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SIZING AND SIMULATION OF HYBRID ENERGY SYSTEM FOR ZERO ENERGY HOUSE IN NAWABSHAH PAKISTAN

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ABSTRACT: *This study presents an optimal configuration of a solar-wind-battery hybrid system for supplying electricity in a zero energy house sited at Nawabshah, Pakistan. The technical, economic and system components was optimized using Hybrid Optimization Model for Electric Renewable (HOMER) software. The software employed average monthly data of global solar radiation and wind speed from The* National Aeronautics and Space Administration *Surface Meteorology and Solar Energy database. The annual daily average solar global radiation of the site was found 5.24 kWh/m^2/day and wind speed 4.7 m/s. The hybrid system was designed for a total connected load of 5 kW. The optimized components of the system was found with solar photovoltaic modules of 4 kW, wind turbine 1 kW, inverter 5 kW, and a battery bank of 48 V, 800 Ah for half day autonomy. It was estimated that the hybrid system could supply energy of 8574 kWh/year. The share of solar photovoltaic portion would be around 77.6% and wind turbine 22.4%. It was established from the study that the hybrid system is quite practical for provision of electrical energy in remote areas of the country.*

Keywords: global solar radiation, hybrid energy system, sizing and simulation, wind speed, zero energy house

1. INTRODUCTION

Energy is considered to be a prerequisite for the existence of human being and essential for socio-economic development of any country. Pakistan is facing acute energy shortages due to dependency on fossil fuels and lack of conventional energy resources. Hybrid energy system is gaining importance as a vital power generating technique for remote areas. It not only helps to promote renewable sources, reducing fossil fuel consumption, but also helps to reduce the emissions from traditional power plants. Pakistan's current energy supply is done by using 38% from oil, 32% hydro, 27% natural gas, and 3% coal [1]. Country is rich in various renewable sources, especially solar, wind and biomass [2]. These resources are fully exploited yet due to less technological development. However, the renewables have huge potential for possible applications in various sectors. The utmost reason for energy shortage in the country is due to the substantial reliance on imported oil for the generation of power. It is reported that the major consumer of electricity in Pakistan is building sector with around 40 to 47%, however, this sector has huge energy saving potential. The dependency of energy generation on crude oil can be minimized by adopting renewable energy utilization bay saving conventional energy utilization in building sector [3]. Although, Pakistan has ample accessibility of solar and wind energy resources yet these resources cannot be easily utilized due to their fluctuating nature [4]. A standalone solar or wind energy system cannot deliver continuous power supply throughout the year during cloudy days when sunlight is not available or during the period when there is low wind speed. This unpredictable and fluctuating nature of renewable energy systems can be minimized through application of hybrid energy system by integrating two or more energy sources.

It is reported that hybrid energy systems are more feasible, reliable and economic as compared to single source of energy system [5]. Yanine et al. [6] examined the life cycle cost of the hybrid energy system using simulation without compromising the reliability and found hybrid systems as cost effective. Nfah and Ngundam [7] modeled a wind, diesel and battery hybrid power system for North Cameroon. It was found that the proposed system is better approach for supplying electricity in remote areas with minimized life cycle cost. Ismail et al. [8] described the technique for hybrid micro-generation system control without energy storage and found that the hybrid systems are practicable. Caballero and Yanine [9] explored that solar and wind hybrid systems are more effective for supply electricity to remote areas of Cameroon without expensive grid extension. Kumar and Manoharan [10] accomplished techno-economic analysis photovoltaic system with diesel generator and battery for a typical house in Malaysia. It was revealed that the developed hybrid system was feasible, flexible and favorable. The various authors have reviewed the hybrid system based on wind, PV with battery storage and found reliable and cost effective [11-15]. The various softwares have been reviewed by the different researchers for analyzing the hybrid systems, like HOMER, RETScreen, HYBRID2, iHOGA and Hybrids. Among all softwares, HOMER had been chosen and preferred for sizing and simulations [16-19]. Since, the intensity of solar and wind is varying with time and location. Therefore, for any particular location, its performance prediction and viability analysis is necessary [20-23]. The various scholars have utilized different optimal design approaches for development of stand-alone hybrid systems for several locations [24-28]. Thus, this study was conducted to discover feasibility and technical-economic study of a hybrid energy system based on solar, wind and battery for application in a standalone energy efficient house i.e. zero energy house at Nawabshah, Pakistan. It is anticipated that the findings of the study will help the stakeholders, policy makers and regulatory authorities of the area to minimize the consumption of energy in buildings.

2. MATERIAL & METHODS

The available renewable energy resources of Nawabshah (26.25^{o}N and 68.41^{o}E), Pakistan was estimated using NASA surface meteorology and solar energy data for the period of ten years. At this location, December and February months are of winter season, from mid-February to mid-April is spring and from April to September is summer season, May-June-July are hottest months of this season and temperatures rises to around 48ºC. The autumn season is short and ranges from October to November. Two most prominent renewable energy resources, solar and wind of the area was evaluated for integration in the zero energy house.

2.1. Solar Energy Potential

The selected site collects ample quantity of solar radiations during entire year due its position. Monthly available average solar global radiations data is presented in Figure 1. It is obvious from the figure that the global solar radiations vary monthly, which ultimately varies PV system power output. The annual averaged global solar radiation according to the acquired data for the site is found 5.24 kW h/m^2/day.

2.2. Wind Energy Potential

The yearly monthly average wind speed data measured at a site is presented in Figure 2. The annual average wind speed of the site was found as 4.7 m/s. The variations in wind speed are observed during whole the year and time to time, the variations in speed of wind can also fluctuate the system performance and configuration.

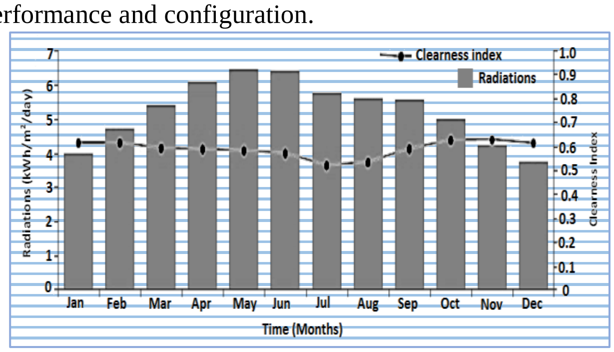

Fig. 1. Monthly average global radiations

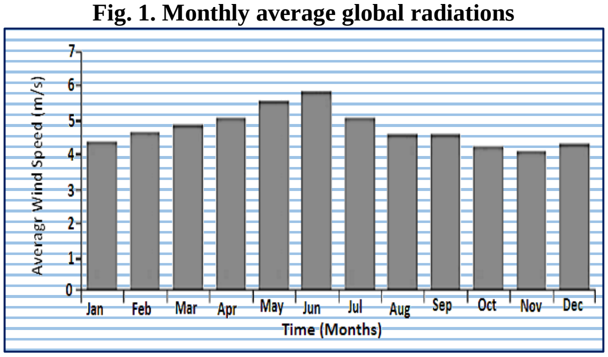

Fig. 2. Monthly average wind speed

2.3. Electrical Load Profile

The monthly average electricity consumption profile of the selected zero energy house is shown in Figure 3. The demand of load varies with different periods of time (like seasonally, monthly, daily and hourly) due to different load demands. The average annual load of zero energy house is found to be 11.3 kWh/day with monthly peak demand of 35.54 kWh/day during the months of May, June and July.

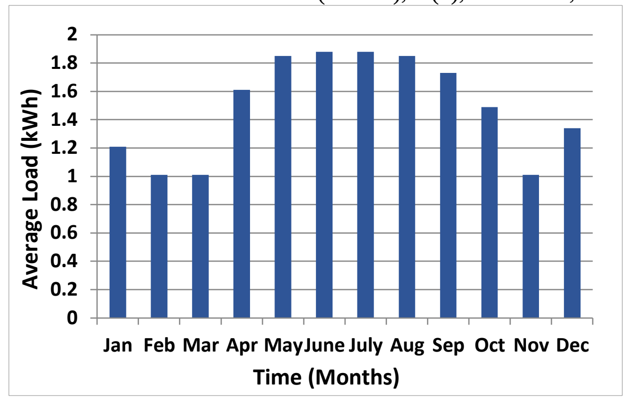

Fig. 3. Monthly Average Load

3. COMPONENTS OF HYBRID SYSTEM

It was found from the study that the solar energy resources potential at a site for the system is most feasible during most part of the year and wind is also available with some fluctuations. Therefore a hybrid system was selected for supplying electricity to the zero energy house, which is comprised of solar, wind and battery for storage as shown in Figure 4. The Hybrid system was developed using Hybrid Optimization Model for Electric Renewable (HOMER) software. The HOMER software is established by National Renewable Energy Laboratory, which is widely used for simulation, optimization and sensitivity analysis of the hybrid energy systems [11]. The HOMER software computes the hybrid system performance, configuration and determines the technical feasibility of system for each hour of the day, month and year along with total life cycle cost. For system optimization, the HOMER evaluates various system configurations and discovers the most economic and technically suitable configuration along with lowest life cycle cost [29]. It also executes the sensitivity analysis of hybrid energy system for several optimizations and the variety of numerous inputs and their effects. This software needs the data for each component of system like size of component, number of units, costs (capital, operating, maintenance and replacement), operating hours and other descriptions.

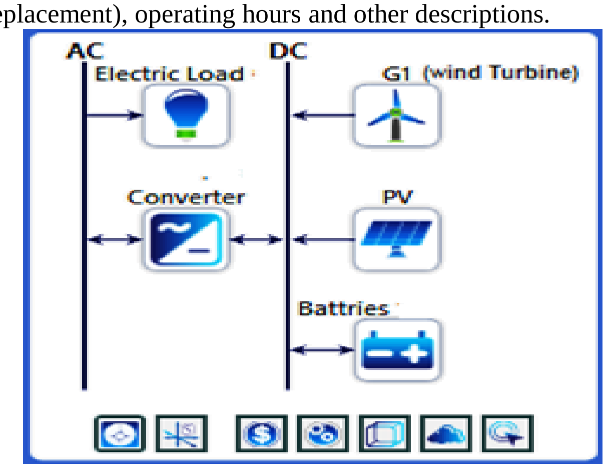

Fig. 4. Schematic diagram of Hybrid energy (solar-wind-battery) system

3.1 Solar Photovoltaics (PV) Module

The characteristics of solar PV modules used for this study are shown in Table 1. The power output (P_{output}) of a PV is obtained by software using Eq. (1), based on monthly average solar global radiations of the site at the inclination of latitude of location [4,30].

$$P_{output} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}} \right) [1 + \alpha_p (T_c - T_{c,STC})] \quad (1)$$

where Y_{PV} is output power at standard test conditions (STC) in kW or the rated capacity of the PV array, f_{PV} is the derating factor of PV in (%), G_T is solar incident radiations on the PV panel (kW/m^2), $G_{T,STC}$ is the incident solar radiation at STC (1 kW/m^2), α_p is the coefficient of power for temperature (%/$^{\circ}$C), T_c is temperature of PV cell ($^{\circ}$C) and $T_{c,STC}$ is temperature of PV cell at STC (25°C). If the temperature effect on the performance of PV array is ignored, then α_p is presumed to be zero and Eq. (1) becomes:

$$P_{output} = Y_{PV} f_{PV} \left(\frac{\overline{G_T}}{\overline{G_{T,STC}}} \right) \quad (2)$$

The overall capacity of Solar PV system is optimized as 5 kW through HOMER software, by giving various search space options as 4, 5, 6 and 7 kWs depending upon the available solar radiations. The approximate capital cost for PV panel per kilowatt as per market of the country (during time of study) is taken as Rs.60000.00, the replacement cost, cost for operation and maintenance (O&M) is considered as zero. The PV system is installed at an angle of latitude of the site; no tracking system is incorporated. The Life time of panels is presumed as 25 years.

Table 1. PV modules characteristics

Parameter	Specifications
Type, Model	Poly-crystalline ECSOLAR, ECS-250P60
Max Power P_{max} (W_p)	250 watt
Voltage at Maximum Power (V_{mp})	30.1 volts
Open circuit voltage (V_{oc})	37.5 volts
Current at Maximum Power (I_{mp})	8.32A
Short circuit current (I_{sc})	8.73A
Module efficiency	15.4

3.2 Wind Turbine

The specification of selected wind turbine is presented in Table 2. The capital cost of wind turbine of 1 kW as per market price of the country taken as Rs.150000.00, running and replacement cost were considered zero, operating and maintenance costs were anticipated as Rs.5000.00 per year and the lifetime of the wind turbine unit was presumed as 25 years. The data source taken for the wind turbine is considered at height of 10 meters, using the power law as given in Eq. (3) [12].

$$\frac{U}{U_0} = \left(\frac{h}{h_0} \right)^{\alpha} \quad (3)$$

where U is speed of wind at power height h, Uo is the speed of wind at height of reference ho, and α is the surface roughness (is mostly taken as 0.14).

The HOMER calculates the power output of wind turbine as given in Eq. (4). It includes a) calculation of hourly average wind speed and monthly at anemometer height b) Through power law equation, compute the wind speed at height of hub. c) Calculate the wind turbine power output by using power curve with assumption of standard density of air. d) Multiply that power output by air density ratio as:

$$\frac{\rho}{\rho_o} = \left(1 - \frac{Bz}{T_o} \right)^{\frac{g}{RB}} \left(\frac{T_o}{T_o - Bz} \right) \quad (4)$$

where ρ is the density of air at hub height, ρo is the density of air at STP conditions (1.225 kg/m^3), T_o is temperature standard (288.16 K), β is known as lapse rate (0.00650 K/m) and g is acceleration of gravity (9.81 m/s^2), R is the gas constant (287 J/kg K) and z is the elevation (m) [12].

Table 2. Wind Turbine Technical Specifications

Parameter	Specifications
Rated power (kW)	1
Charging volt (Volt)	48
Quantity of Blades (numbrs)	3
Blade Rotor diameter (m)	3.1
Startup wind speed (m/s)	3.0
Rated speed of wind (m/s)	9.0
Rated rotating rate (r/min)	500
Tower height (m)	10
Initial cost (Rs)	150,000.00
Replacement cost (Rs)	150,000.00
Operation & maintenance cost	5000.00 per year

Table 3. Specifications of Batteries

Battery	Specification
Life time	5 years
Nominal voltage	12V (48V per string)
Nominal capacity	200 Ah (800 per string)
Batteries per string	4(48V)
Initial cost	Rs.100000 per string
Replacement cost	Rs.100000 per string
Operation & maintenance cost	Rs.5000 per year

Table 4. Specifications of Inverter

Inverter	Specification
Type	SBR-400
Power rating	4 kW, 5kW, 6kW
Batteries	48V
Capital cost	Rs.20000 per kW
Replacement cost	Rs.20000 per kW

3.3 Battery Storage

The purpose of batteries is to store electrical energy. The stored energy is utilized during the time of when power is not available from the hybrid PV and wind generating units. The capacity of selected batteries were 12V and 200 A. Four batteries were connected in series per string and the search option of strings one, two or three was given in the software. The specifications of the selected batteries are given in Table 3. The initial capital cost of batteries was taken Rs.100000.00 per string and Rs.25000.00 per battery, replacement cost Rs.100000.00 per string and operation & maintenance cost Rs.5000.00 per year. Each string can produce 800 Ah of electricity. It was assumed that the batteries will be charged by the PV arrays during day time and also by wind turbine when during its availability.

3.4 Inverter/Converter

The inverter converts the power from direct current (DC) to alternating current (AC) as the PV panels produce the power in direct current. The hybrid system involves both the AC and DC current systems. Therefore, it is essential to transform the power from DC component to AC load for maintaining the flow of energy. The details of the selected inverter are given in Table 4. Different input sizes of inverters of 4, 5 and 6 kW were given in the simulation analysis in HOMER software for search space. The capital cost is taken Rs.20000.00 per kW, therefore Rs.80000.00 for 4kW, Rs.100000.00 for 5kW and Rs.120000.00 for 6 kW and the life time of the inverter is taken as 25 years. The replacement cost was taken as Rs.20000.00 per kW, and operation and maintenance (O&M) cost Rs.5000 per year.

4. RESULTS AND DISCUSSION

The simulation results of the proposed hybrid system for supply of electricity in the zero energy house are given in Table 5. The Solar-wind-battery system was found economical, independent and flexible. It can be used as an off-grid mode because of battery back-up and suitable of isolated locations with no carbon dioxide emission and other pollution from the generating unit.

The average monthly electric power generated by the whole arrangement and the consumption of zero energy house is presented in Table 6. It was observed from simulation that the proposed hybrid system will be of 5kW capacity. Out of that, 4kW will be generated from solar PV and 1kW from wind turbine along with 5kW inverter and 800 Ah battery bank of half day autonomy. The total electricity produced from the system was estimated to be 8574 kWh/year. The share of solar PV will be 6661 kWh/year (77.6%) and wind turbine 1913 kWh/year (22.4%). The average monthly estimated electricity production from each source of hybrid unit is described in Figure 5. The maximum average monthly power generation output from the system was found 1.2 kW in month of June and minimum 0.9 kW in month of November, December and January.

Table 5. Optimum simulations results

PV (KW)	wind (kW)	Battery unit	Converter (kW)	Initial Capital cost (Rs)	Replacement (Rs)	O&M (Rs)	Total (Rs)
4.0	2	4	4.0	740,000	173,554	78,431	991,985
4.0	3	4	4.0	890,000	173,554	86,273	1,149,827
5.0	1	8	5.0	775,000	347,108	109,804	1,231,912
6.0	1	8	5.0	835,000	347,108	109,804	1,291,912

Table 6. Energy generated by system components and consumption

Production	kWh/year	%	Consumption	kWh/year	%
PV array	6661	77.69	AC Load	2724	100
Wind turbine	1913	22.31	DC Load	0	0
Total	8574	100	Total	2724	100

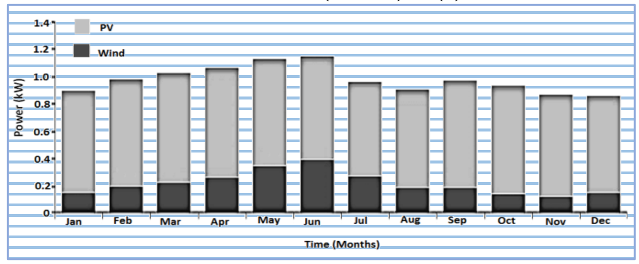

Fig. 5. The average monthly electricity generated by the system

The estimated performance of the selected solar PV and wind turbine units is shown in Table 7. The total electricity production of a PV system was observed to be 6,664.40 kWh/year with an average of 18.26 kWh/day. Similarly, the total production from wind turbine was found 1913 kWh/year. The capacity factor for PV System was estimated as 19.02% and for wind turbine 10.92%. The levelized cost for PV system was Rs. 5.19 kWh/year and wind turbine Rs 21.04 kWh/year.

Table 7. Specifications of solar system and wind turbine

Sr. No.	Description	Solar	Wind
1	Total rated capacity (kW)	4.00	1.00
2	Mean output (kW)	18.26	0.22
3	Capacity factor (%)	19.02	10.92
4	Total production (kWh/yr)	6,664.40	1,913.00
5	Levelized cost (Rs/kWh)	5.19	21.04

4.1 Economic Analysis

In addition to technical analysis, the economic analysis is a fundamental measure for success of any project. The economic analysis of the hybrid system was carried out using HOMER software. The anticipated cost occurred from the hybrid energy system along with all components as shown in Table 8 and Figure 6. The PV array's initial capital cost was found Rs.240000, O & M cost Rs.31373.00, the total cost is Rs.271373.00. The initial capital cost of wind turbine was estimated to be Rs.300000.00, operation and maintenance cost Rs.15685 and total cost of Rs.315685.00. Similarly, the initial capital cost of batteries was found Rs.100000.00, operation and maintenance cost Rs.31373.00, replacement cost Rs.173554.00 and the total cost Rs.304927.00. The total cost for inverter was determined to be Rs.100000.00, with no O & M and replacement cost.

Moreover, the total cost of proposed hybrid system was estimated to be Rs.991985.00, with an initial capital cost of Rs.740000.00, operation and maintenance cost Rs.78431.00, and replacement cost Rs.173554.00. It was found that the PV array cost is around 32.43% of the total initial capital cost, while the wind turbine 40.54%. The storage batteries and inverter contributes 13.51% each of the total cost of the proposed system [31,32].

Table 8. Cost summary of Hybrid (Solar PV-wind-battery) system

Element	Capital (Rs)	Replacement (Rs)	O&M (Rs)	Total (Rs)
PV array	240,000	0	31,373	271373
Wind Turbine	300,000	0	15,685	315,685
Battery	100,000	173,554	31,373	304,927
Converter	100,000	0	0	100,000
Total system	740,000	173,554	78,431	991,985

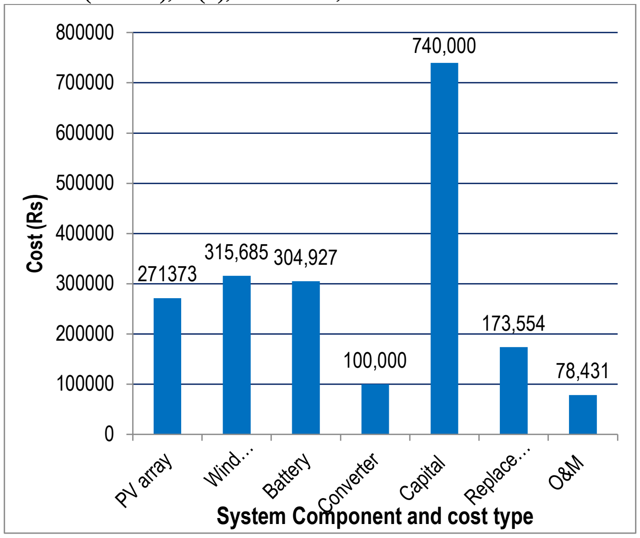

Fig. 6. The cost summary by system components and cost type

5. CONCLUSIONS

This study was carried out to examine the techno-economic feasibility of a solar-wind-battery hybrid system for supplying electricity in a zero energy house located at Nawabshah, Pakistan. The sizing and simulation of system components was performed using Hybrid Optimization Model for Electric Renewable (HOMER) software. The monthly average data of global solar radiation and wind speed from The National Aeronautics and Space Administration Surface Meteorology and Solar Energy database. The annual daily average solar global radiation of the site was found 5.24 kWh/m^2/day and wind speed 4.7 m/s. The hybrid system was designed for a total connected load of 5kW, with solar photovoltaic modules share 4 kW, wind turbine 1 kW, inverter 5 kW, and a battery bank of 48V, 600 Ah for half day autonomy. It was established from the simulation that the hybrid system could supply energy of 8574 kWh/year to the zero energy house with 77.6% from solar photovoltaic and 22.4% from wind turbine. The optimized system was found feasible for supply of electricity in standalone systems. Such type of hybrid renewable energy units could be very usefull in remote areas and places with sufficeient availability of sunlight and wind.

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