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Feasibility Study of Zero Energy Houses: Case Study of Magrun City - Libya

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Abstract: The residential load is one of the largest consumers of the electric energy in Libya that could be supplied by renewable energies. Renewable energy technologies and systems can be a good solution to build "Zero Energy Buildings". A zero-energy house is proposed for Maqrun city. It is intended to use wind turbine with batteries as a storage system to supply electric energy demand for this house.

The intended house average daily electric energy demand is estimated to be 35 kWh/day. Two WECS were selected to supply the energy demand each of size 6 kW. The energy produced by the selected wind energy conversion system (WECS) is about 23,894 kWh/yr and the expected capacity factor at the site is about 23%. Modeling of energy demand of the house and simulation of its performance was performed using excel sheets and HOMER software.

دراسة الجدوى لبيت طاقة صفري ـ دراسة حالة لمدينة المقرون ـ ليبيا

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ملخص: تعتبر الأحمال السكنية أحدى أكبر الأحمال استهلاكا للطاقة الكهربائية في ليبيا والذي يمكن توفيرها عن طريق الطاقات المتجددة. يمكن أن تكون تقنيات وأنظمة الطاقة المتجددة حلاً جيدًا لبناء «مباني الطاقة الصفرية». تقترح هذه الورقة إنشاء بيت طاقة صفري بمدينة المقرون من خلال استخدام توربينات الرياح لتوليد الكهرباء و بطاريات كنظام تخزين للطاقة بهدف تلبية الطلب على الطاقة الكهربائية لهذا المنزل.

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قدر متوسط الطاقة الكهربية اليومية للمنزل بنحو 35 كيلو وات / ساعة. و قد تم اختيار عدد 2- توربينة رياح لتزويد المنزل بالطاقة الكهربية المطلوبة سعة كل منهما 6 كيلو وات حيث بلغت الطاقة الناتجة عن نظام تحويل طاقة الرياح 23,894 كيلو وات ساعة/ السنة، وبلغ معامل السعة للموقع 23 %. استخدم برنامج اكسل في نمذجة الطلب على الطاقة للمنزل ومحاكاة أدائه و مقارنة النتائج والتحقق من صحتها بواسطة برنامج هومر.

Keywords: *zero energy houses, renewable energy, wind energy, modeling energy systems, HOMER software.*

1. INTRODUCTION

Zero electric energy houses ZEH are defined as houses that optimally combines commercially available renewable energy technology with the energy efficiency construction techniques. “Zero Energy” housing, also, could be defined as housing with greatly reduced energy demand that allows the energy demand to be balanced by an equivalent generation of electricity from renewable energy sources [1] .

As the energy demand around the world increase, the need to alternative energy sources is increased. In addition, the rapid depletion of conventional energy (fossil fuel) resources on a worldwide basis has necessitated an urgent search for alternative energy sources to provide the present energy demands. The clean green renewable sources of energy are expected to play more significant role in the global energy future. Many countries devised plans and strategies to integrate renewable energy sources in their future energy mix to secure their energy demand and mitigate emission problems caused by conventional energy sources [2]. Variable renewable energy sources are the most candidate sources at different countries such as Europe [3].

With the growing interest of many countries to use renewable energy technologies advancement of optimization methods of renewable energy systems have been developed [4-11]. Different models for renewable energy system sizing, energy planning and energy supply -demand forecast as well as emission reduction are studied and tackled by several researchers during last few years . The number of researchers during (1989-2009) exceeded 550 research papers, mostly from USA, followed by India and China [4]. Demand side management (DSM) was investigated to reduce the need for energy back up in Europe and increase the share of renewable energy [11]. Since residential sector is the highest contributor to energy consumption in several countries optimization methods for DSM of residential sector was studied and given an important attention [13]. Renewable energy sources and energy policies are assessed in MENA region [14,15]. The potential of these renewable energy sources are abundant and suitable technologies for each country in the region could be utilized [14].

Current and future renewable energy sources utilization in Libya was studied [16-18] and the potential of CSP as one of possible renewable energy technologies that could be implemented in Libya was investigated [19]. Energy consumption by residential sector was investigated and the effect on the peak demand and future trends was evaluated [17].

Many countries are seeking ways to continually increase energy efficiency and reduce energy consumption. Commercial and residential buildings alone account for 43% of primary energy consumption in the Libya. The demand for energy by the commercial sector with 12%, and the residential sector represents 31% of the total electric energy consumption, as shown in figure (1) [20].

Buildings have a significant impact on energy use and the environment. They play an important role in the transition to clean energy use. Commercial and residential buildings use almost 40% of the primary energy and approximately 70% of the electricity in the United States. The energy used by the building sector continues to increase, primarily because new buildings are constructed faster than old ones are retired. Electricity consumption in the commercial building sector doubled between 1980 and 2000, and is expected to increase another 50% by 2025 [1]. On the global level, the final energy consumption in buildings has increased by 5% during 2010- 2017. Also, the accounted for 36% of the final energy use in 2017 and about 40% of CO^2 emissions related to energy use [21]. Investment in energy efficiency in buildings, global wise, has increased by only 4.7% in 2017 compared to annual growth of 6-11% during 2014- 2016 [21].

Libya has to make use of its renewable energy resources, such as solar, wind, not only to meet increasing demand, but also for environmental reasons.

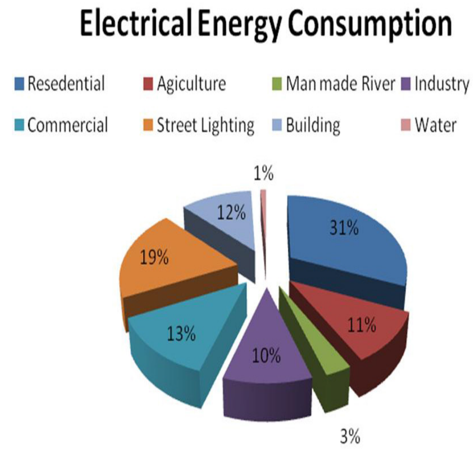

Figure (1). Total Electric Energy Consumption by Sector in Libya

Libya has a long coast which extends over 1800 km with good wind potential. The average annual wind speeds measured at 10 m height exceed 5m/s. At Magrun the average wind speed at 10 m height is 5.8 m/s, at 20 m height is 6.5 m/s, and at 40m height is 7.2 m/s [22,23]. Libya has high potential of wind. This huge amount of wind distributed all over the country. It can provide the future electricity needs for Libya and its neighboring countries. Wind energy was utilized mainly for water pumping few decades ago. After oil discovery in Libya these wind pumping systems were ignored. In recent years and with global interest in using alternative sources of energy for different reasons such as energy security and other global environmental issues, Libya started devising new plans to include renewable energy sources in the national energy mix including wind energy [23]. There were several studies concerning assessment of wind potential for some locations in Libya were performed [24-32]. However, zero electric energy houses using wind energy as an active system has not yet been tackled and studied seriously in Libya.

This study aims to assess the feasibility of using wind energy to supply electricity demand of a house which is proposed to be completely isolated from the electric network and to be used as self-sufficient system.

2. SYSTEM COMPONENTS AND MODELING

The main goal of zero energy house (ZEH) system is to achieve the right balance between daily needs of electrical energy consumed by the loads proposed for a house in Magrun city and daily produced electrical energy by the proposed Wind Energy Converter System (WECS). The daily consumed electrical energy by the loads was estimated and the suitable size of a WECS was selected according to the following modeling and sizing analysis [33-39]. The proposed configuration of the system is shown in Figure 2.

Combining wind turbine with batteries as a storage system, can guarantee high electrical energy supply and reliability at household.

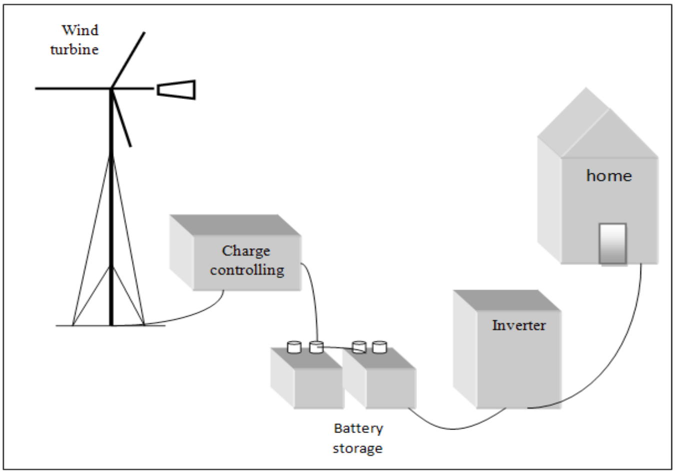

Figure (2). Block diagram of the hybrid system

2.1 Wind Turbine Modeling and Sizing

The power output of a wind turbine is determined by its power curve and the instantaneous wind speed at the sight of installing this wind turbine. A mathematical model for the power curve of a wind turbine taking into account these parameters is as follows [33]:

$$P_v = P_R\left[\frac{V^n - V_I^n}{V_R^n - V_I^n}\right] \quad (1)$$

Where: (P_v) is the output power of the wind turbine (kW), n is a degree of equation, (V) m/s is the wind speed at any time, (V_I) m/s is the cut-in speed of the wind turbine, (V_R) m/s is the rated speed of the wind turbine, and (P_R) kW is the rated electrical output power of the wind turbine. Or the energy (delivered to the load) is given by,

$$E_D(t) = \Sigma_{t=1}^{8760}\left(E_W(t) - E_L(t)\right) \quad (2)$$

Where (E_W) is the output energy of the wind generator of a wind system and (E_L) is the load energy demand.

The result of equation (2) may be either positive ($E_W>E_L$) or negative ($E_W<E_L$). If energy difference is positive then there is an excess in energy (EE), while if it is negative then there will be an energy deficit (E_D). The excess energy is stored in batteries in order to be used in case of energy deficit. Meanwhile, energy deficit can be defined as the disability of the wind turbine to provide power to the load at a specific time.

2.2 Battery Bank Modeling and Sizing

The battery is one of the important elements in wind/battery system. The batteries are used because of the intermittent nature of the wind energy sources. The output power from the wind turbine varies with wind speed variations throughout the day. A battery bank between the DC bus out of the charge controller of the system and the load will compensate and act as a power supply during no wind times.

The type of batteries used in such systems are mostly, lead-acid. It is used due to its low cost, high energy efficiency and low operating temperature. Lead-acid batteries are still the most common type for backup systems. A charge controller between the wind turbine and batteries is to be used to regulate charging and discharging of the batteries. The energy flow across the battery can be expressed by [34]:

The proposed sizing process starts by defining the specification of a wind turbine, storage battery, locations, and oad demand. Then hourly wind speed for the selected location is obtained. At this point the energy balance is calculated using equation (4) as well as the excess energy. Here the battery size (CB) is estimated using the excess energy as follows [38, 39]:

$$C_B = \frac{\sum_{i=1}^{8760} Excess\ Energy\ y_i \times \eta_B}{V_B} \quad (4)$$

Where ($\boldsymbol{\eta}_B$) and (V_B) are the charging efficiency and the battery voltage respectively.

$$E_{Battery}(t) = \begin{cases} E_{Battery}(t-1) \times \eta_{inv} \times \eta_{discharging} - E_L & E_D < 0 \\ E_{Battery}(t-1) \times \eta_{discharging} + E_W & E_D > 0 \\ E_{Battery}(t-1) & E_D = 0 \end{cases} \quad (3)$$

2.3 Charge Controller

Charge controller is an essential component to control charging and discharging of batteries. It protects them against both excessive overcharge and deep discharge. Charge controller shall switch off the load when a certain state of discharge is reached, also shall switch off battery from the DC bus when it is fully charged. Charge controller can be adjusted to deal with different charge and discharge conditions. Charge controller act as interface between each of wind turbine and battery bank where the battery is connected.

2.4. Converter

A converter is required for systems in which DC components serve an AC load or vice versa. A converter can be either an inverter converting DC to AC or a rectifier converting AC to DC, or both.

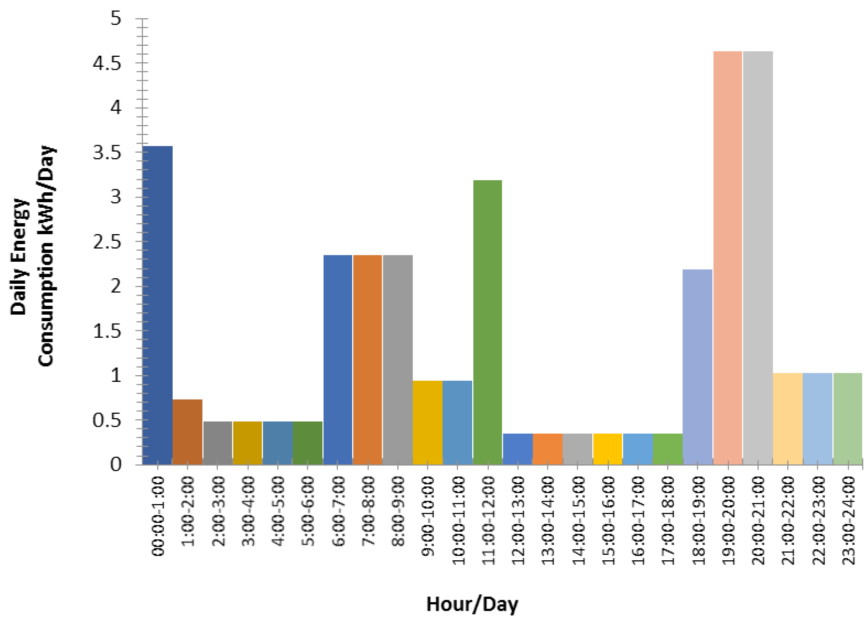

Figure (3). Daily energy consumption in household

In the wind-battery system, a converter with a nominal capacity of 12 kW was used in order to meet the house load and energy requirement. The Converter can be modeled as follows [34]:

$$P_{con} = P_{bout} \times \eta_{inv} \quad (5)$$

Where: (P_{con}) is the output power of battery bank converter, (P_{bout}) is battery bank output power, and (η_{inv}) is the efficiency of converter in its charge mode.

2.5 The energy consumption

The amount of electrical energy in kilowatt-hour for the devices in the household can be calculated as [35,36]:

$$E = P \times T \quad (6)$$

where P: is appliance power and T: time. Therefore, the electricity consumption for each appliance per day during one year was calculated in order to obtain the electric load of house. The household includes different devices that consume electric energy. The daily consumption is shown in Figure (3).

3. THE SITE LOCATION AND HOUSE DESCRIPTION

The household is one floor house in residential complex at Magrun Village. Magrun is a coastal city in northeast part of Libya and almost halfway between Benghazi and Ajdabiya, as shown in Figure 4. It is located at 31° 33' 21" N, 20° 09' 20" E. and the average wind speed at the site is 7.2 m/s (at 10m height a.g.l.).

Figure (4). Al Magrun location

4. METHODOLOGY

Wind data of the local area in Magrun was considered and the energy consumption of appliances was calculated. With this information it is possible to calculate the reference energy load of household. Sizing of the required system was performed using above modeling equations. Microsoft Excel spreadsheet and HOMER software were used in performing the analysis.

HOMER is a powerful tool for sizing and optimization of energy systems. It contains a number of energy component models and evaluates suitable technology options. The simulation was performed in order to obtain the optimum power system configuration that meets the previously mentioned load profile. The input data for the simulation are presented in the following sections.

5. HOMER SIMULATION

5.1. Electric Load

The electric Load of the proposed house at Al Magrun has been estimated as in Figure 3. The annual and daily load profiles are shown in Figure 5. And the annual peak load was calculated as 6.70 kW.

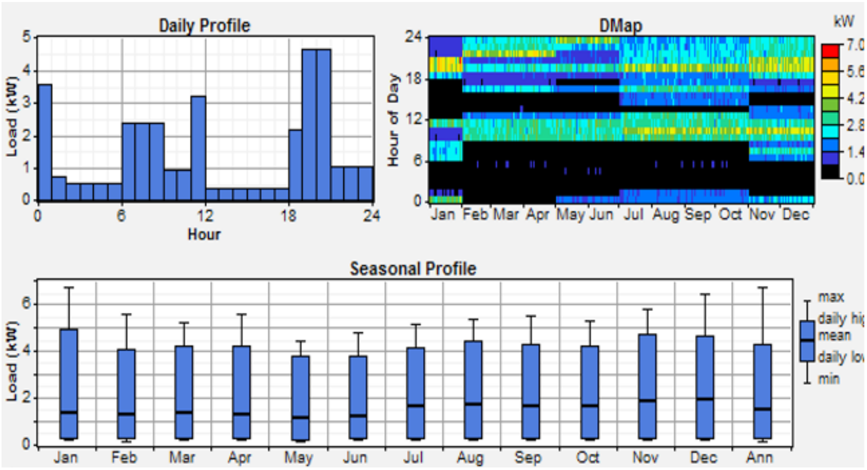

Figure (5) Daily Load profile of the household

5.2. Wind Speed Data

Wind data of Al Magrun city of one year in 2004. Data was supplied by Renewable Energy Authority of Libya (REAOL). It is measured at three heights (10, 20, and 40 m a.g.l.). The data was for one year and averaging period is 10 minutes. Data was analyzed in order to estimate the frequency distribution at the site, which is required for the estimation of the energy generated by the WECS at the site.

Wind data at 10 m for Magrun site was used as input for HOMER software and the seasonal variation of wind speed was presented in Figure (6). It could be noticed that the average wind speed of the respective area at 10m height is 5.76 m/s.

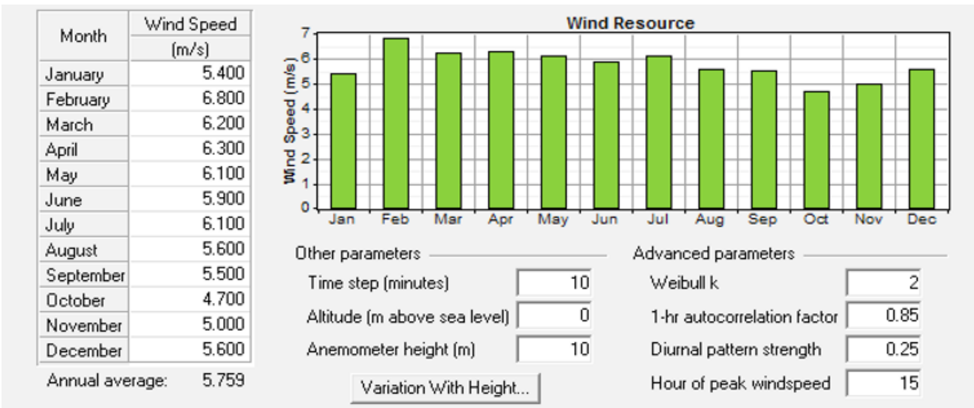

Figure (6) monthly wind speed variation

5.3. Wind Turbine Sizing

Proven 6kW wind turbine was selected from HOMER program data base in this paper. The cut in wind speed was considered as 2.5 m/s and the cut off wind speed is 19 m/s. Technical parameters are stated in Table 1 and the power curve is shown in Figure 7.

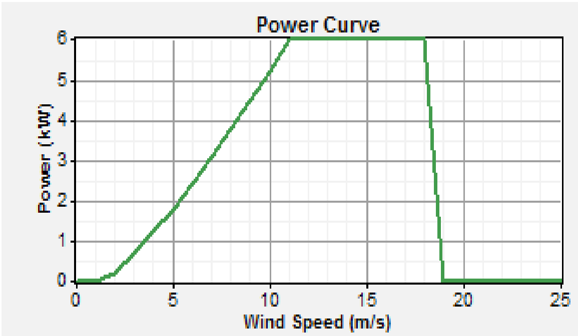

Figure (7) The power curve of Proven 6kW wind turbine

Table (1) Wind Turbine Characteristics

Parameter	Value
Cut-in speed (m/s)	2.5
Rate wind speed (m/s)	12
Cut-out wind speed (m/s)	19
Rate power (kW)	6
Rotor diameter (m)	4.5
Hub height (m)	9-15
Battery charging (V) DC	48
Head weight (kg)	600
Tower weight (kg)	360-656

5.4. Charge battery

US -185HCXC2 (12V,250Ah,3kWh) battery was chosen from HOMER program data base and have been utilized in the hybrid system. Technical parameter is stated in Table 2, and Figure 8 shows the relationship between capacity and the current of US -185HCXC2 battery. It has a nominal voltage of 12 Volts and nominal capacity of 250Ah (3 kWh). Batteries considered by HOMER in the simulation, are shown in table 4-2 below.

5.5 Inverter

The size of AC inverter was selected from HOMER program to be 12 kW. It has an efficiency of 90%. Technical parameters of the inverter are stated in Table 3.

Table (2). Technical parameter of US -185HCXC2 battery

Parameter	Value
Nominal capacity	250Ah
Nominal voltage	12 V
Roundtrip efficiency	80%
Min state of charge	40%
Float life	8 yrs
Max charge rate	1A\Ah
Max charge current	12.5A
Lifetime throughput	804kWh
Suggested value	1. 657kWh

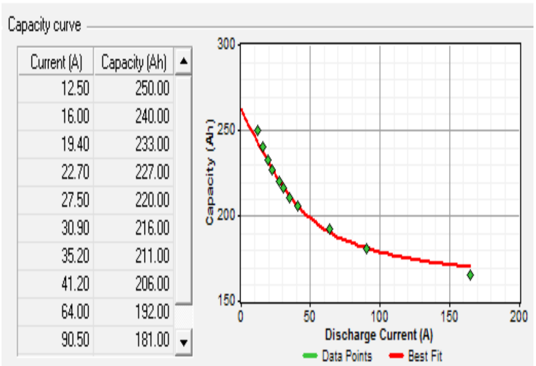

Figure (8) The relationship between capacity and the current of US -185HCXC2 battery

Table (3). Technical parameter of inverter

Parameter	Value
Sizes to consider	12 kW
Lifetime	15 yr
Inverter efficiency	90 %
Inverter can parallel with AC generator	Yes
Rectifier relative capacity	100%
Rectifier efficiency	85%

6. ECONOMIC ANALYSIS

The economic analysis was performed using HOMER software. The analysis included the most important economic indicators: the net present cost (NPC), payback period and savings-investment ratio. The project lifetime was set at 25 years and interest rates was set at 5% with the inflation rate of 2%. The initial capital cost (ICC) was $6000 for the wind turbine and the operation and maintenance cost as 6% of the ICC.

The NPC is defined as the total cost associated with the project over its lifetime. These costs include the initial capital cost of installation, its replacement cost, the operations and maintenance cost. The mathematical representation of this is given by equation (6.1)

$$NPC = {}^{AC}\!/\!_{CRF} \quad \text{.......} \quad (7)$$

Where: *AC* is the sum of the annualized costs of components that constitutes the renewable energy system and the capital recovery factor *CRF* is expressed by equation (6.2) below:

$$CRF = {i(1+i)^n}\Big/{(1+i)^{n-1}} \quad (8)$$

Where i is the interest rate, and n represent the number of years. The Discount Factor (DF) accounts for the present value of money in any year within the project lifetime. It is represented mathematically by:

$$DF = 1\Big/(1+i)^n \quad (9)$$

The payback period (*PB*) is the number of years it would take for the net investments in the system to become positive. This could be mathematically expressed by:

$$-IC + \sum_{j=1}^{P} CF_j\Big/(1+i)_j = 0 \quad (10)$$

Where IC is the initial cost, *CF* is cash flow, i represents interest rates and j number of years. HOMER assesses its economic outputs based on net present cost and renewable factor.

7. RESULTS AND DISCUSSIONS

Libya is characterized by the availability of renewable energies, especially wind energy. The paper studies the possibility of using renewable energies to feed residential loads without connection to the grid (off-grid). The electrical energy consumption of the house is supplied totally by WECS and battery system, which means that the house energy demand is balanced by the energy produced by the WECS and battery system or (zero energy house).

Sizing and modeling of the energy system to supply energy demand for the house was performed and was compared using HOMER software. It gave promising results for zero energy buildings.

The Magrun site is located at 31° 35' 21" N, 19° 59' 20" E. It was taken as a case study for the purpose of this study.

7.1. Analysis of Wind Data

Analysis of wind data was performed and the results showed that the annual average wind speed is 5.8 at 10m height, 6.4 m/s at 20m height and 7.2 m/s at 40m height.

Table 4 shows the average wind speed for each month for Magrun site and Figure (9) shows the diurnal pattern for each month at 10 m height, which is the WECS hub height.

7.2. The monthly energy density and frequency distribution at the site

Wind data was analyzed in order to estimate the monthly average wind speed at the turbine hub height. The probability density function using Weibull distribution was calculated and the energy density was estimated. Weibull frequency distribution is presented in Figure (10).

Table (4) The average wind speed for each month for Al Magrun site

Months	Average wind Speed at 10m	Average wind Speed at 20m	Average wind Speed at 40m
Jan	5.4	6.1	6.9
Feb	6.8	7.6	8.4
Mars	6.2	6.9	7.7
Apr	6.3	7.1	7.9
May	6.1	6.8	7.5
Jun	5.9	6.5	7.1
Jul	6.1	6.7	7.3
Aug	5.6	6.1	6.7
Sep	5.5	6.1	6.7
Oct	4.7	5.3	6.0
Nov	5.0	5.7	7.2
Dec	5.6	6.4	7.1
Average	5.8	6.5	7.2

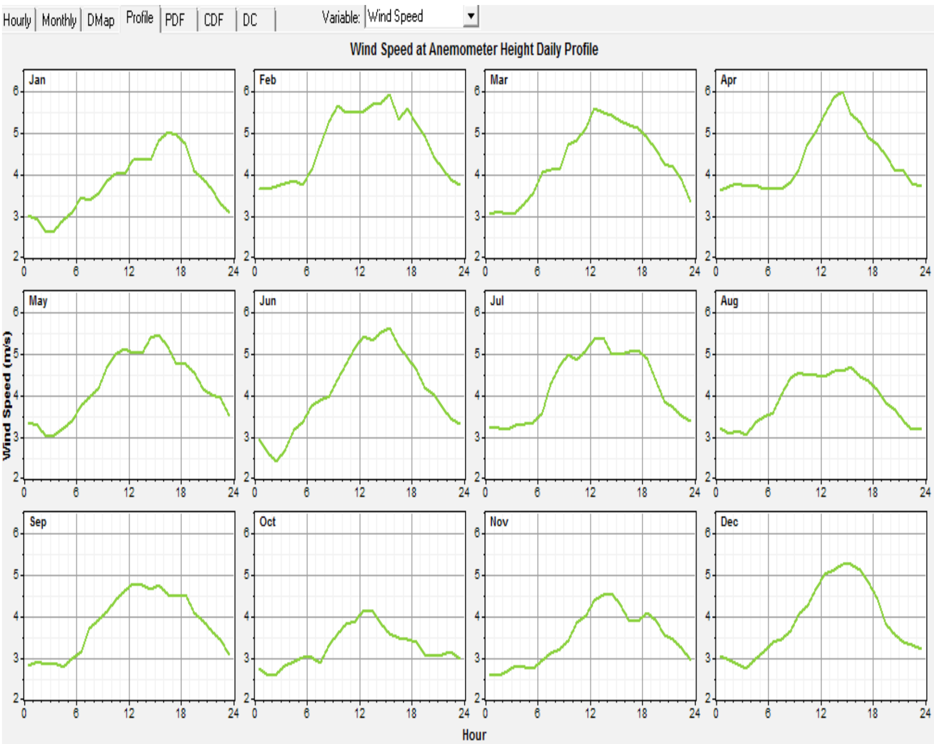

Figure (9) Daily Wind speed profile for each month at 10m height

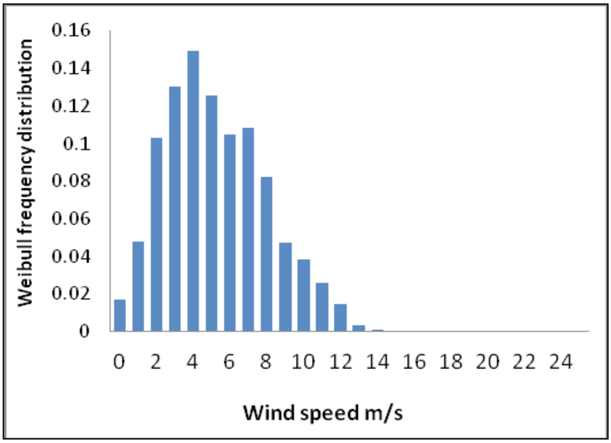

Figure (10). Weibull wind speed frequency distribution

7.3. Sizing of the hybrid system

7.3.1. Sizing of wind turbine

The average daily energy consumption of the proposed house was estimated in section (3.1) as 35 kWh/day. Two WECS's were selected to supply this energy demand of 6- kW each. The average energy produced by the proposed wind turbine using wind data of Magrun site is 23,894 kWh/yr. The monthly energy produced by the wind turbine and energy consumed by the household is shown in Figure 11. It could be noticed that in December the highest energy is produced and the lowest is in November. From the calculation it was found that the average excess energy is 8.106 kWh/yr and the capacity factor at Magrun location, was calculated as 23%.

7.3.2. Battery sizing

The minimum number of days of autonomy that should be considered as in equation (4.4) were taken to be 9 days and the maximum allowable depth of discharge is taken as 80%. Batteries used in wind turbine are sized in ampere hours under standard test condition of 25C^o.

Battery manufacturers usually specify the maximum allowable depth of discharge for their batteries, since the depth of discharge is a measure of how much of the total battery capacity has been consumed. The capacity of the battery bank in ampere-hours required for this household using battery voltage of 48 V would be 7926.56Ah. The selected battery type was (US 185 HCXC2 Battery). Its technical specifications are shown in Figure 12 and its price is $250. With DC-voltage of 48 V, the number of batteries for the proposed household would be 8 parallel branches with each branch contains 4 series batteries.

7.3.3. Inverter

The inverter size was selected by combining load power divided by the efficiency of the inverter, which is 10 kW. The selected inverter type was (AIMS, PICOGLF120W48V240V S), and the price of the inverter is 3409$, the capacity of the inverter is 12 kW pure sine, 48Vdc/240Vac 120/240Vac Split Phase Output.

The results obtained from the sizing of the proposed hybrid system can be summarized as shown in Table 5.

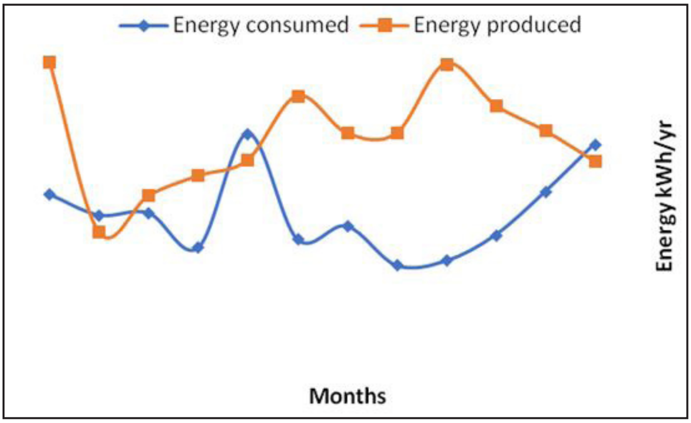

Figure (11). The monthly energy produced and energy consumed

Figure (12). US 185 HCXC2 Battery

Table (5) Summary of the system components

Component	Description of the component	Result
Daily load of household	Daily energy consumption	35 kWh/day
wind turbine	Energy production of wind turbine	23.894kWh
Battery bank	Battery bank capacity	8207.8Ah
	Number of batteries in series	4
	Number of batteries in parallel	8
	Total number of batteries required	32
Inverter	Capacity of the inverter	10kW

7.4. Sizing of the hybrid system using HOMER program:

7.4.1. Sizing of wind turbine

The household daily load was used for HOMER program sizing calculations. The HOMER optimum sizing with minimum cost results in selecting of two wind turbines of 6-kW each of Proven type. The monthly average electric power production of the Hybrid Energy System for Magrun is shown in Figure 13.

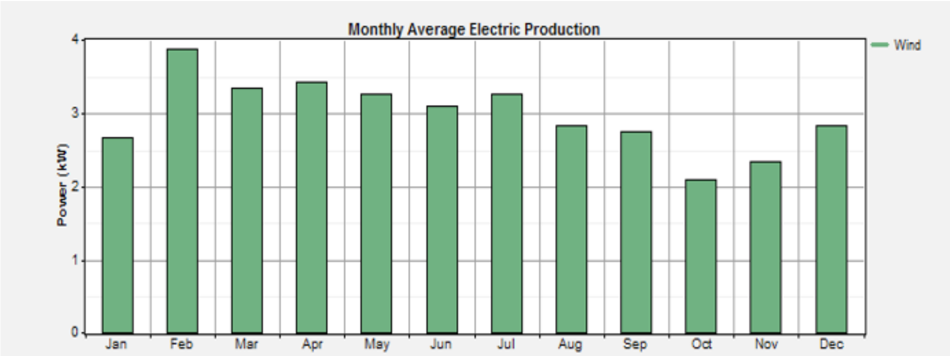

Figure (13) The monthly average electric power production

The optimal solution for the proposed household is composed of wind/Battery power system configuration. It is composed of two wind turbines with total power of 12kW and 8 batteries in parallel and 4 batteries in series, as well as a 10kW power converter.

Figure 14 displays a typical daily power output (kW) of the Proven 12 kW wind turbine generation in the simulation scenario correlated to hours of a day over a period of 12 months. It is shown that power output begins to increase shortly after 6 am until 18pm. Wind power output during the day steadily varies in the similar way, and the output reaches its maximum in the mid day. The seasonal variations of wind power output are shown in Figure 15.

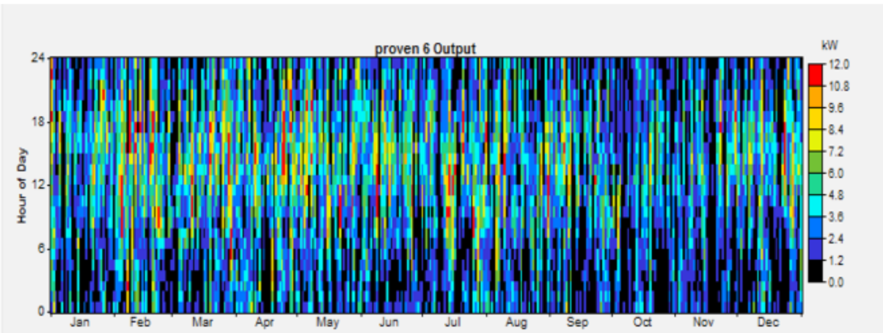

Figure (14) Proven wind turbine output

7.4.2. Battery storage system

Figure 16 shows the Battery storage daily power output over a given year. The battery state-of charge is high, the power output from the battery storage will be higher February, March, April to September to compensate for wind energy shortfalls during other months and to meet requ ired load demands.

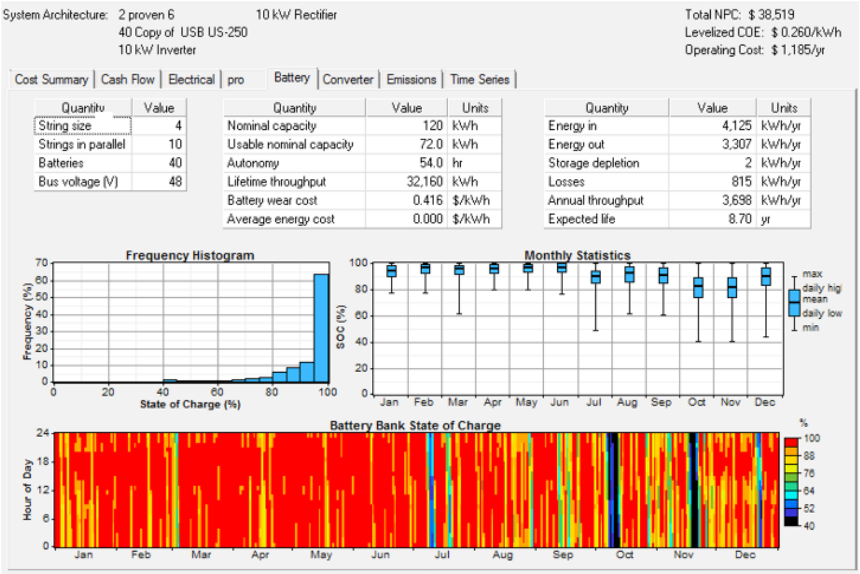

Figure (15) The battery bank state of charge of The US battery

7.4.3. Inverter

The Inverter efficiencies were assumed to be 90% for all the sizes considered. The selected size is 10 kW. The Inverter output is shown in Figure (16).

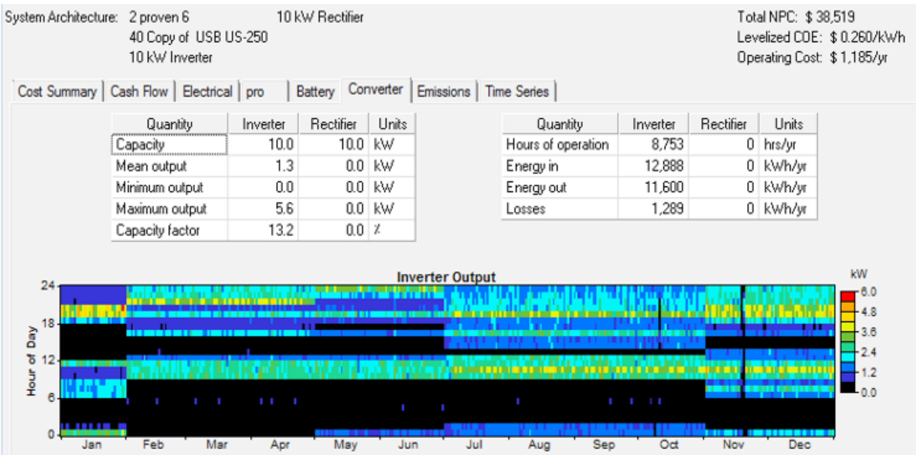

Figure (16) The Inverter output

7.5. Economic results

The economic analysis was performed for a wind energy converter and battery hybrid system using HOMER software. The initial capital cost is $12,000 for both wind turbines and the operation and maintenance cost was taken as $716. Detailed costs for each component of the hybrid system and Net Present Cost (NPC) of each are presented in Figure 17. It was assumed that the discount rate is 5% and the inflation rate is 2%. The main economic results are: the total Net Present Cost (NPC) for the energy system was about $36,256, the levelized cost of energy (LCOE) is about 0.26$/ kWh and the system payback period are 7- years. The electric energy cost for homes in Libya is about $0.02 /kWh. This cost is subsidized by the government. The real generation cost is much higher than such cost and will be in favor of using wind energy.

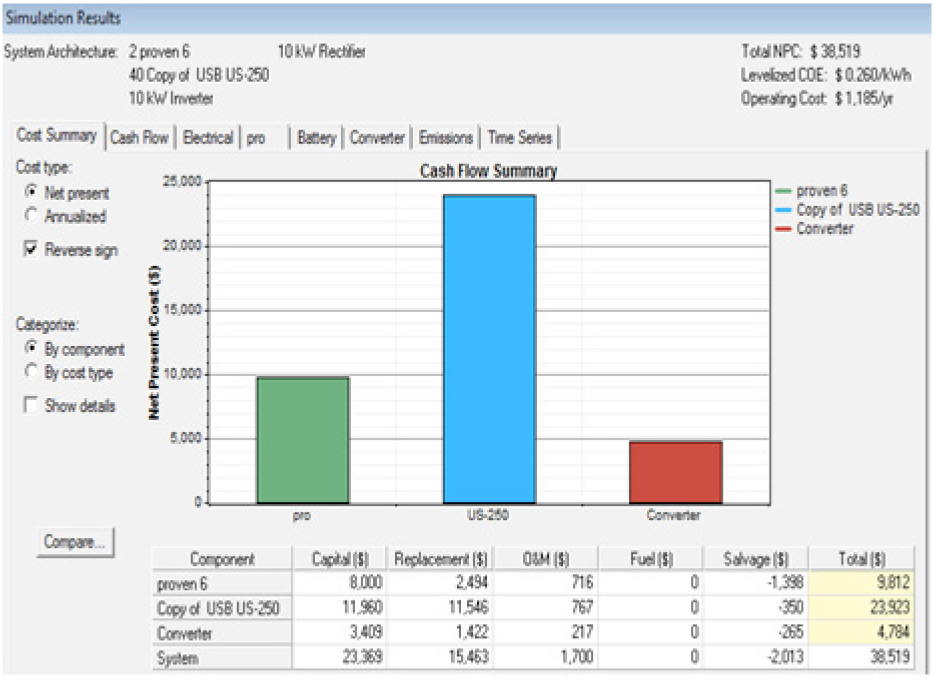

Figure (17). The cost summary of the hybrid system.

7.6. Comparison of the results

The results of the of the system sizing using Excel sheet calculation was compared with the results obtained by HOMER program. The summary of the results is presented in Table 6.

Table (6). The comparison of Excel sheet calculations and HOMER program

Component	Calculation	Homer simulation
Energy produced kWh/yr	23.894	26.058
Energy consumed kWh/day	35	32
Excess energy kWh/yr	8.106	12.924
Total net present value $	33.294	39.519

Also, the results of the economic analysis were compared with economic analysis performed by HOMER software are shown in Table 7, which presents the total net present value for a wind turbine, energy converter and battery hybrid system. It could be noticed that the results of the total net present cost for the whole system are comparable.

Table (7). shown the total net present value for a hybrid system component

Component	Type	Net present value	Homer imulation
wind turbine	Proven 6kW	25.908$	9.812$
Battery	US 185 HCXC2	1.158$	23.923$
Inverter	AIMS, PICOGLF120W48V240V	6.228$	4.784$
Total		33.294$	38.519$

8. CONCLUSIONS

It could be concluded that zero energy house concept could be feasible for sites where wind is available with suitable wind potential during different times in a year. The results obtained using Excel sheet and HOMER software. Both ways can be very realistic and gave very promising results for zero energy housing. The simulation results indicated that the electricity supply for the proposed house in Magrun could be generated by installing wind/Battery power system. Two wind turbines each of 6 kW with a battery system were used to supply the average energy demand of about 35 kWh/day for this house. The average annual energy production by the WECS's was 23,894 kWh/yr and the excess energy was about 8.106kWh/yr. The total net present cost using Excel sheet is $33,294, while using HOMER software is $38,519. The payback period is 7-years and the LCOE is $0.260/kWh.

The hybrid system was designed to meet the worst cases during the year, so during the months of high-level availability of wind, excess energy will be stored in batteries or dumped to supply auxiliary loads. In future scenarios, when feed-in tariffs law exist the excess energy can be sold to the utility grid to reduce the cost of energy. So, further work could be performed including electricity network integration to the system and compared with the above results.

The supply of electric energy through wind energy in such independent system can alleviate the problems of blackout and electricity shortages that started to appear in recent years in Libya. If such systems are available in the local market, they would be a better choice instead of conventional generators that people are using right now to solve the electric energy shortages to supply their homes and would save the environment from tons of pollutants in addition to noise and thermal pollution.

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CONFLICT OF INTEREST

The authors declare that there is no conflict of interest.

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