Application of Renewable Energies for Optimal Electricity Generation in a Building in Khodabandeh, Zanjan

Mohammad Ameri, and Elnaz Hariri

***Abstract*—**This study evaluates the feasibility of electricity generation using renewable energies for a normal non-commercial building in city of Khodabandeh, Zanjan situated in the northern part of Iran. The main objective of this study was to find, compare and differentiate the optimum size of different wind, PV and hybrid wind-PV systems with battery storage, that were capable of fulfilling the energy requirements of a typical residential building. For this purpose, the wind energy potential and its characteristics were assessed in terms of 3-hours periods and at 10m height in 2013. With 3.6 m/s of wind speed and 4.38 kWh/m^2/day of solar radiation, Khodabandeh was the most reasonable place in Zanjan province to establish a renewable energy system. Hybrid Optimization Model for Electric Renewable, known as HOMER was used to optimize the design of the renewable system. Energy load, wind speed, solar radiation, wind turbine model, PV panel, inverter, and battery were the inputs. The results showed that the hybrid system of a wind turbine and PV was the most optimized system option.

***Index Terms*—** Hybrid, Khodabandeh, Wind Speed, Solar Radiation.

I. Introduction

The absence of power network in outlying areas and high costs of grid extension due to long distances and unwanted environmental effects lead to use of alternative sources, like renewable energies, to generate power. In areas with less potential in fossil fuel energy alike, using renewable energies can be more cost effective, clean and more easily attainable. Besides, since each renewable source might be unreachable for a period of time, combining energy sources as a hybrid system is a warily choice and gives more reliability. Different combination of each source can be used regarding each area trait.

A hybrid solar-wind system uses both solar and wind energy sources, and hence the efficiency and power reliability of the system increase. Adding a storage bank to this system can still reduce the risk and uncertainty of this hybrid system, but with the increase in the final cost of the system.

The analysis and design of micro power systems can be challenging, due to the large number of design options and the uncertainty in key parameters, such as load size and future fuel price. The renewable energy sources add further complexity because their power output may be intermittent, seasonal, and nondispatchable, and the availability of renewable resources may be uncertain.

In recent years, much research and many feasibility studies have been performed on hybrid energy systems around the world, leading to valuable insights which show the importance of the subject [1-6].

Fazelpour *et al.* [7] analyzed the feasibility of hybrid systems for a medium-size hotel on Kish Island, Iran. They have economic optimization included in the assessment by using the Homer software as the optimization tool. Renewable and non-renewable energy sources (fossil fuels) were considered, and the final adoption of both cases was primarily based on their associated cost and efficiency.

Celik [8] has addressed the sizing and techno-economic optimization of an independent PV-wind hybrid energy system with battery storage. A novel sizing method has been introduced in this study in which the level of independency, i.e. the fraction of time for which the specified load can be met, and the cost of the system have been considered.

El Tous and Abdel Hafith [9] have considered a flexible simulation model for a hybrid off-grid Photovoltaic / Wind system using Matlab.

Kaldelis and Zafirakis [10] have estimated the appropriate size of a wind and solar driven stand-alone system in Greek territory, so as to meet the energy demand of typical remote consumers under the criterion of the minimum installation cost.

Kolhe *et al.* [11] investigated the design of an off-grid hybrid system in Sri Lanka for a supposed outlying village to find the optimum configuration. They have also assumed that after 10 years, there would be a grid extension, so the on-grid case was also studied.

Among the countries in eastern Asia, China leads the world in using renewable energy sources with the total capacity of 378 GW. Chong Li *et al.* [12] have studied the feasibility of an independent hybrid wind/PV/battery power system for a household in a village in China using one 2.5 kW wind turbine, 5 kW of PV array and 8 units of 6.94 kWh batteries.

Several studies were leaded in Iran, investigating feasibility of renewable energies application. Ataei *et al*. [13] have

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considered application of a hybrid system for a commercial building, analyzing time domain performance of such system using HOMER.

The main objective of this study was to find, compare and differentiate the optimum size of different wind, PV and hybrid wind-PV systems with battery storage, that are capable of fulfilling the energy requirements of a typical household apartment in Khodabandeh region in Zanjan located in the northern part of Iran..

We aimed to simulate wind and PV power systems in HOMER, including battery bank in the model as a backup. The load consumption data, wind and solar data in the site, as well as wind turbine power curves of manufacturers, first were considered as inputs of the systems and then the system simulation was performed based on those inputs.

II. Input

A. Wind speed

Wind speed data used as this study's inputs were obtained in 3-hours periods and at 10m height from Zanjan province meteorology center in 2013 (Fig. 1) [14]. The wind speed was considered as a continuous random variable in energy related computations which can allocate any value in a range. But since wind speed measures in Khodabandeh station were done in 3-hours periods, and therefore are a discrete function, Weibull distribution function [15] was used to replace the measurements with a continuous distribution function.

B. Solar radiation

Solar energy is renewable, unlimited and does not pollute environment. However this energy is greatly varies during days and seasons, and is under the influence of meteorological conditions. Moreover the efficiency of conversion of the solar energy to electricity is way too low compared to wind system. Khodabandeh City is located in geographical position of 36.12 and 48.55 latitude and longitude respectively, and 2800m above sea level. The annual average of solar irradiation is estimated to be 4.9 kWh/m^2/day. Fig. 2 shows the daily radiation in each month in Khodabandeh which is obtained from Iranian Renewable Energy Organization [16].

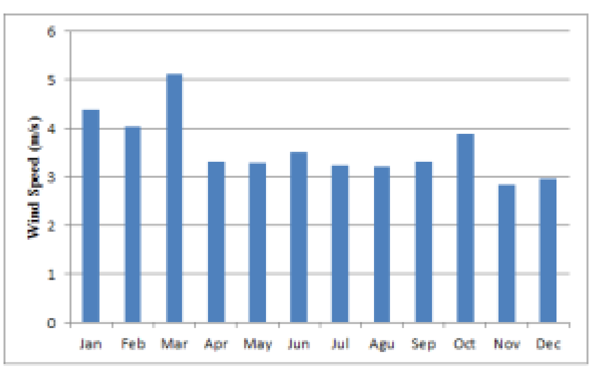

Fig. 1. Average monthly wind speeds of the site.

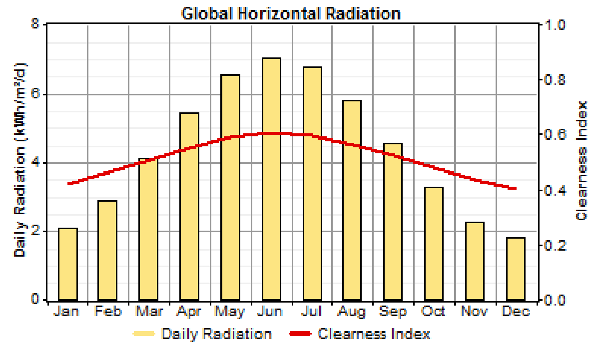

Fig. 2. Solar radiation data of the studied location.

C. Energy consumption profile for a single family house

With analyzing domestic consumption data, one could identify the basic characteristics of load curves of households which changes on a periodical basis.

In this study, a sample building was selected to test the feasibility of the designed hybrid renewable energy system. A typical sample of the daily load profiles of the building is shown in Figs. 4-7 for every months of a year. It can be seen that, the maximum load occurs during 6 P.M. and 12 P.M.

The equipment and electrical devices used in this building were a 70 W TV, a 300 W refrigerator, a 350 W washing machine, a 1000 W iron, and a 120 W PC. The peak load was considered to be around 918 W.

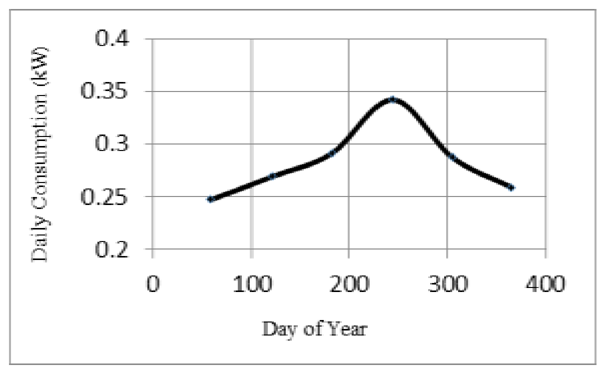

Fig. 3. Daily electricity consumption for generated data.

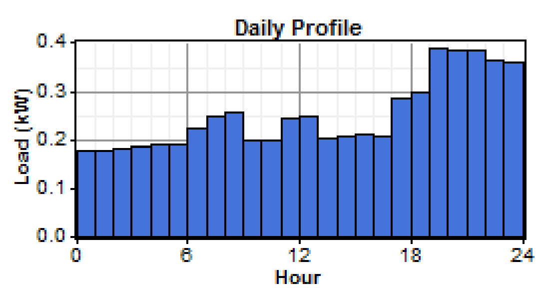

Fig. 4. Spring energy load profile for the household.

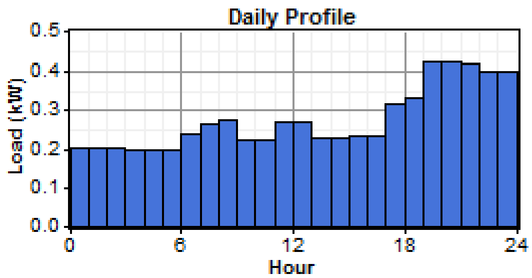

Fig. 5. Summer energy load profile for the household.

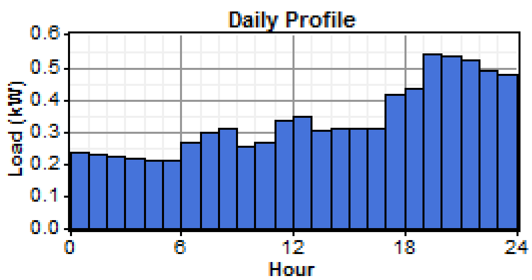

Fig. 6. Autumn energy load profile for the household.

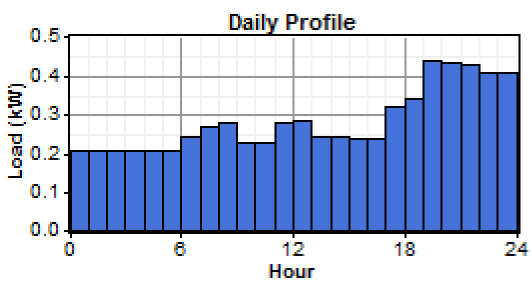

Fig. 7. Winter energy load profile for the household.

D. *Technical data from the manufacturers*

Because of low wind speed in the region, in order to choose an appropriate turbine, small turbine below 15 kW for wind speeds between 2 and 3 m/s were taken into account. Knowing that smaller turbines can be used in a set and cause less fluctuation in output and increase the reliability of the system, one can have a number of small wind turbines instead of a larger one. This means that in case of one of the turbine failure, the whole wind system would not fail. Thus, numbers of 1.5-kW WINDSPOT 1.5 [17] turbines have higher power production than one 15-kW STEP V2GL turbine at the low wind speeds of the site (Fig. 8). Moreover, the sizing with 1.5-kW wind turbines would have smaller overestimation as well as underestimation of the size of the optimized system. Thus, our estimation about needed capacity would be precise enough.

Though mono-crystalline solar panels are more expensive than poly-crystalline ones, their efficiency is higher, they live longer and are space efficient [18]. Mono-crystalline panels were selected based on these reasons and assumed to be inclined with 52^o slope. Adding battery bank to the system will increase the efficiency and reliability of the system. Moreover, connecting the batteries in series and creating string causes higher energy production capacity. The key physical properties

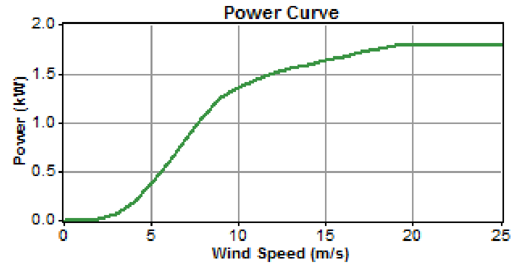

Fig. 8. Power curve of the wind turbine.

of the battery are its nominal voltage, capacity curve, lifetime curve, minimum state of charge, and efficiency. Two Surrette-S-550 lead-acid batteries used in each string, producing 5.2 kWh of electricity. Different number of strings, varied from 1 to 7, was used to find the optimized configuration. Each battery estimated to costs 340 US \$ with the life expectancy of 1400 cycles with DOD of 50%. Because in this system DC devices are used to generate power for AC components, a converter is required. A converter is a device that converts electric power from DC to AC in a process called inversion, and/or from AC to DC in a process called rectification. The selected inverter for this study is an off-grid inverter which costs 400 US \$ and is capable to convert 12 V input to 220 V output with 1000 W of rated power. A lifetime of 20 years was assumed in which the both inverter and rectifier efficiencies were assumed to be 93%.

III. System Simulation Tool

The HOMER Micro power Optimization Model [19] is a computer model developed by the US National Renewable Energy Laboratory (NREL) to assist in the design of micro power systems and to facilitate the comparison of power generation technologies across a wide range of applications. HOMER models a power system's physical behaviour and its life-cycle cost, which is the total cost of installing and operating the system over its life span. HOMER allows one to compare many different design options based on their technical and economic merits. It also assists in understanding and quantifying the effects of uncertainty or changes in the inputs [20].

To calculate the salvage value of each component at the end of the project life-time, HOMER uses the equation:

$$S = C_{rep} \frac{R_{rem}}{R_{comp}} \tag{1}$$

where S is the salvage value, C_{rep} is the replacement cost of the component, R_{rem} is the remaining life of the component, and R_{comp} is the lifetime of the component.

Using the following equation, HOMER calculates the total net present cost:

$$C_{NPC} = \frac{C_{ann,tot}}{CRF(i, R_{proj})} \tag{2}$$

where $C_{ann,tot}$ is the total annualized cost, i the annual real interest rate, R_{proj} the project lifetime, and CRF(.) is the capital recovery factor. Also, HOMER uses the following equation to

TABLE I: HOMER SOFTWARE INPUT DATA

Component	Model or Size	Life time	Purchase Cost	Replacement Cost	Maintenance Cost	Quantity
Wind Turbine	Windspot1.5kW	20	2501US$/turbine	2501US$/turbine	50 US$/y	0-4
PV Module	1-7 kW	20	1667 US$/kW	1667 US$/kW	20 US$/kW/y	-
Battery	Surrette S550 (6V,428Ah)	12	340 US$/battery	340 US$/battery	-	0-15
Inverter	1-3 kW	20	400 US$/kW	375 US$/kW	-	-

calculate the levelized cost of energy:

$$COE = \frac{C_{ann,tot}}{E_{primp} + E_{def} + E_{grid,sales}} \quad (3)$$

where $C_{ann,tot}$ is the total annualized cost, E_{prim} and E_{def} are the total amounts of primary and deferrable load, respectively, that the system serves per year, and $E_{grid,sales}$ is the amount of energy sold to the grid per year.
HOMER defines the levelized COE as the average cost per kWh of electrical energy produced by the system. All systems are ranked in relation to net present cost [21-22].

IV. RESULTS

Fig. 9 depicts different configuration used for optimization, their initial costs, and NPC.

It can be seen that the PV system and wind system have used 12 batteries, while the hybrid system has less number of batteries, i.e. 10. Also, all three systems used a 1 kW inverter.

The optimization results of all three system designs are provided in Figs. 9, 10 and 11.

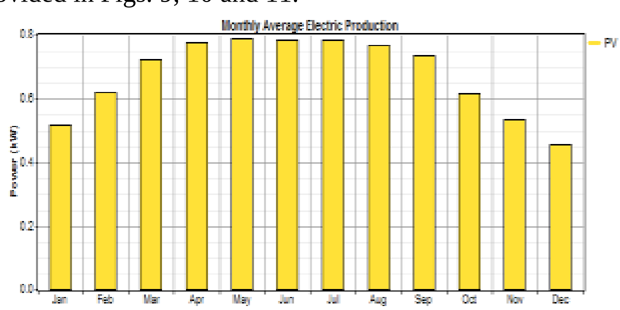

Fig. 9. Monthly average electricity production from the optimized PV-battery system.

Highest solar electricity generation levels occur between March and September, as can be seen in Fig.9, while wind power system in Fig.10 demonstrates a decrease in power production from April to September.

In the Fig. 11, it is observed that wind energy has a dominant contribution in the hybrid energy model in January, February and March and has a total share of 39% in energy generation, while the solar system has 61% share in total energy generation and is dominant in the rest of the year.

The annual and excess energy production in each system is presented in table II. The wind and solar system share in energy production is 2123 kWh and 3287 kWh, respectively. The lowest energy production belongs to hybrid system.

The net present cost of energy means the present value of investment and utilization of a model during its life. This value is the main financial characteristic to compare energy systems. The cost of electricity (COE) is the mean cost of per kWh of produced electricity in selected system. Figs. 12, 13 and 14 represent a summary for implementing each system.

As shown in the Figs., the wind turbines are the most expensive element of the wind system with 4 turbines cost 10000 US $, then is the battery bank with 4800 US $ and inverter with 400 US $ of initial investment. Since there is no

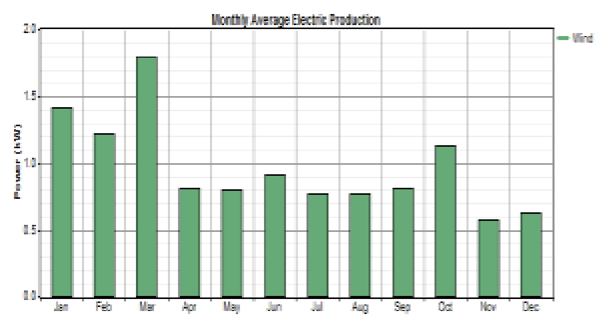

Fig. 10. Monthly average electricity production from the optimized wind-battery system.

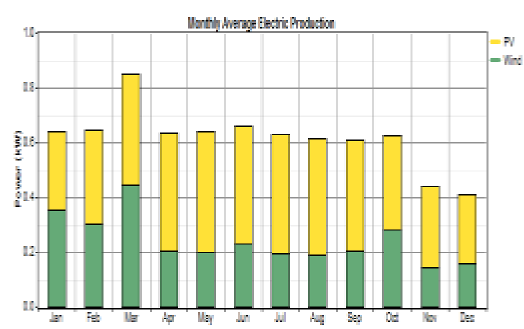

Fig. 11. Monthly average electricity production from the optimized Hybrid wind-PV-battery system.

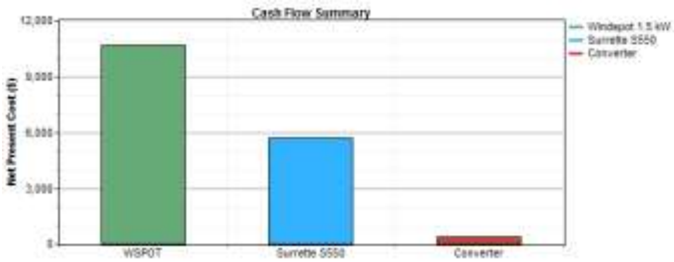

Fig. 12. Cost summary of the wind energy system.

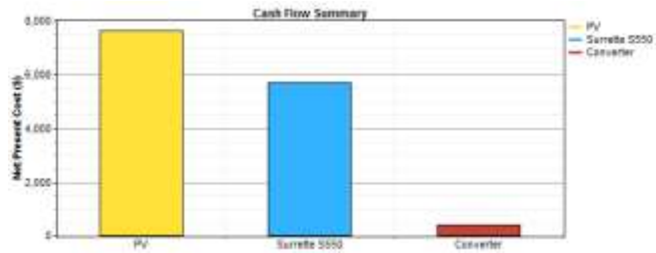

Fig. 13. Cost summary of the PV energy system.

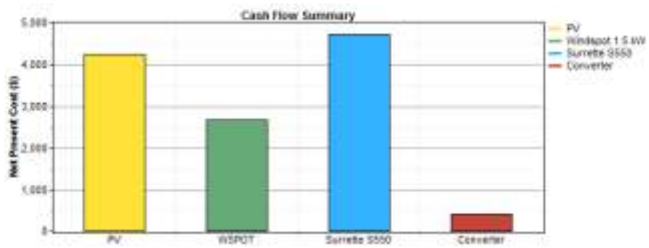

Fig. 14. Cost summary of the hybrid wind-PV energy system.

power selling to the grid, there is only 70.5 US $ is saved annually. Therefore, the NPC cost is more than initial investment and it is 16744 US $.

In the optimized PV system, 4.5 kW PV panels costs 7500 US $, battery bank costs 4800 US $ and inverter is 400 US $. The NPC cost in this case is estimated as 13700 US $.

Unlike the last two case, in hybrid system the most initial investment is for battery bank with 3400$, then is the PV system with 4168 US $, and a 1.5 kW wind turbine with 2050 US $. The NPC cost of this system is 12046 US $.

The comparison of each system cost is presented in table III. The NPC cost for optimized hybrid system is 12% and 28% less than PV-battery and turbine-battery systems, respectively.

According to financial analysis presented above, it is obvious that the hybrid wind-PV-battery system is the most economical solution with 39.8% of total cost for PV array, 32.4% for battery bank, 24% for wind turbine and 3.8% for inverter. The cost of electricity generation in this system is 0.424 US $/kWh. The most economic configuration for hybrid system is using 2.5 kW PV panel, one 1.5 kW turbine and one 1 kW inverter plus 10 batteries.

V. Conclusion

This study aimed for a normal building, considering off-grid case and only sought to examine the possibility of using the power generated by a stand-alone wind or photovoltaic system in Khodabandeh city, in Iran. The selected optimized systems were:

- Solar system with 4.5 kW PV panel, twelve 5.2 kWh

Table II

The Comparison Of Annual Electricity Production Among Optimized Different Systems

System	Annual Energy Production (kWh/y)	Annual Excess Electricity (kWh/y)
Wind System	8493	5497 (64.7%)
PV System	5916	2774 (46.9%)
Hybrid System	5410	2398 (44.3%)

Table III

The Cost Comparison Among Optimized Different Systems

System	Capital Cost ($)	NPC ($)	COE ($)
Wind System	14482	16774	0.59
PV System	11982	13700	0.482
Hybrid System	10469	12046	0.424

Surrette batteries, and one 1 kW inverter, 11982$ initial capital cost;

- Wind system with four 1.5 kW turbine, twelve 5.2 kWh Surrette batteries, and one 1 kW inverter, 14482 initial capital cost;
- And hybrid system with one 1.5 kW turbine, ten 5.2 kWh Surrette batteries, and one 1 kW inverter, 10469 initial capital cost;

Comparing each system cost and investment needed, the hybrid system was selected as the most economic option available. Therefore, the hybrid energy systems are more reliable than single source systems. As single source systems such as wind power and solar power often have fluctuation in power production in different months of a year, by application of a hybrid system, the flow of electricity will be more continuous and also the variations and fluctuations will be balanced out, as the lack of sufficient solar radiation and wind speed rarely happen simultaneously.

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