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Cost Effective Exploration and Environmental Sustainability of Stand-alone Hybrid Wind/Solar System at Karufi, Pakistan

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Abstract- Solar and wind energy technologies offer a renewable and hygienic energy source. These lavish in nature, unhindered and bottomless resources are of great importance globally now a day. This paper presents economical assessment and environmental feasibility of a hybrid Standalone wind/PV hybrid system in Karufi (Gufanwala) Pakistan, with energy consumption of 18.250MWh annually. HOMER (Hybrid Optimization Model for Electric Renewables) is used to determine the financial and environmental feasibility of Hybrid wind/solar PV renewable system. Multiple hybrid arrangements of wind turbines, PV (photovoltaic) array and battery sizes are sensibly chosen so that we get the optimal solution for the system regarding life-cycle cost method. It is found that the proposed stand-alone system with 100% renewable fraction (13 % solar and 87% wind) to be the cheapest to run the configuration with Cost of Energy (COE) of 0.319 US $ / kWh. When the diesel price is fixed to 1.5 US $ / litre, the COE for the system with 0 % renewable penetration is calculated to be 0.990 US$/kWh, i.e. approximately 3.1 times more than the projected stand-alone system. The proposed hybrid wind/PV system can also avoid additive emission of 2.0 tons of Greenhouse Gas (GHG) equivalent of CO_2 annually into the indigenous atmosphere under deliberation.

Keywords- COE; HOMER; Hybrid; Pakistan; Optimization Methods.

I. INTRODUCTION

As the world population is growing day by day, as the fossil fuels are depleted with the everyday come and as the global environment is going to become warmer due to the GHG more emissions, the search for the new technologies independent of the factors is the hot spot of today. Most of the research is being done in the exploration of the modern technologies based on renewable-energy system (RES) or the blend of conventional and alternative sources worldwide. These unconventional energy sources contain wind, geothermal, tidal, biofuels, solar, and wave. One can design the system utilizing one or more than one sources of energy. The mix of these sources simultaneously is called hybrid energy system for the production of energy. Small hybrid energy systems are one way to allow energy production which is most efficient and most economical to meet the domestic load. The objective is to implement the small-scale systems with two or more sources together. Moreover, the hybrid power systems have much more efficiency in terms of consistency and the cost of generation [1-3].

A number of research tasks were performed in dealing with the Feasibility and the economic analysis of hybrid systems. According to Ntanos et al. [4], a quality of life can be improved through small-scale systems based on renewable energy. An economic feasibility report [5] of standalone hybrid system containing wind turbines and biomass sources is proposed for remote area 'Jangiah' of Baluchistan which results shows the least COE of 0.118 (US$/kWh). The authors have investigated the hybrid system for space heating system [6]. They founded that the said system has the low ratio between the cost and benefits. According to [7], the Solar PV and wind hybrid system for the Base Transceiver Stations (BTS) is more economical than the fossil fuel-based electricity. Moreover, this system gives the least COE and zero emissions. Reference [8] has proposed a standalone hybrid system for Sanodar Village in Bhavnagar District, Gujarat State, India. The authors have analyzed that Solar PV alone with batteries and converter gives the least COE than the hybrid of solar and wind which gives slightly higher COE. [9] has suggested an off-grid system by hybridizing Solar PV/Wind/Biomass/Battery sources. The optimal system provides the least COE 0.293 ($/kWh) by the hybridization of these three renewable sources. It is found that hybrid system is the excellent and optimal choice instead of the wind or solar alone system. With the hybrid system, system's reliability increased and cost to the system is mainly due to the more renewable parts within the system. An optimal system is proposed for economic and technical study for a village, in Resham-Jo-Tar, Tharparkar district, Sindh, Pakistan [10]. The optimal system consists of Solar PV/Wind/Battery system which provides least COE and NPC costs, furthermore the energy share of solar PV is 74% and wind of 26%. To encounter the energy constraints Base Transceivers Station (BTS) Oromia, Etiopia, [11] compared the systems performances of standalone hybrid solar PV/ wind system and solar PV/battery system. It was suggested that solar PV/battery system offers least COE and NPC than the hybrid system. In [12], a hybrid energy system was proposed comprising of a solar PV/ Wind/ Battery system for a largest metropolitan city Victoria, Canada. The proposed system provides least COE, NPC and Operating cost. Furthermore, the hybrid system provides 64.3% excess electricity with 100% renewable fraction. Another optimal hybrid system was suggested for the Malo Bheel district Tharparkar, Sindh, Pakistan [13]. The suggested hybrid system comprises of solar PV /Wind/ Battery bank which provides COE 0.132 ($/kWh) and NPC $ 66,445. The hybrid system gives least COE than the solar PV and wind system's COE alone. In [14], the authors suggested planning and techniques for implementation of hybrid Solar PV and wind systems. An optimal sizing algorithm is proposed for implementation of hybrid PV-wind turbines and battery system in Nigeria [15]. [16] weighed the enduring presentation of a hybrid solar/wind arrangement. This research provides the comparison between grid connected and stand-alone system in terms of their performance. The fossil fuels are depleting and the emission into the air is increasing. Thus, it is the utmost need to give more emphasis on hybrid renewable energy systems worldwide.

Since there are no electrical networks available in villages of Pakistan, the electrification of remote areas can only be accomplished by the hybrid renewable system, whether stand-alone or grid connected. Unfortunately, in the literature, a wide-ranging study dealing the economic capability and technical probability of hybrid wind/solar system in Pakistan has not yet been carried out.

The chief emphasis throughout this paper is to evaluate the wind and solar power potentials accessible at Karufi (32_65′ N, 72_82 E) and to intend optimal hybrid blend for electrification of the proposed site. This research work entails the different facts, like techno economic analysis, energy production examination, and GHG emission by switching the existing diesel generator system with hybrid wind /solar system. The existing one proceeds as 0% renewable system and the proposed hybrid system takes as 100% renewable system.

The wind and direct solar data are taken from NASA [17]. HOMER (Hybrid Optimisation Model for Electric Renewable) is used for Feasibility and economic investigation of stand-alone PV/wind hybrid systems. HOMER is developed by NREL (National Renewable Energy Laboratory, USA), appears repeatedly in the literature as a preferred tool [18]. HOMER is a software tool that can handle the different combinations of sources available. In HOMER, there are distinctive constraints, which must be satisfied in order to become the feasible solution. The main focus of HOMER's optimization is based on cost analysis, i.e. Net present cost (NPC) is the sum to the cost of system components, replacement cost and the operational & maintenance cost of system components. HOMER gives a set of optimal possible systems according to the constraints given and the ascending order cost of the energy units from top to bottom [19-20]. The feasibility study was conducted to integrate renewable generation into existing energy system for Popova Island using HOMER [21]. It was concluded that energy mix with renewable sources for Popova Island could reduce the cost of electricity and mitigate the greenhouse gas emissions. Another study proposed biomass-photovoltaic hybrid energy system for rural electrification using HOMER [22]. In this research, two study cases were presented that show economical and technical viability of the system.

The paper pays attention to the recommended hybrid PV/wind system with 100% renewable penetration so that the dependency on fossil fuels could be eliminated and in turn purify the environment from the poisonous gases.

II. Background of Research

Majority of Pakistan's population lives in towns and villages. The villagers deprive from the electricity facility as the urban population enjoys this facility. In Pakistan, the far away villages have no infrastructure of power transmission and distribution. Hence, Pakistan has low per head electricity utilization. The demand of electricity throughout the country is more than the generation. Therefore, the extensive load shedding is being scheduled throughout the country [23].

In Pakistan, according to the statistics presented in [24], energy demand per head has doubled as was in 1971. Pakistan is one of the top 25 GHG emitting countries. Pakistan has a lot of CO_2 emission and according to estimate; Pakistan contributes 2.85 % world's total CO2 emissions [25]. Electricity generation from conventional sources influences the environment negatively. Thermal power plants are the major reasons for the pollution. These plants add total 32 % of CO_2 and 42% of the SO_2 in the atmosphere of Pakistan [26]. In various parts across the country, sun remains elevated mostly 7 to 8 hours per day and the country gains sunshine more than 300 days/year. Moreover, the solar average insolation of Pakistan which is about 5-7 kW h/m^2 which is ample to meet energy demands of the country [27-32]. United States National Renewable Energy Laboratory (NREL) developed 50 m wind map of Pakistan, which indicates that many regions of the country have a good potential for generating wind energy. Wind energy generation in Pakistan has a capacity factor of more than 25%, which is internationally considered suitable for the installation of economically viable commercial wind farms [33]. Hence, Pakistan Government must take initiative for the development of such energy systems and also launch some awareness campaigns so that sustainable energy generation could be implemented to meet the load demand in peak hours [34-35].

The above situation of energy crises and having abundant with renewable resources in Pakistan motivated the researchers and government to pay more devotion for the exploitation of solar and wind renewable resources.

III. System Description

Hybrid renewable systems comprises of different combinations of photovoltaic modules, wind turbines and batteries. Such noticeable Suppleness of renewable hybrid system has clear benefits for adapting a system for a specific site's energy resources, expenses, and electric power desires. In this paper, a 100% renewable wind/solar hybrid system with 2kW PV panels, two wind turbines of 2.5 kW each and 12kw power converter is used to satisfy the load demand curve of the small village (Karufi) located at (32_65' N, 72_82' E) Pakistan. The battery banks are also indulged in the system to store the extra energy obtained from the both sources. For fiscal analysis, HOMER comprises of three main economic parameters; initial capital cost, Replacement (substitution) cost and operational and maintenance (O&M) cost. The cost in this study is calculated in US ($) dollars.

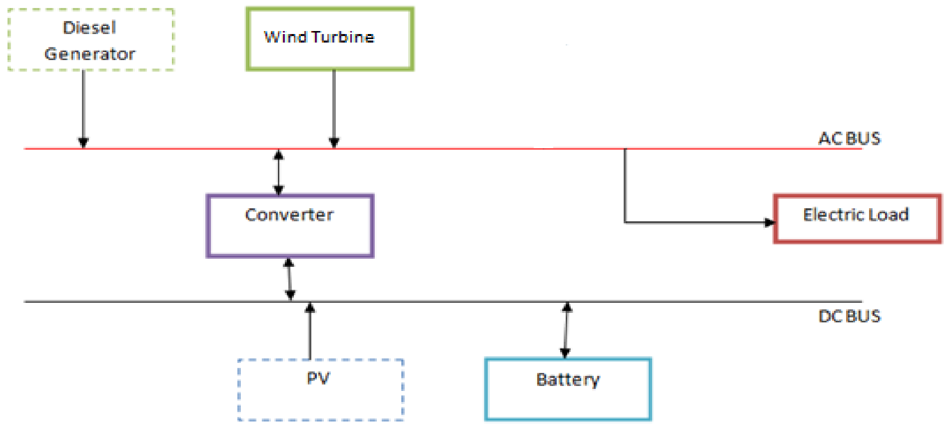

Fig. 1: Block diagram of proposed Hybrid energy system

3.1. Electrical load

A small town is selected, for instance, to examine the viability of the projected system. Fig 1 and Fig 2 show a pattern of town load on an hourly basis of whole week. The electric load consists of small, medium, and large houses, and one store. The loads include of primary usage household appliances such as lightning, washing machines, air conditioners, television and iron. During working hours, from 10AM to 5PM of weekdays (Monday to Friday) the load consumption is lower than that of weekends (Saturday and Sunday). The proposed system has maximum demand of 5kW. The total energy consumed annually can be calculated by the energy profiles given below and is 18.250MWh with an average daily energy consumption of 50kWh.

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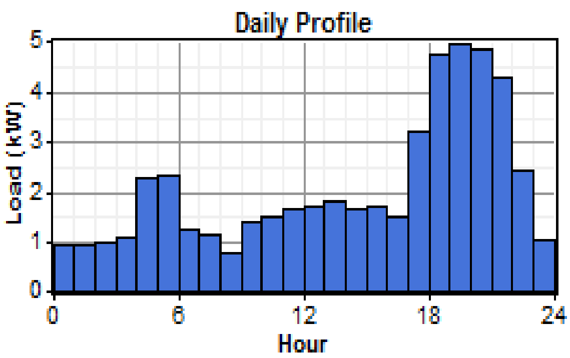

Fig. 2: Hourly load profile on weekdays

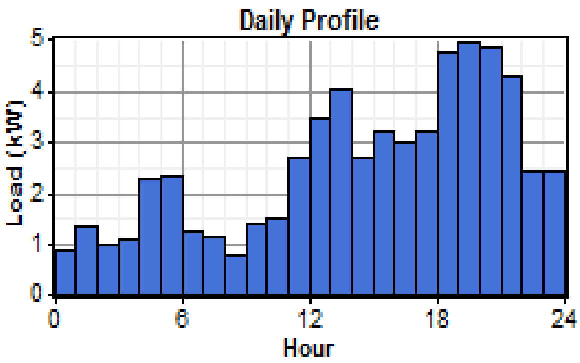

Fig. 3: Hourly load profile on weekends

3.2 Wind energy

An hourly wind speed data is obtained from the NASA Surface Meteorology and Solar Energy web site [17]. Fig. 3 demonstrates the monthly averaged wind speed data obtained. The wind speed ranges from 5.590m/s to 9.160m/s with an annual average of 7.596m/s. The Weibull parameter (k) which describes the breadth of wind distribution speeds annually is 2.0 with an autocorrelation factor of 0.85. A low value of k corresponds to a broad wind speed distribution. The strength of diurnal (active day time) variation pattern is 0.25. A medium value of strength of diurnal pattern shows less dependency on the daytime. The probability density function of wind speed is illustrated in Fig. 4.

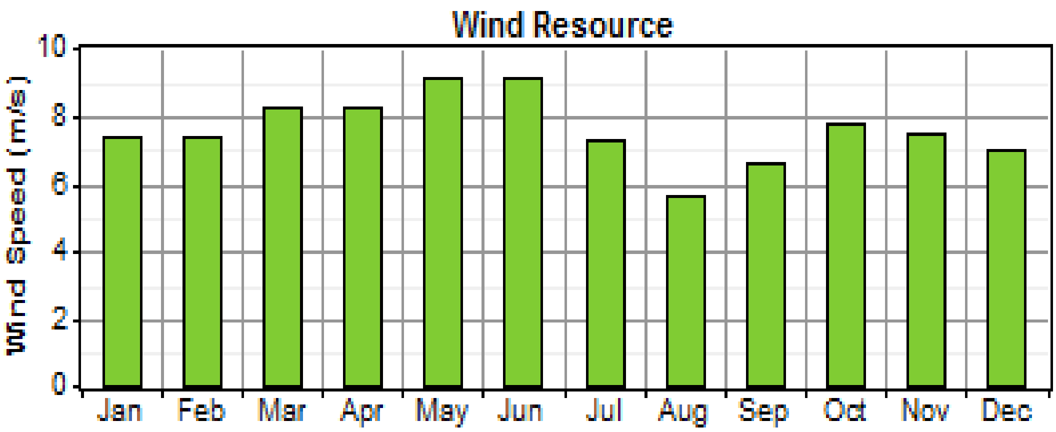

Fig.4: Monthly averaged wind speed data

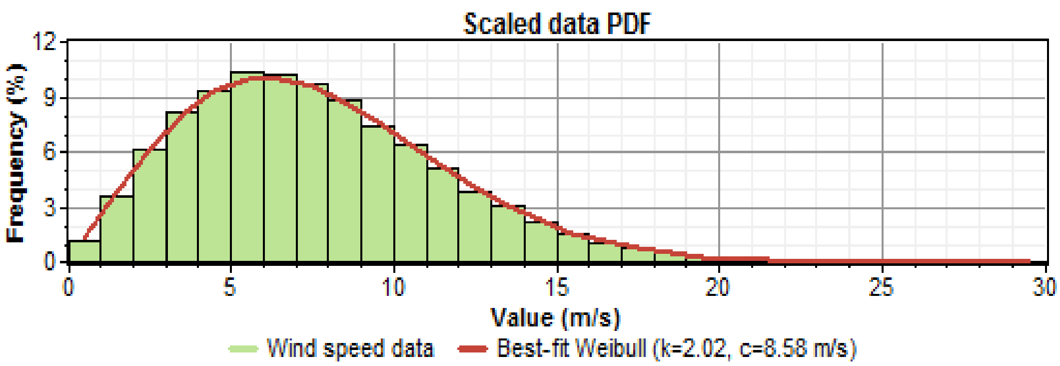

Fig. 5: Probability density function of wind speed

3.3 Wind energy conversion system

A horizontal axis wind turbine with rated power of 2.5 kW is chosen for this study. The mechanical characteristics of wind turbine are listed in Table 1 [36]. The cost of the wind turbine system, comprising installation cost, controller and tower kit is 20950 US$. Replacement Cost of the wind turbine is 18300 US$. Operating and Maintenance (O&M) cost is assumed at 2% of the system cost. The power curve (power versus wind speed) of 2.5 KW wind turbine is shown as in Fig 5.

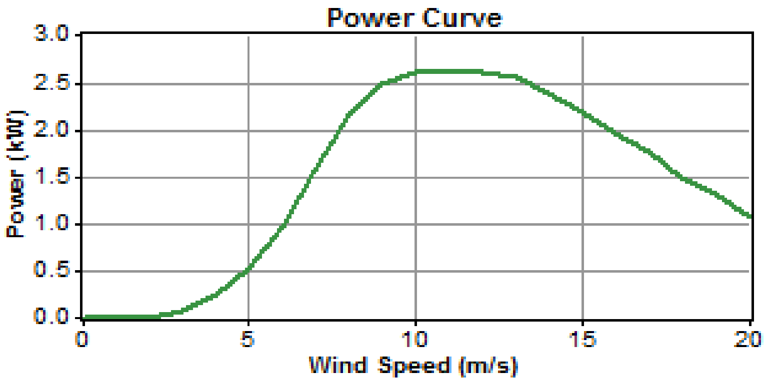

Fig. 6: Power curve of 2.5 KW wind turbine

Table 1: Mechanical characteristics of selected wind turbine **[36]**

Rated power	**2.5kW**
Cut in wind speed	3 m / s
Cut out wind speed	20 m / s
Nominal wind speed	9 m / s
Power regulation	Fixed pitch stall
No of blades	3
Rotor diameter	5m
Hub height	12.25 m. or 6.25 m

3.4 Solar energy resource

Intensity of solar radiation for a specific area can be obtained from the NASA site [17]. The solar radiation ranges from 2.737kWh/m^2 /day to 7.024kWh/m2/day with an annual mean of 5.021kWh/m2/day. The average clearness index is 0.589. The radiation pattern of the location is drawn in Fig 6 with the clearance index. It is seen from the fig that the mean solar radiation is up to the mark throughout the year. The diurnal variation of solar radiation per month with the hourly distribution is shown in Fig. 7.

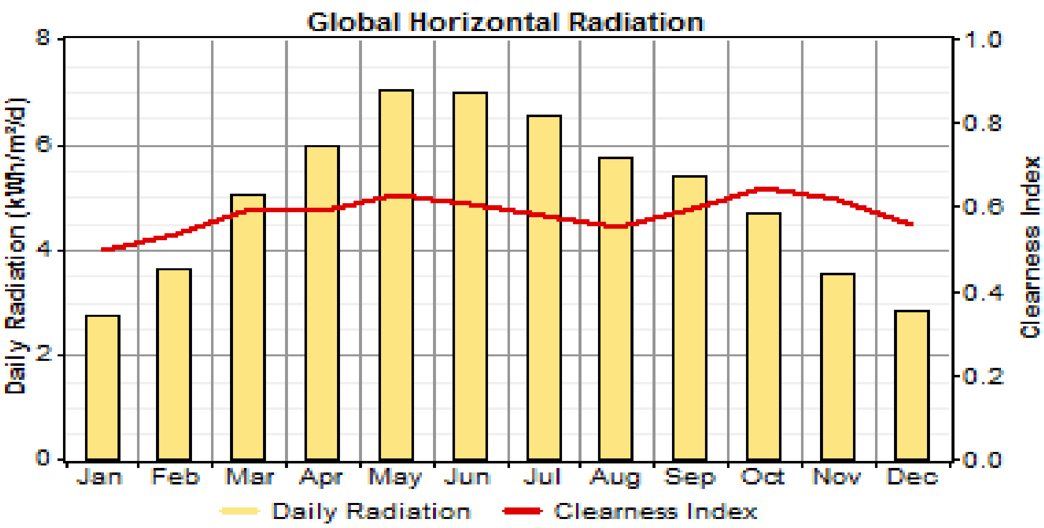

Fig.7: Clearance index with radiation data

3.5 Photovoltaic arrays:

The setting up cost of a photovoltaic cell module fluctuates between 5000 \$/ kW$_{pk}$ and 9000 \$ /kW$_{pk}$. 6000\$ / kW$_{pk}$ is estimated in the proposed work for the production of electricity from the solar panels. The substitution cost is given by the manufacturers as 4800\$/kW$_{pk}$. The number of the photovoltaic array considered here are 0 (No PV array), 2, 4, 6, 8, 10, kW$_{pk}$. The energy generated by PV array is reduced due to the change in temperature and the dust particles on the array. This derating factor is 90 % in our case of study, i.e. an about 10 % reduction occur during the production from the panels due to the derating factor.The power generation due to PV and wind turbine is shown in Fig.8. The input power of the battery used in kW is also given in the same Fig.

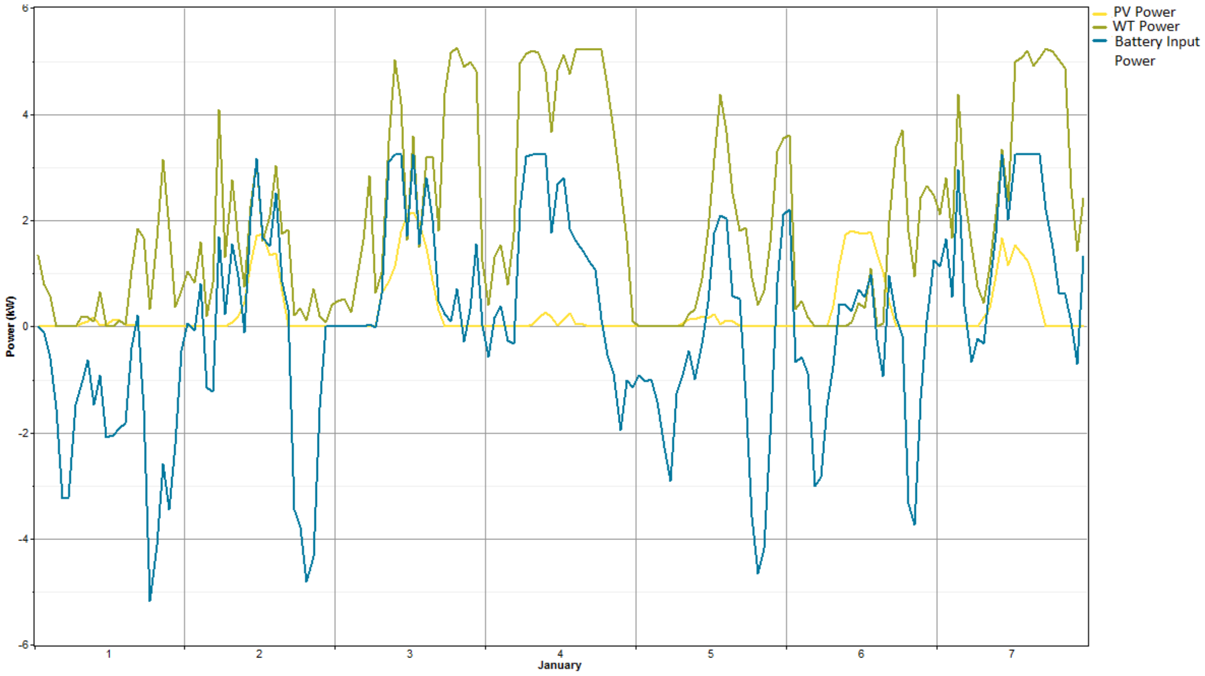

Fig.8: Power generation of proposed system from solar PV, Wind and Battery input Power for 1st week of January

3.6 Battery bank

The *capacity* of a battery is defined as the amount of energy that can be withdrawn from it starting from a fully-charged state. But the capacity of a battery depends on the rate at which energy is withdrawn from it. The higher the discharge current, the lower the capacity. One can create a capacity curve by measuring a battery's capacity at several different constant discharge currents. The state of charge (SOC) of battery used is shown in Fig 9.

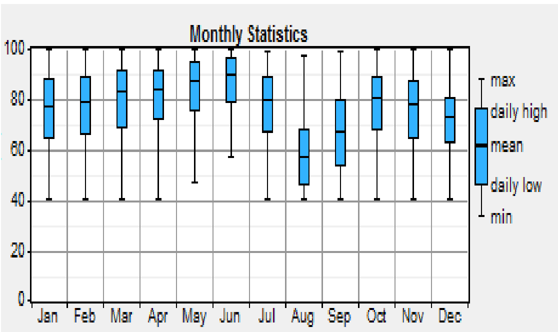

Fig.9: Battery state of charge (SOC)

3.7 Converters

The converter used in the simulation costs approximately 800 $/kW. According to the manufacturers, the converter can work about 15 years without any damage. The sizes of converters considered are 0, 2, 4, 6, 8 kW. The efficiency of inverter is taken 85% while the efficiency of rectifier is considered 90% regardless of the sizes used.

3.8 Generator

The initial capital cost, substitution cost and the O & M cost of the diesel generator are taken as 6000$/ kW, 5400$/ kW and 0.2 $/ h, respectively. The storage of the fuel is assumed to be accomplished by a fuel tank. It is found that the minimum loading of the generator is 20 % of full capacity to meet the demand. HOMER software is used to calculate the total time in hours of the generator to force work on.

3.9 Control strategy

In HOMER, two options for control strategies are given. In cycle charging strategy, the battery banks are charged from the generator power if the generator is already in ON position. However, PV array and win turbine are the preferred sources to charge the battery banks fully in the load following strategy.

The load following strategy is being used for simulation. In our analysis, we see the surplus energy from the renewable sources. Therefore, load following strategy is the best policy in our case of study.

IV. Results and Analysis

Based on the above system configuration, HOMER displays 8400 runs simulation. Among them, 8 system configurations are categorized in Optimization results. The optimization results are those which meet all the conditions and constraints given by the user. It is suggested to pick best two out of 8 optimized results for comparison purpose. The most suitable and appropriate system given is the system configuration with 100 % renewable penetration. This is a hybrid PV/wind system with 2 KW_{pk} PV panels, two wind turbine of 2.5 KW each and 12 KW sized power converter. The capital cost of the system is 12,000 $ with O & M cost of 1395 $ /year per annum. The sum of the all costs is called Net present cost (NPC) and the total net present cost (NPC) of the system becomes 82,424$ and cost of energy (COE) is equal to 0.330 $ / kWh. The second system with 0 % RE has larger cost. The COE of that system is 0.590 $ / kWh) if we reduce the diesel price up to 1.0 $ /litre.

4.1. Energy production analysis

The suggested standalone hybrid PV/wind hybrid system is the only optimum solution which is capable to satisfy the load demand of selected place with 100% of renewable fraction (solar power 13% and wind power 87 %). The mean wind speed is 7.5963 m/s, and the global solar radiation is 5.021 kWh/m^2 /d. The energy penetration by the RE sources is listed in Table 2.

Table 2: Energy impact of different renewable sources of proposed system

Parameter	**Wind**	**Photovoltaic (PV)array**
Per cent contribution, %	87	13
Capacity factor, %	53.8	20.9
Mean output power, kW	2.69	0.42
Annual energy output, (kWh)	23555	3667
Annual hours of operations, (hours)	8253	4363

The monthly average energy generation contribution of the photovoltaic modules remains almost constant with minor difference between the peaks, as shown in Fig. 8. While the wind production varied throughout the year. It is highest during the month of May with the production of 3.20 KW and minimum in August with 1.75 KW.

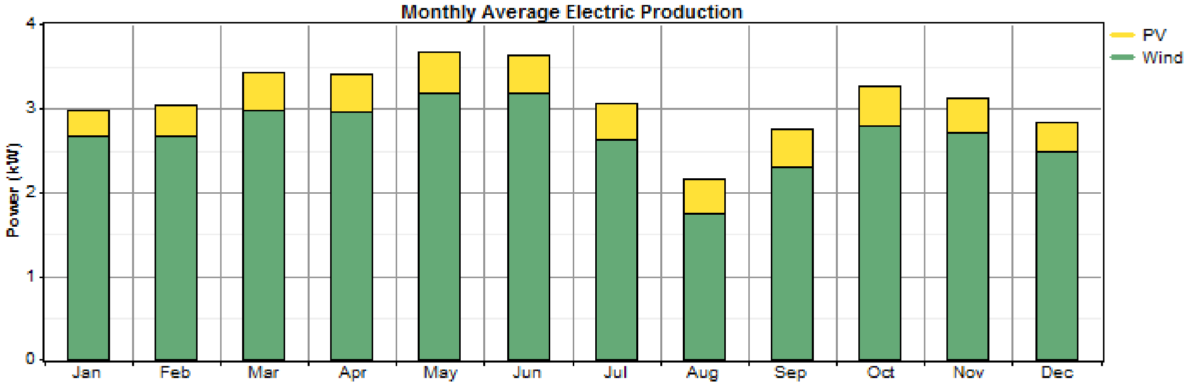

Fig. 9: Monthly average electricity production contribution by solar and wind individually

4.2. Greenhouse gas (GHG) emissions

The proposed PV/wind hybrid system with 100% renewable fraction is a highly efficient system in terms of GHG emissions. It is concluded that addition of 2.0 tons of GHG equivalent of CO_2 per annum in to the local environment of the village under consideration could be avoided. As the life of the project is 20 years, this figure becomes 40 tons. This results in fewer health hazards. Table 3 shows the comparison of quantity of the gases added to the system with 100% renewable energy penetration and that with 0 % RE penetration. It is obvious from the table that the proposed system with 100 % RE penetration will save 100 % addition of each.

Table 3: Comparison of GHG emissions of proposed system with existing system

Pollutant	**Emissions (kg/year) 0 % RE Penetration**	**100% RE penetration**
Carbon dioxide	19,243	00
Carbon monoxide	47.5	00
Unburned hydrocarbons	5.26	00
Particulate matter	3.58	00
Sulphur dioxide	38.6	00
Total GHG	19,337.94	00

4.3. Economic Analysis

The cost of the system with 100 % renewable penetration is shown in Fig 10. This system contains photovoltaic cell cost, wind turbine cost, battery bank's cost and inverter cost. The cost to the system with 0 % renewable penetration is shown in Fig 9 with each component cost. Table 4 and 5 shows the summary of various costs associated with each component of two systems (system with 100 % renewable penetration and the system with 0 % renewable penetration) respectively. Their corresponding annualized net present cost (NPC) is shown in table 6 and 7 relatively.

From Fig 9 and 10, it is concluded that the generator is contributing highest in terms of cost and the converter the least. If we compare the initial cost, O & M cost and substitution cost of both systems, we can easily say that the initial cost of system with 100 % renewable penetration is more than that of the second system in comparison. But the COE of the system with 100 % renewable penetration is much less to second system with generators.

Additionally, in 100 % RE penetration, we can save 1.7 barrels of fuels due to the non- dependency of fuels in the system. If the cost of fuel per barrels is estimated 80 US $, then in a monetary form, a revenue of 136 US $ can be saved per barrels usage. In our case, the hybrid system with 100 % RE penetration produces 18.25 MWh energy. This saves the 31.025 barrels of fuel and thus US $ of 7399.46 $ per annum. As the life of the system is 20 years, we can save the total revenue of 147989.25 US $ for the 20 years. We can also avoid the dependency on fossil fuels for the whole period. Additionally, in this way earning of carbon credit can be achieved, which generates revenue of 20 US $ for each ton of GHG evaded in the atmosphere. Therefore, a country can generate revenues of total 800 US $ throughout the life of the project.

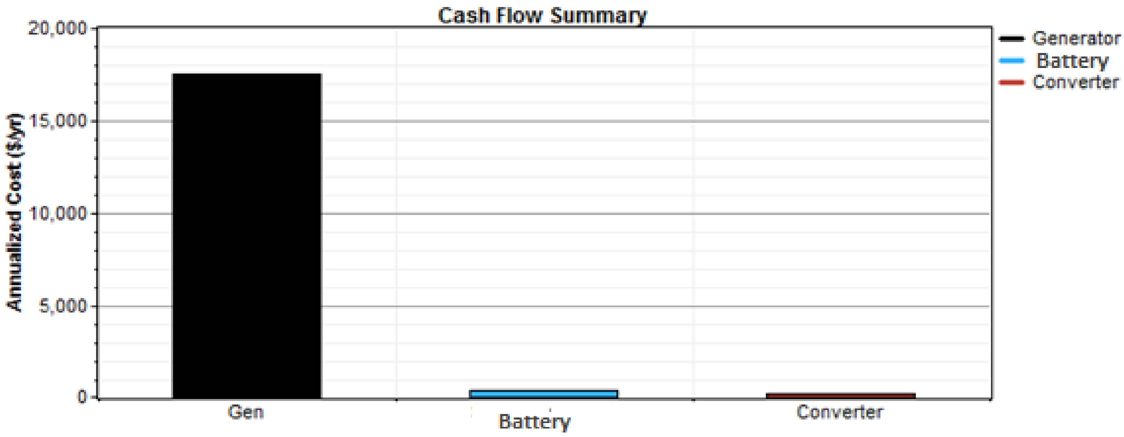

Fig. 10: Cash flow of the existing power system

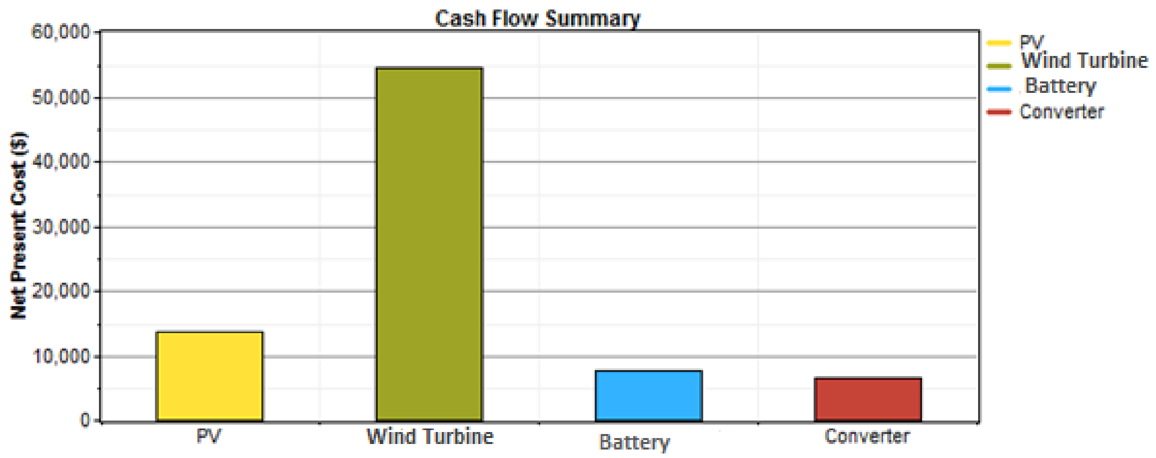

Fig. 11: Cash flow of the proposed hybrid PV/wind system

Table 4: Different types of costs associated with proposed hybrid PV/wind system.

Module	Size	No.	Investment ($)	Substitution cost ($)	O&M ($)	Fuel ($)	Salvage ($)	Sum ($)
PV	1kW	2	12,00	3,618	141	00	-2,126	13,633
Wind Turbine	2.5W	2	41,900	13,794	70,47	00	-8,106	54,635
Energy Storage	4V	12	4,080	2,809	1,691	00	-877	7,703
Convertor	1 kW	6	4,800	2,078	00	00	-425	6,453
Total System Cost			62,780	22,299	8,879	00	-11,535	82,424

Table 5: Different types of costs associated with the existing system.

Module	Size	Investment ($)	Substitution cost ($)	O&M ($)	Fuel ($)	Salvage ($)	Sum ($)
Generator	5kw	6,000	23,231	13663	205,985	-1470	247,410
Energy storage	4v	2,720	1,873	00	00	-585	5,135
Converter	1kw	1,600	695	00	00	-142	2,151
Total System Cost		10,320	25,797	14,790	205,985	-2196	254,696

Table 6: NPC of proposed standalone hybrid system

Module	Investment ($/year)	Substitution cost ($/year)	O&M ($/year)	Fuel ($/year)	Salvage ($/year)	Sum ($/year)
PV	851	257	10	00	-151	967
Wind Turbine	2,973	979	500	00	-575	3,876
Battery	289	199	120	00	-62	547
Convertor	341	147	00	00	-30	458
Total System Cost	4,454	1,582	630	00	-818	5,848

Table 7: NPC of the existing system

Module	Investment ($/year)	Substitution cost ($/year)	O&M ($/year)	Fuel ($/year)	Salvage ($/year)	Total ($/year)
Generator	426	1,648	969	14,615	-104	17,554
Battery	193	133	80	00	-41	364
Convertor	114	49	00	00	-10	153
Total System Cost	732	1,830	1,049	14,615	-156	18,071

V. Conclusion and Future Work

This paper focuses to utilize the two renewable sources for energy purpose, i.e. solar radiations and wind source. Since the fossil fuels are depleting rapidly, the daily energy requirement can be met by the usage of the renewable sources. This paper takes into account the case of a small village Karufi (Gufanwala), at (32_65´ N, 72_820 E, Pakistan). It is concluded that the most feasible and economic system is with 100% renewable energy penetration hybrid wind/ PV system (13% solar and 87% wind). The COE of the system is 0.319 US$/kWh. The system that has to be considering in comparison is 0% renewable penetration with diesel generator only. It is calculated that the COE for the diesel only system is much more than that of the system with 100 % renewable penetration i.e. around (3.1) times more than the hybrid system. Furthermore, the solar energy backed less resourcefully to the suggested standalone system than the wind-energy source. The paper pays attention to the recommended hybrid PV/wind system with more renewable dissemination so that the dependency on fossil fuels could be eliminated and in turn purify the environment from the poisonous gases.

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