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Technical and Economic Evaluation of Hybrid wind/PV/Battery Systems for Off-Grid Areas using HOMER Software

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ABSTRACT

Incremental consumption of electrical energy, reduction of fossil fuel resources and environmental pollution problems caused by them are the main reasons, which tend the managers and officials in countries energy sector to develop use of renewable systems. In the not-too-distant future the use of renewable energy such as wind and solar will be very important and will play predominant role in economic indices of power systems. In recent years, technological advances in renewable energy and increasing price of petroleum products promote system managers to use low-cost and low-emission energy resources in form of hybrid systems and widespread propagation of electricity generation have been developed in remote areas. In Hybrid systems two or more sources of renewable energy is typically adopted, which increases the reliability of these systems. In this paper, the technical and economical consideration of a wind and solar hybrid system to supply electrical energy for a number of remote users (aid and medical emergency Shelter in Yazd) is provided. In order to investigate optimization and economic analysis of the proposed hybrid system, the HOMER software is used. The results of Simulation in HOMER software show that Solar cells and wind systems with average generation power of 896 kWh/yr. and 343 kWh/yr., consist proportion of 72 and 28 percent of the total generated energy respectively, which are dedicated to satisfy the loads.

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1. INTRODUCTION

The indiscriminate use of fossil fuels and the release of excessive environmental pollution have increased the global temperature. According to statistics released by the International Energy Agency, currently annually significant emission about 30 billion tons of carbon dioxide produces from burning fossil fuels in the world, about 40 percent in which is related to the production of electricity and heat. According to estimations made by the International Energy Agency, due to lack of control of this trend, the amount of carbon dioxide will double the current value till 2050, that will increase the earth temperature, destroy glaciers and rise sea's level and so on. This phenomenon imperils the human habitancy on Earth. Therefore, renewable energy can be a convenient and efficient way to overcome this problem.

According to energy consumption statistics in 2011, 19% of the final consumption in the world has been satisfied by renewable resources, in which 9.3% is met by traditional biomass energy, 3.7% by hydroelectric energy, 4.1% by modern renewable energy sources and 1.9% by wind, solar, geothermal, etc. According to available and published statistics by deputy of Electricity and Energy Ministry in Iran in 2012, the largest portion of consumption of energy carriers in 2012 is related to crude oil and petroleum products and natural gas with 89.19%. According to the same statistics renewable energies were provided only 0.7%

of the total energy demand in country in 2012. This indicates that despite the high potential of wind and solar in the country, unfortunately, just small portion of its capacity is used.

Solar and wind energy are among renewable and clean energies, which are as a free and inexhaustible source and have the ability to convert to other forms of energy. Iran with north latitude between 25 to 45 degrees is among the appropriate areas in terms of sun radiation. The lowest annual average radiation in Iran is about 3.8 belongs to Rasht and the highest is 5.9 relevant to Bam. Aside from the shore of the Caspian Sea in Iran the sunny days consist 63 to 98% of year. Due to high amount of solar radiation it can be said that most provinces in Iran are located in the suitable radiation areas.

Furthermore, due to existence of windy areas the design and construction of windmills has been common in Iran from 2000 BC. The studies and calculations, which have performed to estimate the potential of wind energy in Iran, have shown that at least only in 26 areas of the country (including more than 45 appropriate sites) the amount of nominal capacity of sites, with an overall efficiency of 33% is around 6500 MW. However, the capacity of wind power plants under operation in country, at the end of 2012 was about 106 MW [1-4].

Wind and solar systems in form of hybrid systems can operate as independent power provider, which can supply Loads without connecting to the network and island mode. This hybrid energy system often leads to more efficient, economic and environmental return than separate wind and solar systems. Hence, use of such systems can lead to provide electrical energy of isolated and not-connected-to-grid loads.

In order to optimize the HOMER software is used. HOMER software is applicable to simulate technical and economical evaluation of hybrid systems that is produced and spread by the US National Renewable Energy Laboratory (NREL). HOMER software not only enables users to compare many different design options according to the technical and economic principles, but also provide the possibility of changes and many uncertainties in inputs. To model a wind and solar hybrid system consists of photovoltaic cells and wind turbines in the HOMER software, information of solar and wind speed should be entered into the considered area of software. In the HOMER optimization process, all different arrangements of power supplying, which satisfy the technical restrictions, search the solution space to achieve the most economical mode for life cycle cost. The software allows the user to examine the effect of changing one variable on the whole system. In this article, at first, the climate and the weather of Yazd has been studied, then it has been attempted to explain the structure of the proposed hybrid system, which is needed to provide electricity of a aid and emergency Shelter in Yazd and then this proposed system will model in HOMER software [5].

2. WEATHER CONDITIONS OF THE UNDER-STUDY SITE

Yazd is located in the central part of the Iran plateau in the vast and dry valley between the Shirkooh and Kharanaq mountains, from 15 degrees and 53 minutes to 40 degrees and 54 of east minutes and from 46 degrees 31 minutes to 15 degrees 32 North minutes. This city is limited from the north to Maibod and Ardakan and from the east to Bafq and from West to the province of Isfahan and from the south to the Taft, Abarkooh and Mehriz cities. The average height above the sea level in Yazd is 1200 meters. The annual average radiation of Yazd is about 5.15.that represents a significant potential for solar energy in the city of Yazd. Table 1 shows average amount of radiation reaching the horizontal surface of the earth in the city of Yazd in different months of the year.

Table 1. Mean daily radiation reached by the horizontal surface of the Earth in *Kwh/m^2 day* in the different months in Yazd

Month	The Average Radiation (*Kwh/m^2 day*)
January	2.78
February	3.75
March	4.61
April	5.39
May	6.53
June	7.19
July	7.33
August	7.17
September	6.11
October	4.83
November	3.39
December	2.69
Average	5.15

Yazd is among areas of Iran, where due to factors such as low rainfall and high evaporation, being away from the sea, being near the dry and vast salt desert and pretty low humidity as well as high temperature put this province among the driest Iran's regions. Moreover in this area, an extreme fluctuation in temperature exists. Yazd city with an average wind speed of 2.5 meters per second is between appropriate locations in Iran, where has the high potential for installing wind turbine. This factor caused to build windward towers in this city from many years ago for ventilation and cooling of air in homes so that it has become as a symbol of city of Yazd [6-7].

Table 2. Shows mean wind speed in m/s in different months in the city of Yazd

Month	The Average Wind Speed (*m/s*)
January	4.4
February	5.1
March	6.0
April	6.6
May	6.6
June	6.1
July	6.4
August	5.7
September	4.4
October	3.8
November	3.3
December	3.9
Average	5.2

3. HYBRID SYSTEMS

Hybrid renewable energy systems are becoming more pervasive than before for power generation in remote areas of the network. Hybrid systems usually use two or more sources of renewable energy, which improves system performance and stability in energy supply. The important matter about hybrid systems that operate independently from the network is that the optimum size of them should be calculated, in order to exist ability of economical implementation with minimum cost. HOMER's optimization software is a tool that is produced and spread by the US National Renewable Energy Laboratory (NREL). In this paper, a solar-wind hybrid system has been studied to supply electric energy required by an aid and emergency residential place in Yazd and implemented in HOMER software. Figure 1 shows the general Schematic of wind and solar hybrid system used in this study.

General schematic shown in Figure 1 is modeled in form of Figure 2 in HOMER Software. Thus, detailed information of various system components such as load and sources are presented in the following parts [8-9].

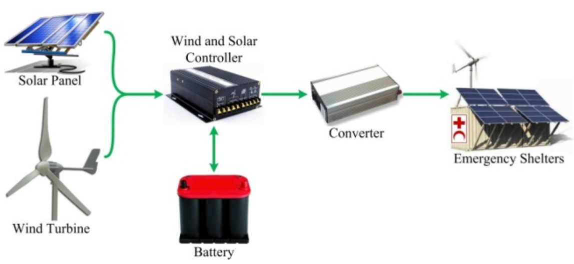

Figure 1. General Schematic of independent energy generation system in this study

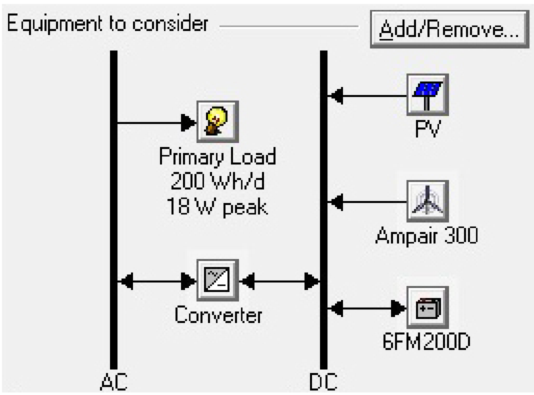

Figure 2. The implementation of the generation system independent of the network in HOMER software

4. PARAMETERS AND CONDITIONS OF THE PROJECT

4.1. Electrical Load

With examining aid and emergency Shelters of the Red Crescent Society organizations of the Islamic Republic of Iran that is in operation or under construction now and electrical energy consumption capacity of an aid and Emergency Medicine Shelter can be calculated by using Ashrae and HSE Standards. The electrical powers are spend in applications such as lighting, air conditioning and other electrical equipment, etc. We should notice that care of patients on aid shelter without electrical energy can be very difficult and often impossible, so accurate calculation of supplying electrical energy by different sources is important. In this article we are looking for supplying electric power of aid and emergency medicine shelter in Yazd province, therefore, the electrical energy consumption of one of the containers is measured and examined at different times. The profile of daily load consumption of studied shelter on a specific day is displayed in Figure 3.

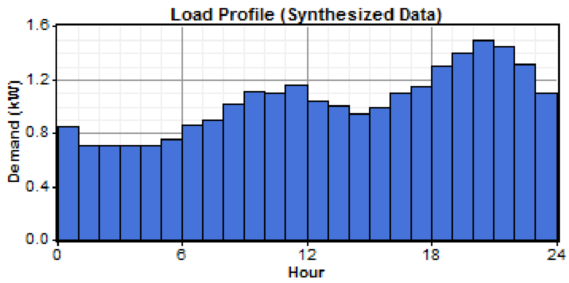

Figure 3. The profile of daily load consumption of studied shelter on a specific day

4.2. Solar Energy Resource

As stated in the project we are acting to investigate the supplying electrical power in aid and emergency or relief and rescue shelter in the city of Yazd. By entering the data of amount of average daily radiation reached to the horizontal surface of the earth in HOMER software and according to the height of the studied site the index of transparency is introduced. Figure 4 shows the output of solar radiation in different months in Yazd (*Kwh/m*^{2} *day*).

4.3. Wind Energy Source

In this paper the data collection of the monthly mean wind speed has been used that is collected by meteorological stations in Yazd. Figure 5 shows the output of the mean wind speed in different months in the city of Yazd (*m/s*).

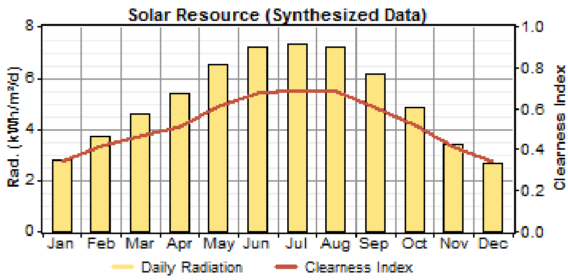

Figure 4. The amount of solar energy in Yazd (*Kwh/m*^{2} *day*)

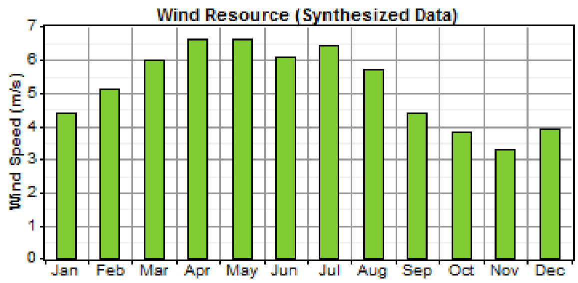

Figure 5. The average wind speed in different months in Yazd (*m/s*)

5. REVIEW THE COMPONENTS OF HYBRID SYSTEM

In this section we will examine the components of the hybrid system used in this case study and will attempt to provide technical and economic characteristics of the proposed models. Hybrid system components used in this case study are: 1- wind turbines, 2- photovoltaic systems, 3- batteries and 4- converter. In the following parts, the technical specifications and proposed model and price of each of used units, hours of operation and other features will be described.

5.1. Wind Turbine

Wind turbines earn their input power from converting wind power to torque that is created by the action of turbine blades. Wind energy has direct relationship with wind density and collision speed with turbine blades. It means that if the wind density or its speed be high, the more energy will be available in the wind, so turbines receive more energy. Due to the aerodynamic properties of wind turbines and direction of the turbine against the wind direction, use a coefficient of the total wind energy that is shown with Cp and is called the turbine performance coefficient of turbine and can show the efficiency wind turbine. According to Betz law the maximum ratio can be 0.593 and in practice due to limitations in the construction, this factor is placed in range of 0.25-0.5. Accordingly the power of the wind that is converted by the turbine can be calculated from (1) [10]:

$$P_{wind} = \frac{1}{2}.\rho.A\,V_{wind}^{3}.C_P(\lambda) \qquad (1)$$

In the above equation, ρ is air density, which at 15 °*C* is $\rho = 1.290 kg / m^3$, *A* is the scanning area of the rotor blades, V_{wind} is wind speed, C_P is turbine performance ratio, λ is the ratio of linear velocity of tip of the blades to the wind speed and is called the *TSR* (Tip Speed Ratio) and its value is calculated by (2):

$$\lambda = \frac{R\,\omega_{rot}}{V_{wind}} \qquad (2)$$

In the above equation, *R* is the blade (the radius of circle that encompasses the blades), ω_{rot} the angular velocity of tip of the blades, V_{wind} is wind speed [11-12].

In this paper, in order to supply required power a wind turbine model 300, with a capacity of 0.3 kW, which is manufactured in Ampair Company, is used. This wind turbine is horizontal axis with three blades, the propeller of three-bladed wind turbine acts against the wind and is placed against the wind flow. Technical parameters of the wind turbine with a capacity of 0.3 kW Ampair-300 model are shown in Table 3. Figure 6 shows the power-speed characteristic of wind turbine model Ampair-300.

Table 3. Technical specifications of under-study wind turbine (Ampair-300)

Architecture	Upwind, 3 Bladed rotor, Self-regulating
Cut-in Wind Speed	3 m/s
Cut-Out Wind Speed	None - continuous generation to 60 m/s
Rated Power	0.3 KW at 12.6 m/s
Maximum Power	~ 0.36 KW
Voltage Options	12 volt DC; 24 volt DC
Turbine Diameter	1200 mm
Weight	10.5 kg
Operating Temperature	-20˚C ~ +50˚C
Design Longevity	20 Years minimum

In this study assumed number of wind turbines is considered to be between 0 to 5. The initial cost of installation and setting up of the turbine with capacity of 0.3 kW is 320$ and replacement fee is 300$.

5.2. PV System

A solar panel is a collection of solar cells that are connected in series or parallel. Each *PV* cell is a *p-n* semiconductor junction that converts solar radiation energy into electrical energy. A sample equivalent circuit of *PV* cells has been shown in Figure 2, that I_{ph} represent the photodiode current, R_j, R_{sh} and R_s are non-linear impedance *p-n* junction, intrinsic parallel resistance and internal series resistance within the cell. R_s resistance is very small and R_{sh} resistance is very large, therefore, to simplify the circuit diagram, both of them can be neglected.

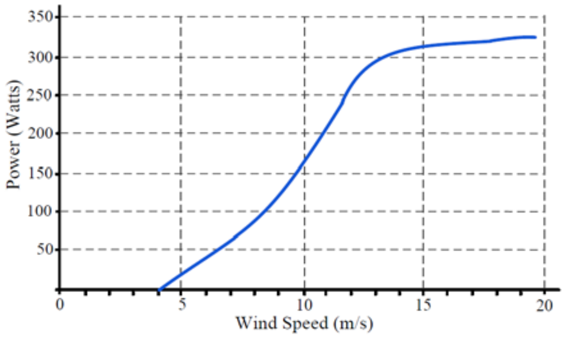

Figure 6. power-wind speed characteristic of under-study wind turbine (Ampair-300)

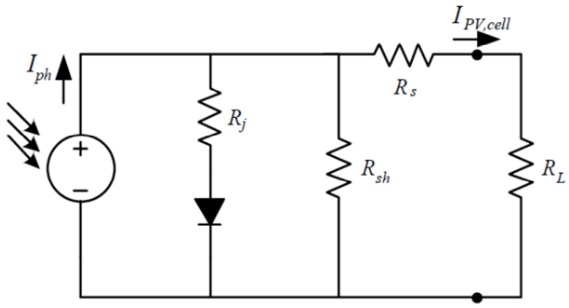

Figure 7. The equivalent circuit of a solar cell

According to the equivalent circuit of PV cell, PV array output current is calculated using (3) as follows:

$$I_{PV} = N_P I_{Ph} - N_P I_{sat}\left[\exp\left(\frac{q}{nkT}\frac{V_{PV}}{N_S}\right)-1\right] \quad (3)$$

That I_{PV} and V_{PV} are current and array of *PV* voltage, N_s and N_p are the number series and parallel cells in the array, *q* is electron charge (1.6*10-19 Coulomb), *K* is the Boltzmann constant (*1.38*10-23 J/°K*), *T* is *PV* array temperature (°*K*) and n is ideal factor of *p-n* junction (between 1 and 5). Also I_{sat} indicates to the reverse saturation current *PV* cell that is dependent on the *PV* array temperature and can be calculated using (4) as follows:

$$I_{sat} = I_0 \times \left(\frac{T}{T_0}\right)^{\frac{3}{n}} \times \exp\left[\frac{qE_{gap}}{nk}\left(\frac{1}{T_0}-\frac{1}{T}\right)\right] \quad (4)$$

Where T_0 is the cell reference temperature, I_0 is cell reverse saturation current at T_0 and E_{gap} is the air gap voltage of semiconductor in a *PV* array. In (1) I_{ph} is changed by changing the radiation amount of S_i & array temperature of *T* that can be calculated by (5):

$$I_{ph} = I_{SC,T_0} \times S_i + K_i\left(T - T_0\right) \quad (5)$$

I_{sc}, T_0 is the short circuit current of the array at T_0 and K_i is temperature coefficient. Based on (1) *PV* power output (P_{PV}) is calculated using (6):

$$P_{PV} = I_{PV}V_{PV} = N_P I_{Ph} V_{PV} - N_P I_{sat} V_{PV}\left[\exp\left(\frac{q}{nkT}\frac{V_{PV}}{N_S}\right)-1\right] \quad (6)$$

This equation shows that the amount of P_{PV} is dependent on S_i and temperature of the *PV* array [13-14].

In this paper, to supply required power, from the solar panel menu 200*W* Crystal Grape solar (*GS-S-200*) is used. The technical specifications of this panel are presented in Table 4.

Table 4. Electrical Specifications of Solar Panel GS-S-200 in standard test conditions (STC)

Maximum Power at Standard Test Conditions (P_{max})	200 *W*
Voltage at the Maximum Power Point (V_{mpp})	36.3 *V*
Current at the Maximum Power Point (I_{mpp})	5.51 *A*
Open Circuit Voltage (V_{oc})	45.6 *V*
Short Circuit Current (I_{sc})	5.71 *A*
Module Efficiency (%)	15.7%
Operation Temperature (°C)	-40 °C ~ +85 °C
Maximum System Voltage (V)	1000*V* / 600*V*
Maximum Series Fuse Rating (A)	10 *A*
Power Tolerance	-2 % ~ +2 %

**(STC): Radiation Rate 1000 W/m^2, Temperature 25˚C, Time 1.5AM.*

In this study, 7 power range of solar panels (200, 400, 600, 800, 1000, 1200 and 1400 *watt*) have been selected and evaluated. The cost of purchasing and solar panels installation and the cost per *kW* is 1,600*$* and the cost of replacing the panels is considered to be 1,400*$*.

5.3. Battery

Lead-acid batteries are used to store excess electricity generated by the proposed hybrid system, and adjust the system voltage and finally to supply the load required power in condition of lock of generation of solar and wind system (reduction of wind speed or solar radiation conditions). Various models of batteries are available in the market for this work. The battery, which is selected for this study is (200*Ah*, 12*V*) Company Vision (*6FM200D*). In this study, the purchase and installation cost of each battery model (*6FM200D*) is 360*$* and 345*$* respectively and cost of replacement of battery is considered to be 360*$*. In this study, the numbers of batteries are assumed to be 0, 1 and 2. Minimum considered lifetime for each battery is 4 years.

5.4. Converter

Electrical converter used in hybrid system is an electronic device that convert the *DC* current (from sources such as batteries, solar panels or wind turbines, etc.) to the alternative current (*AC*), or conversely. The conversion type of these converters (*DC-AC* or *AC-DC*) is different, which depends on type of application in the hybrid system. The converter is used in this study is a *DC-AC* converter. The converted *AC* current can vary based on required voltage and frequency that is controlled by the appropriate transformers and circuits. *DC* to *AC* converter Selected for this study is a 1000*W* Inverter Model *IPS-1200* manufactured by *KEBO* Electrical Company. In this study, the number of assumed *DC* to *AC* converter has been considered to be 0, 1 and 2. The initial cost of installation and triggering of Each *IPS-1200* with a capacity of 1 *kW* is 200*$* and the cost of replacement is 185*$* [15-16].

6. SIMULATION IN HOMER SOFTWARE

In *HOMER* software, the net present cost or final net cost (*NPC*) is used in order to calculate the system life cycle and the costs include: installation, replacement, fuel, etc. all costs and revenue is evaluated by constant interest rate over a year period. In this assessment, in order to affect inflation in computation, equation (7) is adopted:

$$i = \frac{i' - f}{1 + f} \tag{7}$$

That in (7), *I* is real interest rate, i' is nominal interest rate, *F* is inflation interest rate.

The main output of economic calculations in the software is the net present costs (*NPC*) which is calculated by (8):

$$C_{NPC} = \frac{C_{\text{annual, total}}}{CRF\left(i, R_{\text{Project}}\right)} \tag{8}$$

That in equation number (8), $C_{\text{annual, total}}$ Annual total cost, R_{Project} Project longevity, *I* real interest rate. To calculate the return on investment in *N* years equation (9) is used:

$$CRF(i,N) = \frac{i(1+i)^N}{(1+i)^N - 1} \quad (9)$$

Which $CRF(i,N)$ is a return factor of investment in N years. In performed optimization in *HOMER* software all possible condition of simulation and best combination with the lowest net present costs (*NPC*), introduced as optimal arrangement. The best achieved combination meet all the preset constraints by the operator with the lowest net present cost [17-20]. The result of optimization in *HOMER* software for mentioned system in the city of Yazd has shown in Figure 8.

PV (kW)	AIR	6FM200D	Conv. (kW)	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Ren. Frac.	Capacity Shortage
0.6	1	1	1	$ 1,840	87	$ 2,834	0.683	1.00	0.01
0.8		1	1	$ 1,840	95	$ 2,932	0.714	1.00	0.02

Figure 8. The result of the optimization performed by the *HOMER* software to the Total *NPC*

7. RESULTS AND ANALYSIS OF OPTIMIZATION CURVE

Details of the various components' costs of a hybrid system gained from optimization results in 20-years lifetime of the project has shown in Figure 9. As can be seen in Figure 9, most of the project costs is related to the photovoltaic system initial cost, but most cost of replacing in 20 years is related to battery that has a large role in total cost of this project. Figure 10 shows the wide curve of cost distribution based on different parts of the system (investment, replacement, operation, fuel and recycling) during the project.

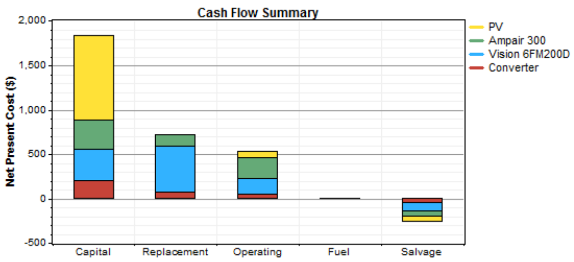

Figure 9. Net costs of the various components of the under-study hybrid system in various sectors

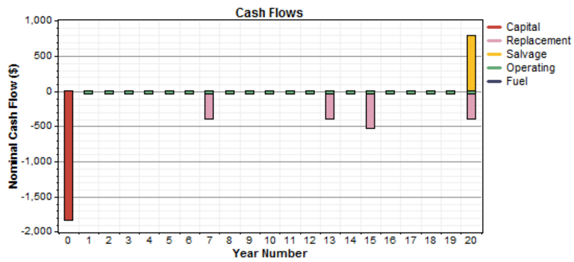

Figure 10. Cost Distribution curve by the different section over the life of the project

Figure 11 shows the average rate of generating power for different months of the year. Accordingly, the average power generated by the solar cells is 896 (*kWh/yr.*), which consist 72% of the total amount of generated energy in under-study hybrid system. Wind turbine generates average power of 343 (*kWh/yr.*), which dedicates 28% of total energy generation. The maximum power generated by solar cells is in June, July, August, and September months and the lowest amount is related to the *December* and *January*. Also the maximum power generated by wind turbines is in *April*, *May*, *June*, *July*, and the lowest are related to *November* and *October*.

In Figure 12 and 13, the amount of output power of solar and wind systems have been shown at different times of day and in terms of capacity and generated power for different months of the year. Surplus electrical power, which is generated by solar and wind systems, saves in the intended Storage system, which is battery. The amount of electrical power stored in the battery is shown in Figure 14 for the time of day and in terms of capacity and generated power for the month of the year.

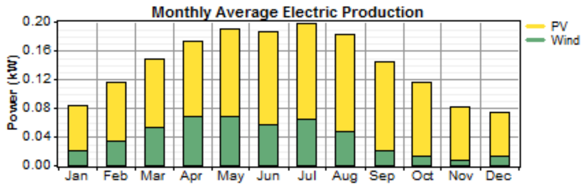

Figure 11. The average amount of power generation of system for different months of the year

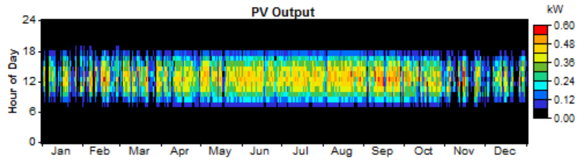

Figure 12. The electrical power output of the solar system at different times of the day

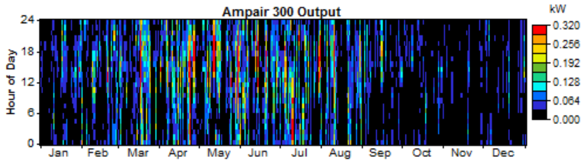

Figure 13. The electrical power output of wind system at different times of the day

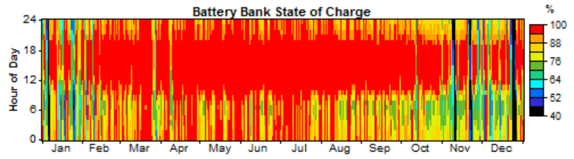

Figure 14. the amount of power stored in the battery at different times of the day

In this system, when the energy generated by solar and wind cells are more than needs of loads, this excess electrical power can be stored in batteries and at hours that the solar and wind system are not capable to generate electric power, the battery starts generation and provides the electrical energy required for load.

8. CONCLUSION

Usually, one of the biggest challenges in remote systems and independent isolated networks is how to supply the fuel and achieve a sustainable energy source. Today, due to advances in the field of renewable energy and increasing prices of oil products, usage of renewable energy has become very common in the form of hybrid systems.In hybrid energy systems, electricity is provided from different energy sources, that the resources work with each other. Hybrid systems compared to systems that use one source to produce electricity, have higher reliability. Two of the most usual sources of energy are solar and wind energy. In this paper we have attempted to examine how to use solar and wind hybrid systems to supply electric power of an aid and medical emergency Shelter in Yazd. Optimization and simulation results in HOMER Software show that the average power generated by the solar cells is 896 *kWh/yr.* which is 72% of the total amount of energy generated by the hybrid system. Wind turbines with average power output of 343 *kWh/yr*. dedicate 28% of total energy production to itself. The results indicate good potential of Yazd for wind and solar energy and also illustrates the proper functioning of the proposed approach to provide the electrical needs of system.

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