according to Betz limit. It is obvious from Fig. 2 that the efficiency is maximum when the wind speed is at 12 m/sec. Thus, this type of wind turbine is only used when the average wind speed is around 10 m/sec to 12 m/sec.

2.4 Biomass Energy

A lot of literature is available on the selection of type of biomass feedstock. The selection of feedstock used depends upon the availability. For example, Malaysia is capable to generate 9111 thousand tons Municipal solid waste in 2015 with an annual increase rate of 2.14 % [21]. In most of the developing countries, animal manure is the one which is easily available especially in remote areas and villages [22].

The conversion of biomass feedstock into biofuels is a very complicated process. This conversion has mainly two types.

1) Thermochemical process
2) Biochemical process

They are further classified into many kinds such as combustion, gasification, pyrolysis, fermentation and anaerobic digestion. Each has its advantages and disadvantages. Among them, anaerobic digestion is the process to convert the biomass into biogas and then further into electrical energy. This has the advantage that it is very simple and practicable even in villages. It does not require much technical support. The equipment used to build the digester is very common and the labor is easily available for the manufacturing of any kind of digester. It is also reported that the anaerobic digestion of cattle manure enhances the production of methane resulting an increase in electric power [23].

The collection of daily cow manure involves the transportation cost. This issue can be resolved by placing the biogas digester near the animal farm. The cow manure is collected and then used in the fixed type anaerobic digester to get biogas (mixture of methane, carbon dioxide and other traces). Fig. 3 shows the monthly available biomass cow dung for the specific remote area. The average collection of the biomass will more or less remain constant throughout the year.

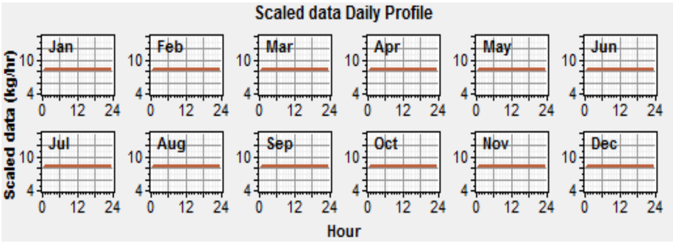

Fig. 3 Animal manure available resource

The biogas is fed to the dual fuel engine whose efficiency can be calculated by the following equation.

$$\eta = \kappa W/m.H \tag{2}$$

Where kW=rated output power of the generator

m=biogas consumption rate

H = Lower heating value of biogas generator whose efficiency curve is given below.

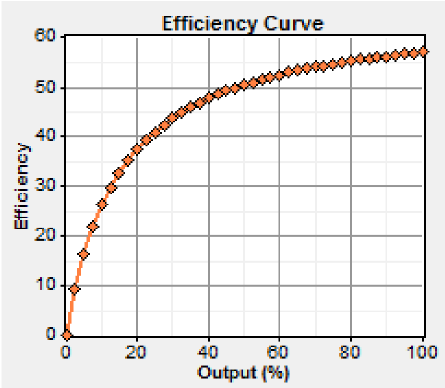

Fig. 4 Efficiency curve of Biogas Generator.

The efficiency of biogas generator depends on the lower heating value of biogas which is given in the literature as 24,500 kJ/kg [24]. Using the value, a curve between rated output and efficiency can be drawn as illustrated in Fig. 4.

2.5 Battery

The battery used for storage is Trojan L16P. The nominal voltage is 6 V with a nominal capacity of 2.16 kWh**.** The lifetime throughput of the battery used is assumed to be 1075 kWh. Fig. 5 shows the capital cost and the replacement cost when used in bulk.

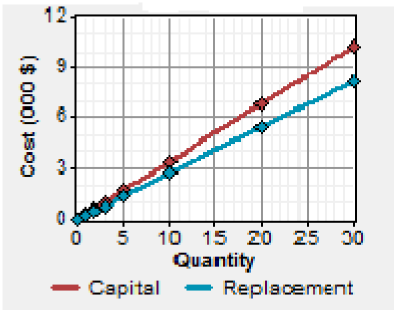

Fig. 5 Cost curve of the battery L16P

The life of the battery bank is based on the lifetime throughput and float life. It is obvious from the Fig. 5 that the cost factor is directly proportional to the no. of batteries in a bank.

3. Economic Analysis

The economic input parameters are needed for HOMER simulation. These parameters include annual real interest rate and project lifetime. After simulation was performed, HOMER ranks all systems according to total net present cost. Besides that, the levelized cost of energy might be taken into account to obtain the optimal results of different system configurations because it is another convenient metric for comparison. All these economic parameters will be discussed in the following sections.

3.1 Net Present Value (NPV)

The formulation for which the given system is optimized is given below. The present worth of the project is given by the formula as below;

$$PW = PWin - PWout \tag{3}$$

Hence NPV can be calculated by the equation

$$NPV = PW - ICC \tag{4}$$

where ICC=initial capital cost.

3.2 Levelized cost of Energy (COE)

Levelized cost of energy is the average cost per kWh and is calculated by the following formula.

$$COE = \frac{C_{annualized}}{E_{DC} + E_{AC}} \tag{5}$$

Where, $C_{annualized}$ is the total annualized cost of the system, E_{DC} and E_{AC} are the DC and AC primary load served by the system respectively.

4. Results and Discussion

The system was simulated using Homer software as shown in Fig 6. This software helps to find the optimized configuration of different system components. It models both conventional and renewable energy technologies in particular biomass and wind turbines which are the options envisaged for energy efficient technologies. Homer is able to evaluate the economics and technical feasibility of the system. First, Homer simulates the working power system by calculating the hourly energy balance for a year. The above mentioned system is simulated using Homer. It returns the optimized possible system configurations in time 2 hours and 14 minutes with 2 sensitive variables.

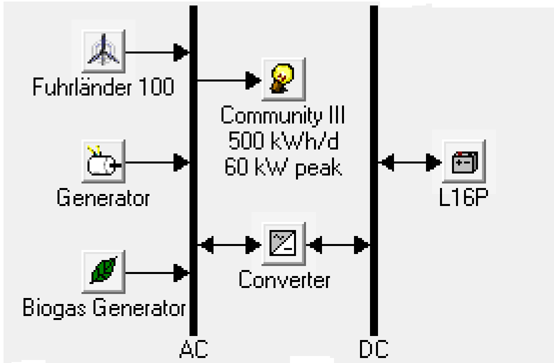

Fig. 6 Wind/Biomass hybrid system.

The Homer results with three different optimized systems.

4.1 Biomass/Wind System with Battery

The most economical system is one in which the renewable fraction is 100 %. This system is called system A. The biomass and wind alone can meet the load at all time in this system with battery units. The initial capital cost of the system is calculated as 97,400 US$ and the levelized cost of energy (COE) is 0.118 US$/kWh.

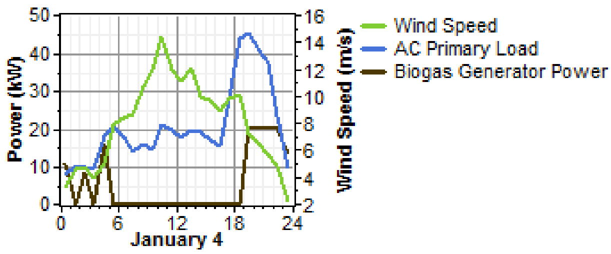

Fig. 7 Hourly power produced and served to load

The Fig. 7 shows the daily wind speed and power generated by the biogas generator. It is obvious that wind turbine share is much more in serving the load as compared to a biogas generator throughout the day since the biogas generator is only to complement the wind energy.

4.2 Diesel/Wind/Biomass System

Another system, which is taken under analysis, consists of wind turbines, biogas generator and diesel generator. The initial capital cost can be calculated to be 183,850 US$ and COE becomes 0.202 US$/kWh. This system is called system B. The increase in capital cost and the COE is because of the Diesel generator and its maintenance cost. The maintenance cost of diesel generator also includes the cost of the diesel itself.

In this system, the share of load met by the biogas generator and fossil fuel generator is shown in Fig. 8.

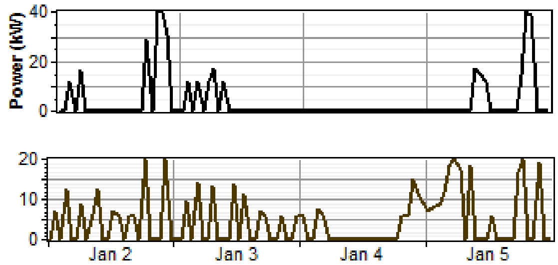

Fig. 8 Power generated by Diesel generator (black) and biogas generator (brown).

It is obvious from Fig. 8 that the preference was given to the biogas generator to fulfill the load demand. The electrical power generated by biogas cannot meet the whole load demand. The rest of the load is met by the electrical power produced by diesel generator. The diesel generator automatically switches on when the load is high enough that cannot be met by wind turbine and biogas generator.

4.3 Diesel/Biomass system with Battery

This system mainly depends on diesel generator production. This system is called system C. In this system, the Diesel generator meets 77 % of total load and 23 % load is met by the biogas generator. The capital cost of this system is less than the system discussed in section 4.2, but the levelized cost of energy is the highest amongst three systems due to the high price of diesel.

Table 2 gives the comparison between the optimized systems in terms of Net present value (NPV and levelized cost of energy (COE).

Table 2. Optimized systems NPV and COE

System Components	FL 100/21	Biomass generator	Diesel generator	NPV	COE
1.Wind/Bio	1	20 kW	-	163204	0.118
2.Wind/Bio /Diesel	2	25 kW	40 kW	313476	0.202
3.Biomass/ Diesel	-	20	40	1290437	0.831

There are three different optimized systems whose different kind of costs can be compared. The systems are given above in Table 2. Net present value (NPV) is the sum of the capital value, replacement value and maintenance value on a real time interest rate. Table 3 gives the comparison between different kinds of cost involved to calculate the NPV.

Salvage value is the value remaining in a component of the power system at the end of the project lifespan. It is assumed here the linear depreciation in the value. It is also assumed that the salvage value depends on the replacement cost rather than the initial capital cost. The negative sign of salvage value indicates that the lifetime of the component is greater than the lifespan of the project for which the NPV is calculated as shown in Table 3.

5. Sensitivity Analysis

Sensitivity analysis is carried out to evaluate the effect of two parameters on NPV and levelized COE.

Table 3. Different types of costs involved

System Components	Capital	Replacement	Maintenance	Fuel	Salvage
FL 100/21	46200	8856	4257	-	-3667
Biogas generator	17000	20658	13073	-	-1951
Diesel generator	48000	-	6353	68160	-1858

At first, the effect of diesel prices on the levelized cost of energy (COE) is illustrated in Fig. 9. The horizontal axis data represents the diesel price variation. It corresponds to 1 US$/litre, 1.2 US$/litre, 1.5 US$/litre and 2 US$/litre. The other parameters, lifespan of project, interest rate and capacity shortage, remain constant. This shows that the system C has the highest COE due to the dependence on diesel generator. However, the variation in diesel prices has no effect on the system A because it has no diesel generator. The prices of fossil fuels on the overall economics of the system show that the system B and the system C can be economical when the prices decreases below 0.8 US$.

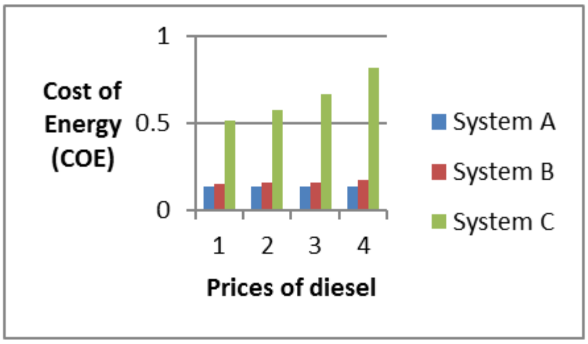

Figure. 9 Effect of Diesel prices on COE

If the lifespan of the components of each system is taken into account and compared, the system A gives COE equivalent to 0.118, 0.116 and 0.115 US$/kWh correspondence to the lifetime of 20, 25 and 30 years. The other systems show same variation in the value of the COE with the change of the lifetime of the project.

6. Conclusion

In this paper, the economic feasibility of hybrid renewable system in one of the remote areas of Balochistan, Pakistan was studied for electricity supply. It is found that the wind speed in the province Balochistan is good enough to start wind turbines projects. The three hybrid systems were analyzed in this paper to the location. The wind /biogas system is found to be the most economical choice with COE equal to 0.118 US$/kWh. This system also helps to reduce the CO_2 emission. The effect of diesel prices and lifetime of the components of the system on COE were also analyzed through a set of different values. The prices of diesel vary from 1 US$/liter to 2 US$/liter with the gap of 0.2. It is observed that ranking of the systems does not affect with the variation in diesel prices. Therefore, it is economically suitable to build the system comprising of the components as a system A for the remote area of Balochistan, Pakistan.

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