

## Techno-economic viability of a hybrid wind and solar power system for electrification of a commercial building in Shiraz, Iran

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**Abstract.** In this paper, techno-economic viability of a hybrid Wind/PV system with a battery and inverter was performed using the HOMER® international optimization model. A commercial building in Shiraz, Iran was selected as a case study to analyze the feasibility study of installing the proposed hybrid Wind/PV system. Before the optimization process, different key parameters such as the monthly wind and solar resource, monthly and daily electrical load consumption, economic constraints such as interest rate and project lifetime, the components features such as the battery or inverters sizes and costs and other related information were collected and imported into HOMER®. The optimization results suggested that the most efficient and economical hybrid energy system is a combination of 9 kW photovoltaic panel, 1 wind turbine (10 kW), 5 batteries and 5 kW converter. The total net present cost (NPC) and the cost of energy (COE) for this system were estimated to be \$89,884 and \$0.619/kWh. The final results of the study concluded that the employment of the proposed hybrid energy system for electrification of the studied commercial building in Shiraz is highly recommended.

**Keywords:** renewable energy; hybrid system; PV array; wind turbine; HOMER®

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### 1. Introduction

Electricity is a major commodity for the socio-economic development of any country. It plays vital role in all activities of human beings in the present scenario. The major part of electricity is developed mainly from the fossil fuel like coal, oil, and gas. These fossil fuels have severe impact over the atmosphere in various aspects. Stock of these fossil fuels is limited and will last hardly till the middle of this century.

A growing interest in renewable energy resources has been observed for several years due to their pollution-free nature, availability all over the world, and continuity. These facts make these energy resources attractive for many applications (Kumaravel and Ashok 2012, Nedaei 2012). Since the oil crisis in the early 1970s, utilization of the solar and wind power has increased significantly. In recent years, hybrid PV/wind systems have become viable alternatives to meet

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environmental protection requirement and electricity demands.

A hybrid solar-wind energy system uses two renewable energy sources. Hence efficiency and power reliability of the system increases. However, aggregating inherently stochastic power sources such as wind and solar to achieve reliable electricity supply is a non-trivial problem.

To use solar and wind energy resources more efficiently and economically, the optimal sizing of hybrid PV/wind system with batteries is important in this respect (Fesli *et al.* 2006). One of the efforts done in application of PV array and wind turbine is constructing hybrid energy system PV/wind/Battery in commercial buildings.

Feasibility study of hybrid energy systems have been an important subject of research around the world in the recent years. For instance, Amutha and Rajini (2015) investigated the economic, technical and environmental performance of various hybrid power systems for powering remote telecom. They concluded that replacing the present arrangement of the diesel power telecom system with their proposed SPV/Wind/Battery or SPV/Wind/Battery/FC is not just economically justifiable but also, its environment-friendly nature makes it an attractive option to supplement the energy supply from other sources. Nafeh (2011) attempted to size an optimal PV-wind hybrid system through minimizing the total cost of the proposed hybrid energy system and maintaining the loss of power supply probability (LPSP) of the system lesser than a certain fixed value. Dursun *et al.* (2013) investigated the possibility of obtaining electricity from solar/wind hybrid systems in the remote Turkish city of Edirne. He attempted to decrease the high cost of operating a stand-alone diesel system and achieve a substantial amount of fuel saving. Ataei *et al.* (2015a) investigated the techno-economic viability of the hybrid energy systems for a rural and remote village in south west of Iran. This remote village has had the problem of electrical grid extension since many years ago. Simulation and analysis of the designed hybrid system was performed using HOMER model and by considering three scenarios. The researchers concluded that, in general, the use of the proposed hybrid system in the studied site, both technically and economically, is strongly recommended. In a recent study, Rezzouk and Mellit (2015) carried out an extensive feasibility study and sensitivity analysis of a stand-alone photovoltaic–diesel–battery hybrid energy system in the north of Algeria. The impact of the storage battery bank size on the total cost of the power system has also been studied; it has been found that this parameter is a decisive factor that determines the optimum share of the solar resource in the hybrid system.

Although there are a lot of research studies in the field of hybrid energy systems, rare research projects dealt with the use of hybrid energy systems with the ability to generate electricity entirely from renewable energy for employment in the commercial buildings. In the current study, the National Renewable Energy Laboratory's (NREL) Hybrid Optimization Model for Electric Renewables (HOMER) software was used to carry out the optimal design and techno-economic viability of a hybrid energy system which uses only renewable source to electrify a commercial building in Shiraz, Iran.

HOMER is software that facilitates design of hybrid power systems. Analysis with HOMER requires information on resources, economic constraints, and control methods. It also requires inputs on component types, their costs, efficiency etc. Sensitivity analysis could be done with variables having a range of values instead of a specific number. HOMER estimates a system's technical feasibility and then performs the economic analysis and ranks the systems according to total net present cost (Ngan and Tan 2012). In the current research, the latest version of HOMER modelling software (version 3.3 - 2015), was employed to perform the optimization analysis of the proposed hybrid renewable energy system.

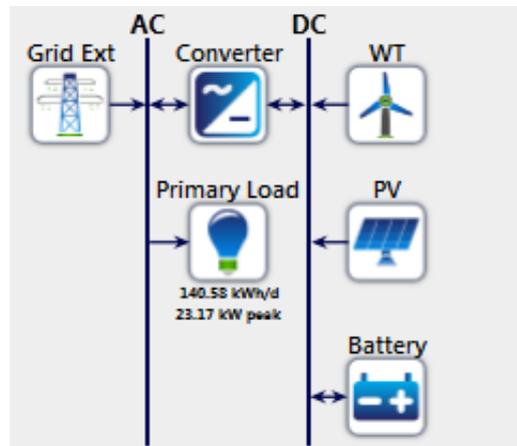


Fig. 1 The proposed HOMER model for a hybrid photovoltaic-wind power system

### 1.1 The studied commercial building

The commercial building which is considered in this study has four floors with 100 employees and in this study, we install all equipment in the roof of this building. The general schematic of hybrid energy system at the roof of this building is shown in Fig. 1. As can be realized from this figure, the feasibility study of connecting the current hybrid system configuration to the national electrical grid was also evaluated.

## 2. Data collection

### 2.1 Solar radiation

Solar power is the energy from the Sun. It is renewable, inexhaustible and it doesn't pollute the environment. Solar radiation is a reliable source of energy that is received in the form of relatively diffuse energy. Its daily cycle varies and may be influenced greatly by meteorological conditions such as cloud, haze and fog. Being radiant energy, solar energy cannot be stored directly. Global solar radiation data are readily available and reliable for all locations (Khan and Iqbal 2005). The solar resource was used for the hybrid energy system is located in the under investigated area with geographical coordinates defined as: latitude  $29.5382^{\circ}\text{N}$ , longitude  $52.5910^{\circ}\text{E}$  and average altitude 1436 m above sea level. The solar radiation data for this region was obtained from the NASA Surface Meteorology and Solar Energy (2015). The monthly average values of solar radiation and clearness index are demonstrated in the Fig. 2. The annual average of solar irradiation is estimated  $5.08 \text{ kWh/m}^2/\text{day}$ .

### 2.2 Wind speed

Wind Power is the energy extracted from the wind, passing through a machine known as the windmill. The windmill in this case is usually called a wind turbine. This turbine transforms the wind energy to mechanical energy, which in a generator is converted to electrical power. An

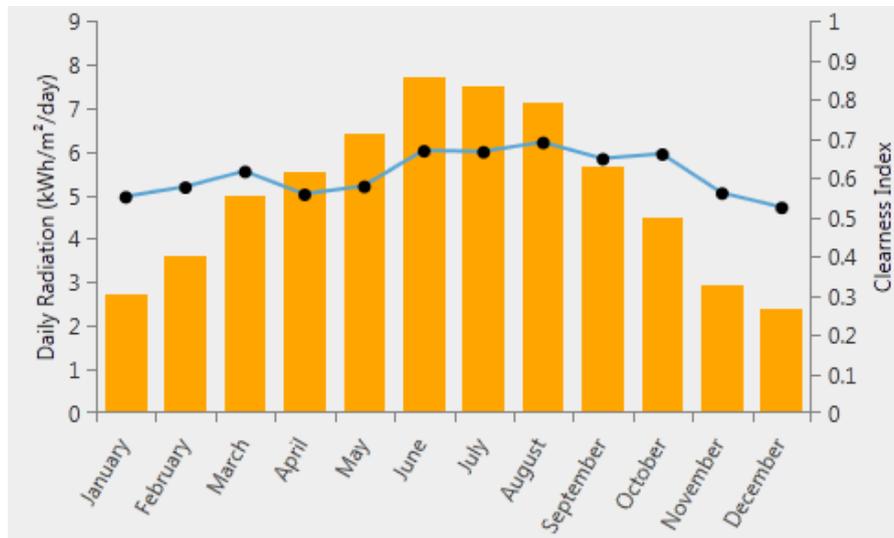


Fig. 2 The monthly solar resource profile for the studied location



Fig. 3 The monthly average wind speed values for the studied region

integration of wind generator, wind turbine, aero generators is known as a wind energy conversion system (WECS) (Ahmed 2010, Nedaei 2014).

Based on the wind speed data obtained from an anemometer tower (that was installed at the roof the building), the average monthly wind speed variations was measured at 40 meters above the surface of the earth and is demonstrated in the Fig. 3. According to Fig. 3, the wind speed values are ranged from the minimum of 4.8 m/s in Jan to maximum of 7.37 m/s in July. As can be realized in the summer months (According to Figs. 2 and 3), there is great potential of solar and wind resource in the studied site.

### 2.3 Electrical load demand

In this study, the WC rooms of building were selected to test the feasibility of the designed hybrid renewable energy system. An estimated sample of the daily and monthly load profile of the

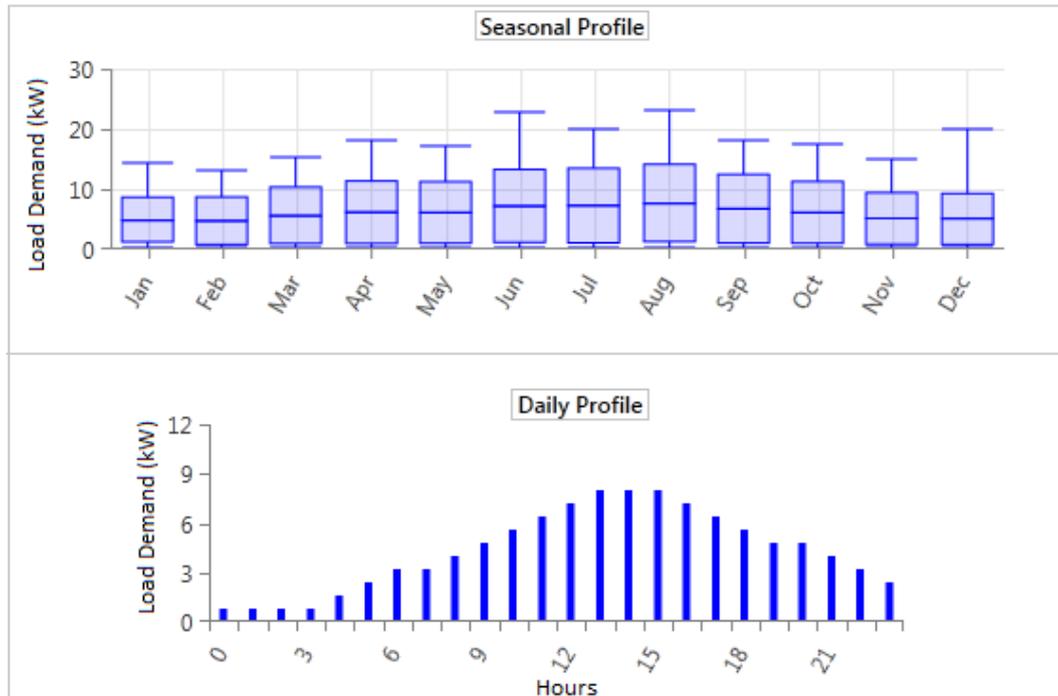


Fig. 4 The monthly and daily electrical load demand values for the studied building

building is shown in the Fig. 4. From the monthly load profile, it can be realized that the average electrical load demand is ranged from the minimum of 4.78 kW in Jan to maximum of 7.43 kW in Aug. The maximum peak load value was observed in the August with value of 23.17 kW. As it is clear, in the summer months, there is more electrical load demand compared to the other months of the year. According to daily load profile, it can be understood that the maximum demand occurs during daytime from 1 pm to 3 pm. The scaled annual average energy demand of the studied building is simulated by HOMER software version 3.3 (2015).

The lighting equipment and other electrical devices used in this building are the following: indoor lamps, outdoor lamp and ceiling fan. The system is assumed to work for 7 days a week.

#### 2.4 PV array

The PV modules consist of independent sub arrays. Each sub array consists of 16 modules. The PV module is a polycrystalline silicon type. The area of each module is  $0.45 \text{ m}^2$ . The panels were modeled as fixed and tilted at 45 degree and mounted such that the module is facing south direction (Zhou *et al.* 2010). The nominal operating temperature of the PV module is at  $45^\circ\text{C}$  in which the efficiency under standard test condition is 15%. The specifications of the modules in the standard condition (at  $1000 \text{ W/m}^2$  radiation and  $25^\circ\text{C}$  temperature), are listed in Table 2.

#### 2.5 Wind turbine

Wind turbines are used to convert the wind power into electric power. Wind turbine systems are

available ranging from 1kW to 9-10 MW. The energy production by wind turbines depends on the wind velocity acting on the turbine. Wind power is used to feed both energy production and consumption demand, and transmission lines in the rural areas. Wind turbines can be classified with respect to the physical features (dimensions, axes, number of blade), generated power and so on.

In this simulation, the model Generic 10 kw (DC) type wind turbine was chosen (HOMER 2015). Table 2 shows the technical characteristics of the wind turbine. For economic assessment, the operating and maintenance cost is assumed to be 4%. The Fig. 5 shows the power curve of the studied wind turbine generated using HOMER.

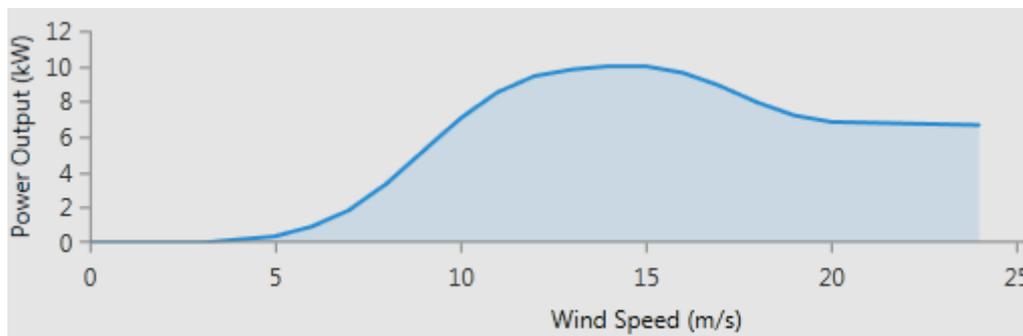


Fig. 5 The power-speed characteristic curve of Generic 10 kW wind turbine

## 2.6 Batteries

The major components of a hybrid energy system include P.V modules, battery and inverter. The most efficient way to determine the capacities of these components is to estimate the load to be supplied. The size of the battery bank required will depend on the storage required, the maximum discharge rate, and the minimum temperature at which the batteries will be used.

The batteries in use for solar systems are the storage batteries, otherwise deep cycle motive type. The battery to be used (Rehman and Al-Hadhrami, 2010; Ataei *et al.* 2015b):

- (a) should be able to withstand several charge and discharge cycles
- (b) should be in low self-discharge rate
- (c) should be able to operate with the specified limits.

Batteries are rated in Ampere-hour (Ah) and their sizing depends on the required energy consumption. The battery capacity is determined by the Eq. (3) (Zoulias and Lymberopoulos 2007 Ataei *et al.* 2015b)

$$BC = 2 * f * W / V_{batt} \quad (3)$$

Where  $BC$  is Battery Capacity

$F$  is Factor for reserve

$W$  is Daily energy

$V_{batt}$  is the System DC voltage

The Generic 1 kWh lead acid (rated at a nominal voltage of 12 V, with a capacity of 83 Ah) storage batteries (HOMER 2015) were chosen in this simulation. In order to produce higher energy

capacity, batteries are connected in series, which form battery string that consists of two lead acid batteries in each string. Each string of battery can produce 4.8 kWh of electricity. Number of battery strings is varied from 1 to 4 strings to assess the performance of energy. The estimated price of each battery is \$267 with a replacement cost of \$267. This battery is characterized by its versatility of application and zero-maintenance design. The life expectancy of battery is 10 years. Different numbers of batteries (5, 10, 15, and 20) were considered in this analysis. The 24 V battery bank originally consisted of 4.8 kWh of storage in (2×2) sealed, valve-regulated, deep-cycle batteries.

### 2.7 Inverter

An inverter is required for a system in which DC components serve as an AC load or vice versa. It can operate as a rectifier which converts AC to DC, an inverter which converts DC to AC, or both. The inverter model used in this project is Leonics S219CPH. It is based on a power unit that operates with a high efficiency and optimal reliability. The estimated capital cost of an inverter (5 kW) is 900 US\$ and replacement cost of 850 US\$ is considered. A lifetime of 20 years was assumed in which the both inverter and rectifier efficiencies were assumed to be 94%, for all sizes considered (Leonics 2014). Various sizes of inverters (1, 5, ..., 50 kW) were considered in the analysis. HOMER was used to simulate each system with power switched between the inverter and the generator. For more detailed specifications, readers are referred to the Table 2.

Table 2 Technical and economic specification for the components of proposed hybrid energy system

Description	Specification
1. PV module	
Type (Model)	Generic Flat Plate PV
Material	Polycrystalline silicon
Nominal power	1 kW
Nominal load voltage	20.5 V
Voltage in maximum power point	16.7 V
Short circuit current	2.96 A
Current at maximum power point	2.74 A
Nominal efficiency	15 %
Capital cost	3500 US\$
Replacement cost	3000 US\$
Operating and maintenance cost	25 US\$/year
Lifetime	25 years
2. Wind Generator (Type: Generic 10 kW)	
Rotor diameter	3 m
Blades	3-carbon fiber composite
Start-up wind speed	3m/s
Rated power	1000 W DC at (12.5 m/s)
Voltage	48 V <sub>DC</sub>

Table 2 Continued

Capacity (kW)	10
Over speed protection	Electronic torque control
Capital cost	50,000 US\$
Operating and maintenance cost	500 US\$ per year
Lifetime	20 years
3. Battery bank (Type: Generic 1 kWh lead acid)	
Nominal voltage	12 V
Nominal capacity	83 Ah
Round trip efficiency	80 %
Minimum state of charge-state of charge (SOC)	30 %
Nominal energy capacity of each battery (V×Ah/1000)	1 kWh
Capital cost	267 US\$
Replacement cost	267 US\$
life expectancy	10 years
4. Inverter (Leonics S219CPH) <a href="http://www.leonics.com">www.leonics.com</a>	
$P_{nominal}$	2000 W <sub>P</sub>
Max input voltage ( $V_{DC, max}$ )	500 V
PV-Voltage MPPT ( $V_{pv}$ )	250-600 V
Max input current	10 A
$P_{max}$	2500 W
Peak inverter efficiency	94-94.4%
AC Input frequency	48-51 Hz
$V_{AC}$	198-251 V
Capital cost	900 US\$
Replacement cost	850 US\$
Lifetime	20 years

### 3. Results and discussion

In this part of study, optimization and simulation analysis of the proposed hybrid energy system was performed using the latest version of HOMER modeling software (HOMER 2015). For the purpose of optimization, different key parameters such as monthly and daily load profile, monthly wind speed and solar resource profile and economic constraints are taken into account. Moreover, the information such as the capacity requirement, sizes and cost of the hybrid system component (wind turbine, PV module, inverter and battery) was also considered and imported to HOMER software.

The simulation is done with a project lifetime of 20 years. Also an annual interest rate of 12% is used in the economic calculations. The schematic diagram of the stand-alone hybrid energy system as designed in HOMER simulation software is shown in Figs. 1 and 6.

The system was simulated to evaluate its operational characteristics, annual electrical energy production; annual electrical loads served, excess electricity, RE fraction, capacity shortage, unmet load etc. A load-following control strategy was used in the simulation. Based on this strategy,

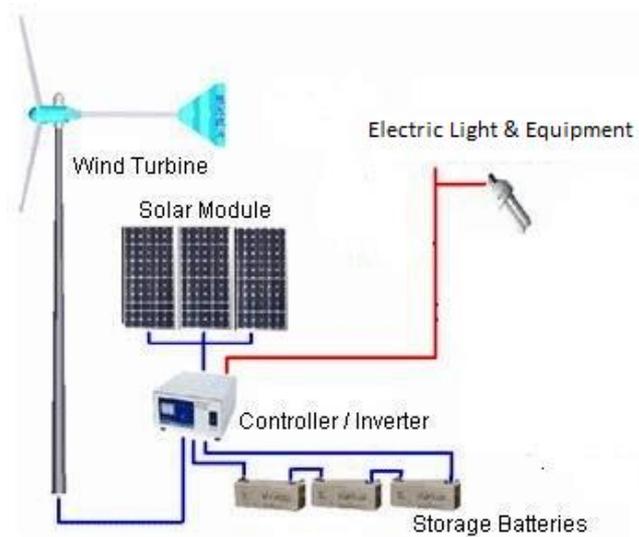


Fig. 6 The proposed model and system structure of the hybrid energy system

Architecture										Cost	System
					PV (kW)	WT	Battery	Converter (kW)		NPC (\$)	Ren Frac (%)
					9.0	1	5	5		89,884	100
					9.0	1	5	10		90,867	100
					9.0	1	10	5		92,309	100
					9.0	1	5	20		92,842	100
					9.0	1	10	10		93,189	100
					10.0	1	5	5		93,529	100
					10.0	1	5	10		94,514	100
					9.0	1	10	20		95,152	100
					10.0	1	10	5		95,976	100
					10.0	1	5	20		96,486	100
					10.0	1	10	10		96,847	100
					9.0	1	15	5		97,141	100
					9.0	1	15	10		97,844	100

Fig. 7 The most efficient hybrid system configurations for the studied commercial building in Shiraz

whenever a power generator is needed it produces only enough power to meet the load demand.

The optimization and simulation process took almost 25 minutes on an Intel core i5 system with 8 gigabyte RAM. Out of 155, 520 simulated cases, there were only 5,760 feasible solutions.

The results are displayed in overall form in which the top-ranked system configurations are listed according to their net present cost (NPC) for possible system type. It is worthwhile to mention that before the simulation process, in the search space of the HOMER software, due to great potential of wind and solar resource of the region and the fact that we aimed to design a hybrid system which uses two natural resources, i.e., wind and solar, no zero value was considered for both PV panels and wind turbines sizes and therefore no PV-only or Wind-only system was suggested by HOMER as the most efficient hybrid configuration.

Fig. 7 shows a list of the possible combinations of hybrid systems in the overall form. As it can be realized from this figure, the most efficient hybrid configuration consists of 9 kW photovoltaic panel, 1 wind turbine (10 kW), 5 batteries and 5 kW converter. The total NPC of such a system would be \$89,884, while the cost of energy was estimated to be \$ 0.619/kWh.

In the Fig. 8, the share of the PV array and the wind turbine for electrical production in each month of the year for the optimum system configuration is demonstrated. It is evident that the PV power output is ranged from minimum of 0.7 kW in Dec to maximum of 2.3 kW in Jun. However according to the monthly profile of wind turbine energy production, the least amount of power output occurred in Nov with value of 0.7 kW, while the highest amount of energy was observed for July with value of 3 kW. In general, the total electrical production of the designed hybrid system is ranged from minimum of 1.5 kW in Dec to maximum of 5.2 kW in July. As can be seen from the Fig. 8, the power production of the proposed hybrid system is more significant in summer season, thanks to the great potential of wind and solar energy in this season. Additionally the contribution of wind power in electrical production is 52.37% which is 4.74 percent more than the solar energy. In fact the share of wind turbine in the hybrid energy system for electrical production is 14,669 kWh/yr, while the share of solar PV panels is 13,339 kWh/yr. Furthermore, the excess electricity for the current hybrid system-which is a surplus of power being produced (either by a renewable source or by the generator when its minimum output exceeds the load) and the batteries are unable to absorb it all-is estimated to be 5,551.8 kWh/yr. The excess electricity can be used to take care of any deferrable load (such as water pumping, ice making and battery charging) and any other unexpected electrical load.

Another point which can be inferred from the Fig. 8 is the capacity shortage value for the proposed hybrid system which is estimated to be 39,166 kWh/yr. As a matter of fact, capacity shortage is a shortfall that occurs between the required operating capacity and the actual amount of operating capacity the system can provide. Besides, Unmet load - which is the electrical load that

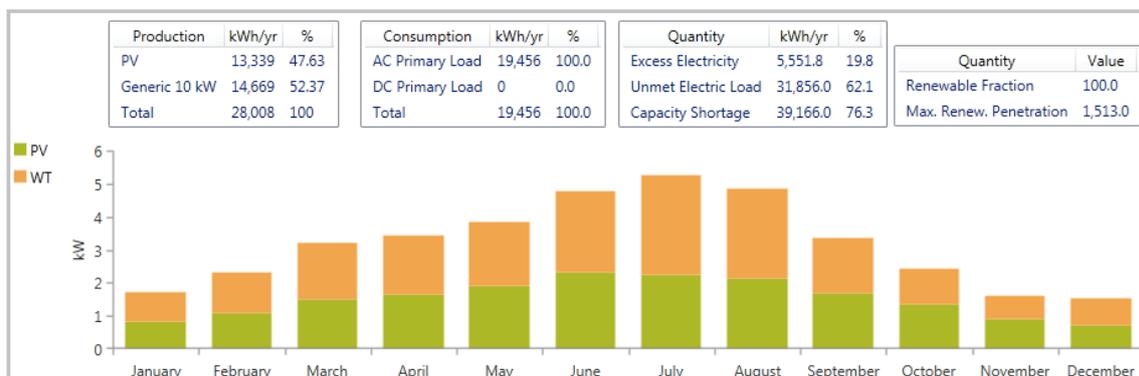


Fig. 8 The share of photovoltaic and wind turbine in electrical production of the hybrid system

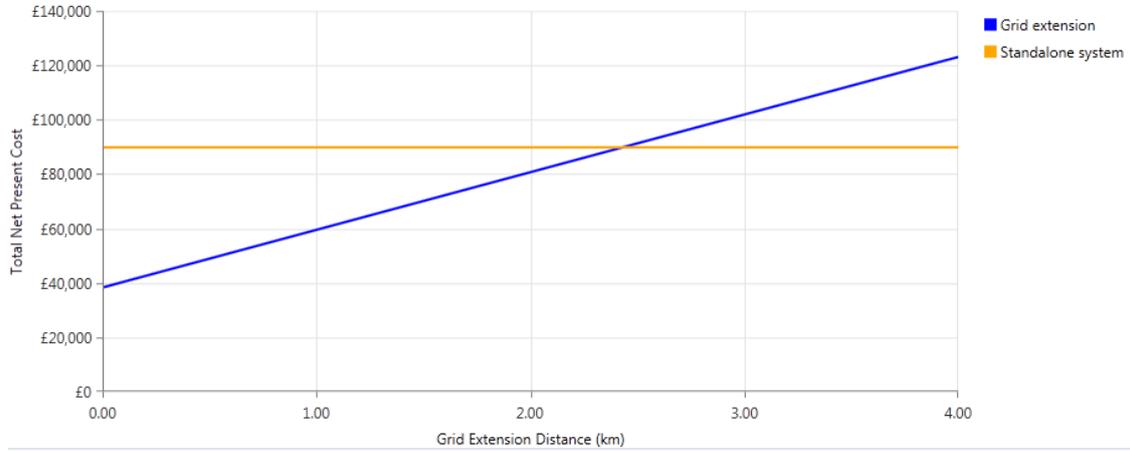


Fig. 9 The grid extension distance versus the total net present cost for a studied hybrid system

the power system is unable to serve-was calculated to be 31,856 kWh/yr. This amount occurs when the electrical demand exceeds the supply.

Another important parameter which is investigated in the design of the studied hybrid energy system is the grid extension distance which is the distance from the grid that makes the net present cost of extending the grid equal to the net present cost of the stand-alone system. Calculating this parameter will help us to know whether or not, connecting the designed hybrid system in the studied building to the electricity grid system is economically justifiable. The grid extension distance can be calculated according to the following equation

$$D_{grid} = \frac{C_{NPC} \cdot CRF(i, R_{proj}) - C_{power} \cdot E_{demand}}{C_{cap} \cdot CRF(i, R_{proj}) + C_{om}} \quad (4)$$

Where:

$C_{NPC}$  is the total net present cost of the stand-alone power system [£]

$CRF()$  is the capital recovery factor

$i$  is the interest rate [%]

$R_{proj}$  is the project lifetime [yr]

$E_{demand}$  is the total annual electricity demand [kWh/yr]

$C_{power}$  is the cost of power from the grid [£/kWh]

$C_{cap}$  is the capital cost of grid extension [£/km]

$C_{om}$  is the operation and maintenance (O&M) cost of grid extension [£/yr/km]

At the present time, the capital and operational costs of grid extension via medium voltage lines in Iran are \$20,000 per km and \$200 per year per km, respectively. Grid power price in Iran is on average \$0.1/kWh (Ataei *et al.* 2015a; Nedaei *et al.* 2014). Fig. 9 shows the maximum distance for the current system, suggested by HOMER, between the utility power lines and the studied site, which would be economically justifiable for grid extension. According to this figure, it can be shown that the breakeven grid extension distance is 2.43 km. Given the fact that the studied commercial building is almost 4.3 km far from the utility grid, the decision pertaining to grid extension for the designed hybrid renewable energy system at the studied building would not be economically possible at the current time.

#### 4. Conclusions

In the recent years, due to the high energy cost and adverse environmental impacts of conventional fossil fuels, renewable energy has gained significance. Using this alternative source of energy reduces the need for combustion of fossil fuels and the consequent CO<sub>2</sub> emission which is the principal cause of the greenhouse effect and global warming. Renewable energy systems consisting of different energy sources (solar, wind, etc.) are the only way to generate electricity in some regions of developing countries.

Solar and wind energy systems are considered as promising power-generating sources due to their availability and the topological advantages in local power generation. However, neither a stand-alone solar nor a wind energy system can provide a continuous supply of energy due to seasonal and periodical variations. To overcome this limitation, hybrid power systems (which include one or more renewable-energy-based generating units such as solar and wind generating units) are combined with battery backups to satisfy the load demand.

In the current research, HOMER model was used to design and analyze the most efficient hybrid renewable energy systems for a studied commercial building which is located in Shiraz, Iran. In the first phase of study, wind and solar resource of the studied site was evaluated. Then by using monthly wind and solar profile, load demand values, economic constraints such as interest rate and project lifetime, the component characteristics such as inverter and battery sizes and cost and other related information were imported to HOMER. After the optimization analysis of the possible and optimum hybrid energy configurations, the most economical and efficient hybrid energy combinations were suggested by HOMER based on their total net present cost of the system and electrical production.

The results demonstrated that the best hybrid combination consists of 9 kW photovoltaic panel, 1 wind turbine (10 kW), 5 batteries and 5 kW converter. The total NPC of such a system would be \$89,884, while the cost of energy was estimated to be \$0.619/kWh. Analysis of the electrical production of the designed hybrid system showed that amount of 28,008 kWh/yr could be produced in each year. It was also concluded that approximately 5,551.8 kWh per year electricity can be generated as excess electricity which is quite significant and can be used for further electrical load demands. In conclusion, it has been demonstrated that the employment of the designed hybrid PV/Wind system with battery in the studied commercial building is technically and economically viable and affordable. Moreover it is evident that the utilization of such a hybrid system can significantly reduce dependency on fossil fuels and thus substantially decrease the emission of greenhouse gases and environmental pollutants. Therefore, the employment of such a system, particularly in the studied commercial building, and in general, for all office residential buildings in Shiraz is strongly recommended.

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