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Techno-Economic Evaluation of the Centralized Hybrid Renewable Energy Systems for Off-Grid Rural Electrification

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Abstract

Pakistan is an energy deficient country and the current power crisis of Pakistan is hampering its economic development. Pakistan is naturally benefitted with different renewable energy resources; out of which solar and wind energy are the main highlights. This research work will provide an assessment of the renewable energy potential of the Baluchistan region. A comparison of the economic and financial analysis for a centralized hybrid renewable energy system has been simulated by using Homer software. Three cases have been proposed in which centralized standalone solar PV system, centralized standalone wind energy system and a hybrid combination of both centralized standalone solar and wind energy system have been studied. Homer software has been used to devise the most optimal solution. The simulations confirm that the best optimal solution is the hybrid renewable energy system for the rural electrification of the proposed region.

Keywords*: AC Micro grids, Centralized Hybrid Renewable Energy Systems, Hybrid Renewable Energy Systems, Rural Electrification, Stand Alone Systems*

1. Introduction

Energy is considered as the key element in the development of a country. The importance of energy in financial growth is recognized by the world and recent studies have established a direct relation between availability of energy and economic growth [1].According to International Energy Agency (IEA) report[2], there would be a 53% increase in the global primary energy consumption up to 2030 and 70% of this value is expected to come from developing nations[3].Currently, renewable energy contributes to only 11% of the world primary energy and this is expected to increase to 60% by 2070[4].To counter these environmental and energy problems there is a need to explore cleaner and environmental friendly energy resources.

Like other developing countries, Pakistan is also facing energy deficit of about 4GW in spite of the fact that Pakistan has huge potential of renewable energy resources[5].The gap between energy demand and supply is increasing day by day. The energy demand of Pakistan is increasing at an exponential rate as shown in Fig 1, whereas on the other hand there is hardly any increase in the energy generation capacity of Pakistan. The installed electric power generation capacity of Pakistan is 21 GW, but the actual generation remains limited between 9 GW to 13 GW[5].

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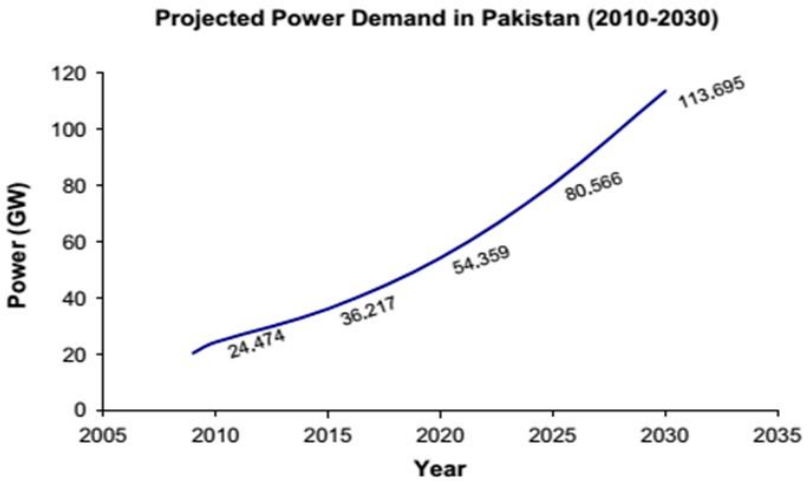

Figure 1. Projected Power Demand of Pakistan

Pakistan has a huge renewable energy potential which can easily overcome the energy crisis of Pakistan but still the renewable energy resources have hardly any percentage in the energy mix of Pakistan. The purpose of the study is to propose the most feasible renewable energy system for the deprived community having no access to the electricity. The area selected for the subject study is a small village of Baluchistan province which is considered as the most deprived area all over Pakistan.

2. Topography of the Location

Baluchistan is the largest Province of Pakistan which covers a large area of about 347,190 Sq Km[6]. The selected area is one of the small communities of the district Chagai which is the largest district of Baluchistan. The terrain of the the Chagai district consists of highlands, plains and deserts with the vast arid zone having very little rainfall. The climate is very hot in summer and cold in the winter. The rainfall is irregular and scanty.

2.1 Estimation of the Available Energy Resources

In order to estimate the available renewable energy resources available at the selected site the monthly daily solar radiation and the average wind speeds were obtained from NASA website. The values of the available solar resource and the wind speed thus obtained were then further used to carry out the simulations on the HOMER. It is important to mention here that the values of the available solar resource and the wind speed values of the NASA are accepted all over the world when carrying out the simulations of the proposed renewable energy projects.

2.1.1 Solar Energy: The potential of solar energy is immense in Baluchistan, with the average solar global isolations of 5-7 kwh/m^2/day, over 95% area (about 2300-2700hr/annum). Figure 2 shows the average daily radiation at the "Killi A.Majeed" near Dalbandin area, for each month of the year. The annual average solar radiation predicted is about 5.42 kwh/m^2/day which is considered very healthy for the feasibility of the solar energy systems.

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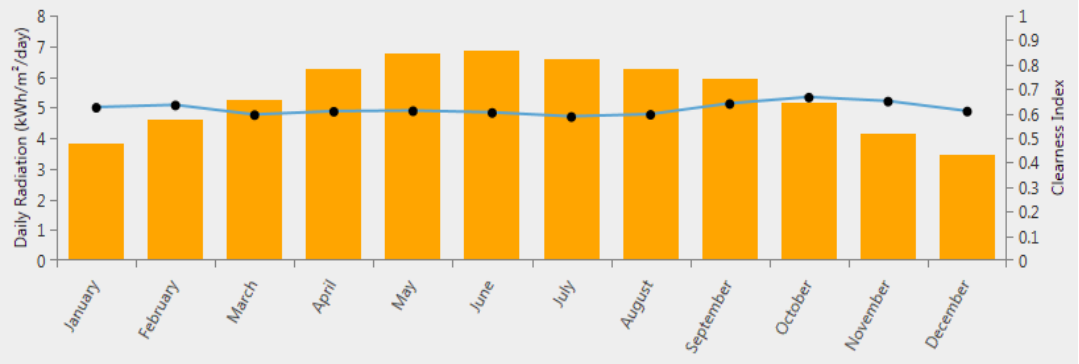

Figure 2. Average Daily Solar Radiation at the Proposed Location for Each Month of the Year

2.1.2 Wind Energy: Pakistan Meteorological Department (PMD) carried out a wind power potential survey of the coastal areas of Sindh and Baluchistan during 2002 to 2004.According to [2] and [7-10]. Pakistan possesses more than 20,000 MW of economically viable wind power potential Baluchistan is blessed with seven wind corridors suitable for wind farms. Figure 3 shows average wind speed predicted at the proposed location for each year. The annual average comes out to be 5.54 m/sec.

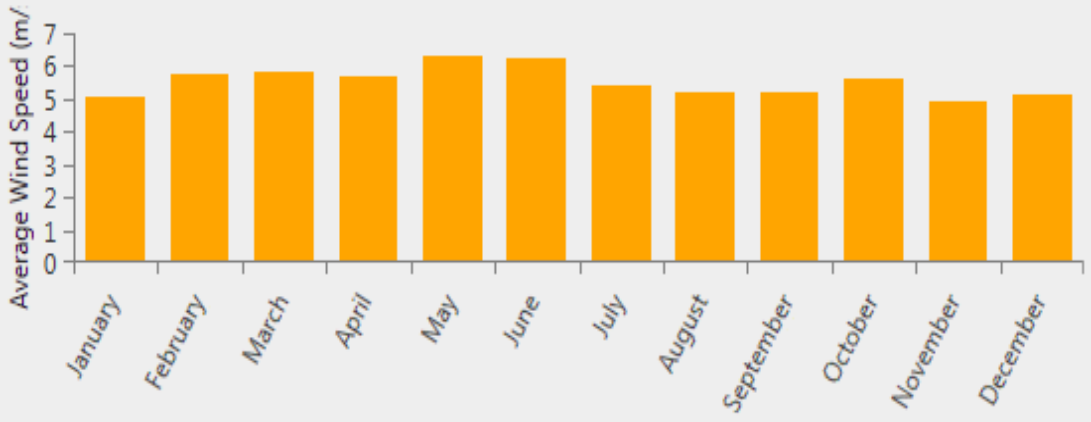

Figure 3. Average Wind Speed at the Proposed Location for Each Month of the Year

3. Methodology

A Hybrid Renewable Energy System (HRES) incorporates two or more electricity generation options based on the renewable energy or fossil fuel unit.Finding the suitable configuration of HRES is related to topography of the location, estimation of the load, available energy resources and devised energy solution [11-16]. Topography of the area and the analysis on the available energy resources has already been explained. Electric load profile and the analysis on the proposed solutions would be explained in the subsequent sections.

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4. Electric Load Demand Profile

In order to estimate the load requirements of the one of the selected locality named "Killi A.Majeed"near Dalbandin area, district Chagai , a survey was being conducted in the community. It was found that Killi A. Majeed has no access to the electricity and all the houses are having almost the same structure and the covered area. According to the survey conducted in the area and the response of the community a common load necessary for the functioning of a single major house was being proposed. The proposed load considered for each home is summarized in the table given below. Daily load profile of the community is presented in Figure 4.

S.No.	Load	Wattage of each Load	Quantity for each house
1.	Energy Saver	25	5
2.	Ceiling Fan	100	3
3.	Fridge	200	1
4.	TV	100	1

Table I. Load Characteristics for the Proposed Renewable Energy Systems

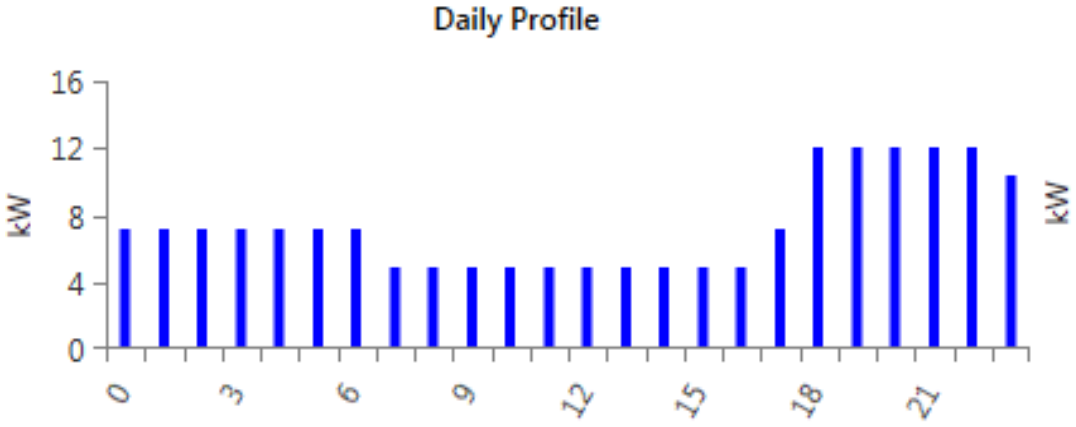

Figure 4. Average Daily Load Profile

In order to estimate the load requirements the load usage was thus divided into three case scenarios as being plotted and shown in Figure 5.

- Load usage during summer season (April-September)
- Load usage during winter season (November – February)
- Load usage between summer and winter season. (March & October).

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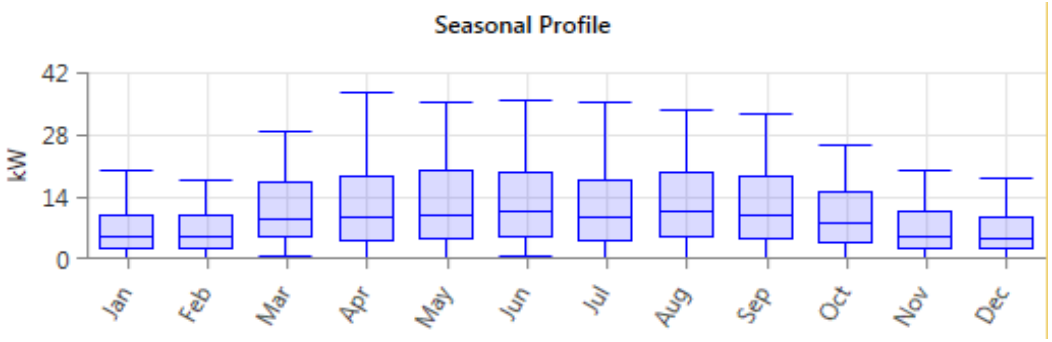

Figure 5. Seasonal Load Profile

5. Devised Energy Solution

HRES are more reliable, better efficient and a source of minimum levelized life cycle electricity generation cost. All these benefits can be availed when optimum design techniques are used. In [4],different software's tools which are being used for systems design and analysis of HRES have been analyzed and HOMER was found to be most widely used tool as it has maximum combination of renewable energy systems and performs optimization and sensitivity analysis which makes it easier and faster to evaluate the many possible system configurations[17-21].

5.1 System Design

The systems consist of PV module, wind turbine, battery and converter. The system schematic has been shown in figure:

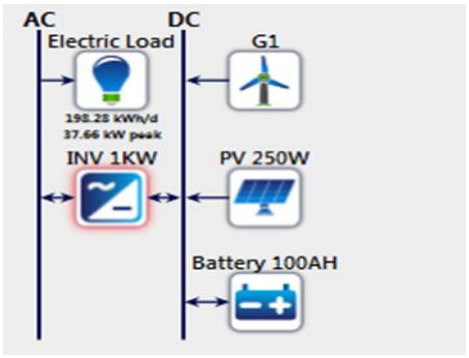

Figure 6. I Schematic of the Proposed System

5.2 Simulation Procedure

Three different renewable energy combinations standalone and Hybrid Renewable Energy systems have been simulated and analyzed by using HOMER software. Due to the non-availability of the national grid only off grid centralized systems have been considered and simulated. The options which are being simulated in the study are:-

- Standalone Solar PV/ Battery System
- Standalone Wind/Battery System
- Solar PV/Wind/Battery Hybrid Renewable Energy System

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5.3 Results & Discussions

After simulating all of the three systems the results are being summarized in the table V.The Cost of Equity (COE) and Net Present Cost (NPC) of hybrid solar PV-Wind- Battery system is $ 0.381/ KWh and $ 326,657, of the standalone solar PV system is $ 0.4/ KWh and $ 335,962 and of standalone wind energy system is $ 0.771/ KWh and $ 603,132.It can therefore concluded that the hybrid renewable energy system is more cost competitive, eco-friendly, low maintenance alternative power solution for rural electrification in the researched area.

Table 2. Comparison of the Proposed Hybrid Renewable Energy Systems (HRES)

Systems	PV	Wind	Battery			Converter	Capital Cost	Replacement Cost	Total NPC Cost	Annualized COE
			battery	Total batteries	Bus Voltage					
PV-Battery System	55 KW	NA	100 Ah	768	48	30 KW	$234,783	$141,041	$335,962	0.4 $ / KWh
Wind-Battery System	NA	90 KW	100 Ah	768	48	30 KW	$409,968	$218,512	$603,132	0.771 $ / KWh
PV-Wind-Battery System	51 KW	10 KW	100 Ah	640	48	30 KW	$230,743	$127,839	$326,657	0.381 $ / KWh

The combinations which are being analyzed are based on the available renewable energy resource of the area. Estimated cost of energy per kW h (LCOE) has been one of items that are roughly comparable. The cost analysis of the proposed hybrid system is provided in Table II, whereas the net present cost and annualized cost of the best possible HRES has been shown in Figure 7 and Figure 8 respectively.

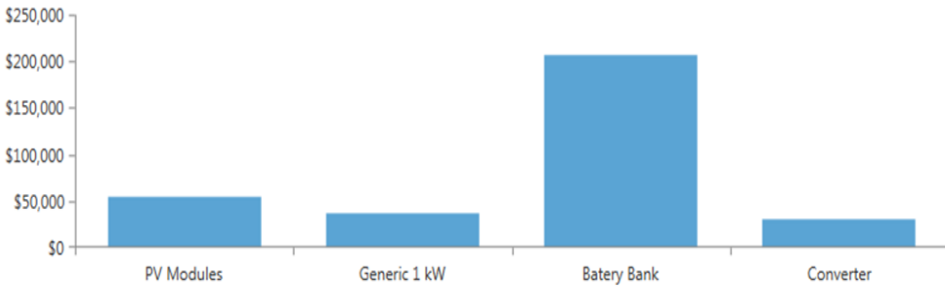

Figure 7. Net Present Cost of PV/Wind/Battery HRES

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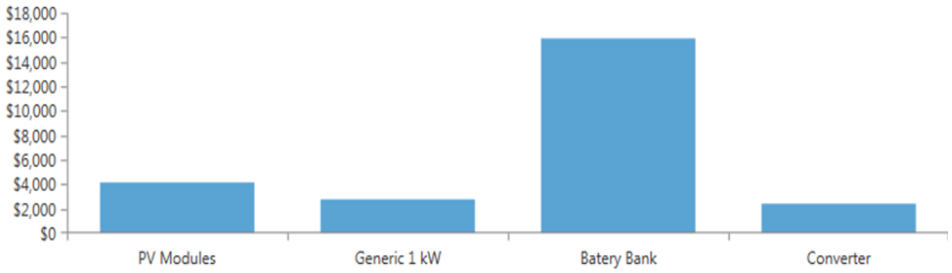

Figure 8. Annualized Cost of PV/Wind/Battery HRES

6. Conclusion

Analysing the energy crises of Pakistan and the depletion of global fossil fuel reserves, it is evident that there is an urgent need of increasing the ratio of renewable energy resources in the energy mix of Pakistan. To meet the anticipated energy demand, hybrid renewable energy systems are considered as the best possible solution for the researched area. This research paper confirms the utility and the cost effectiveness of the HRES as compared to the stand alone Solar PV systems and the wind energy systems. The simulations and results of the HOMER showed that the rural electrification using hybrid renewable energy system can act as a reliable solution for the community having no access to the electricity.

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