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Design and Implementation of Hybrid Power Plant to Feed a Residential Area

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الملخص
يهدف هذا البحث الى تصميم وتقييم محطة توليد للطاقة الكهربائية تعتمد على كل من الطاقة الشمسية وطاقة الرياح، وذلك لتوفير الطاقة اللازمة لمنطقة سكنية بمدينة الزاوية ((المنطقة السكنية ديلة)). كانت الخطوة الأولى واللازمة هي دراسة وتحليل كل من الطاقة الشمسية وطاقة الرياح في المنطقة المستهدفة بالاعتماد على برنامج RETScreen. اعتمادا على معدل استهلاك الطاقة في المنطقة السكنية تم تحديد قدرة المحطة بقيمة 2.1 MW مقسمة الى 1.8 MW للمزرعة الشمسية و 0.3 Mw لتربينات الرياح والذين تم تصميمهما وتحديد كل الاحتياجات لها بمساعدة مجموعة من البرامج الحاسوبية. وفي الختام تم القيام ببعض الحسابات المالية والاقتصادية والتي من شأنها معرفة تكاليف الانشاء والتشغيل والصيانة ومدي إمكانية تنفيذ هذا المشروع على أرض الواقع، مع القيام بحساب العمر الزمني لهذه المحطة والمقدر بـ 20 سنة، وحساب التكلفة الرسمية لكل كيلووات من الطاقة الكهربائية ومقارنتها بسعر الدولة لمعرفة نقطة التعادل الاقتصادي, والتي قدرت بحوالي 8.3 سنة.

Abstract

This project was mainly focusing on possibility of building a solar wind hybrid power plant is to power the residential buildings in Zawia City which is ((Deela residential area)). The weather profile data for Solar and wind were studied and analyzed for the proposed area. Based on the power consumption; it has been decided that a 2.1 MW power plant is adequate choice to satisfy the demand. This load will be divided to 1.8 MW for the solar field and 0.3 MW for the wind farm according to the energy potential in the selected site. The system components and requirements were designed and specified using amount of software. The hybrid system costs including the initial costs, operation and maintenance costs have been calculated for a 20 years lifetime in order to calculate the electricity price and the payback period which is turned out to be (8.3 years).

Keyword: *Solar power, wind turbine, Hybrid system, Levelized Cost of Electricity, Payback Period.*

1- Introduction

The objective of this project is to study the possibility of building a solar wind hybrid power plant is to power the residential buildings. Also to show that this technology is a feasible option for electricity generation in Libya. The study was started by investigating the availability of both solar and wind energy in the desired location. The design of wind turbine rotor has been modeled by Qblade software. The data of solar radiation and wind speed were taken from the RETScreen software database, then system configuration, performance and financial analysis done by simulation tool, RETScreen. The basic requirement of the electric load has been determined to be 2.1 MW as peak load. In order to meet the load demand of the residential area it was needed to store the excess power generated in batteries storage for the sustainable energy storage.

2- System Components

Solar wind hybrid renewable energy systems have increasingly become popular as stand-alone power systems for providing electricity. In general, such a system is required, the PV modules mounting, the wind turbine tower, the DC-AC inverter, the safety equipment such as fuses, the measuring instruments, the batteries, the charge controller/regulator, the backup power resource for battery storage systems, switches and sockets[1].

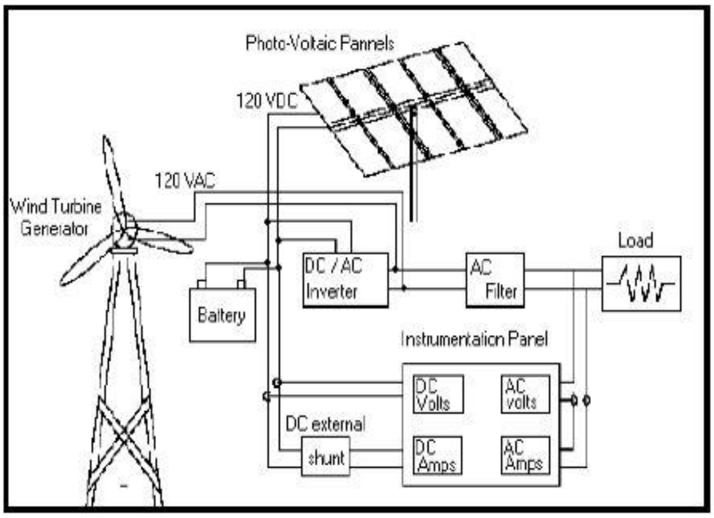

Figure 1 Hybrid energy system components. [1]

3- Methodology and Data

The residential units are currently supplied by the general electricity grid. According to General Electricity Company of Libya, the units have three 11kv to 380v converters with capacity of 0.5MW for each converter during normal operation conditions, in case of an increase in demand; these converters could reach a capacity of 0.7MW. Based on this information; it has been decided that a 2.1 MW power plant is adequate choice to satisfy the demand. This load will be divided to 1.8 MW for the solar field and 0.3 MW for the wind farm according to the energy potential in the selected site. By considering the load demand, it is clearly noticeable that the value of DNI and wind speed of Alzawiyah perfectly reached the requirements of building a 2.1 MW solar wind hybrid Power plant. The land chosen for this project is located in the north of Az Zawiyah city near the coast as shown in figure 2. It is a government owned land that has an area around 45 hectares. The proposed land has some characteristics which is summarized as following:

- City: Alzawiyah
- Country : Libya

- Time zone: Gmt+2
- Elevation : 17 m
- Longitude : 32.79 deg
- Latitude: 12.72 deg
- Total area : 450,850 m^2 (0.45 Km^2)
- The proposed site is located near to a road which makes transportation easier during installation and operation.
- Mediterranean Sea provides the water demand for the utility needs.

Figure 2 Satellite photo for the proposed land.

Because of the difficulties of collecting the weather profile date of Alzawiyah City, Zuara weather profile was chosen and analyzed based on the similarity with Alzawiyah weather conditions. According Zuara weather profile data, the annual average DNI is determined as 5.32 Kwh/m^2/day. In addition, the annual average wind speed is calculated to be 4.6 m/s as shown in figures 3 and 4.

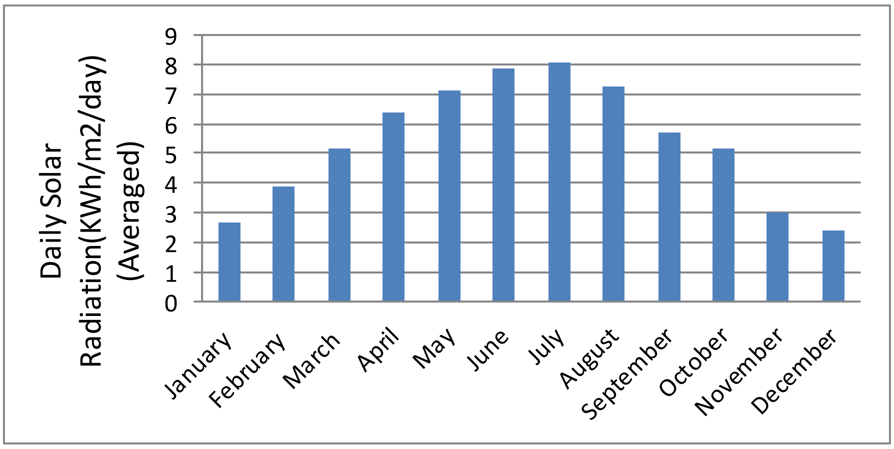

Figure 3 Monthly Average Solar Radiation-Horizontal.

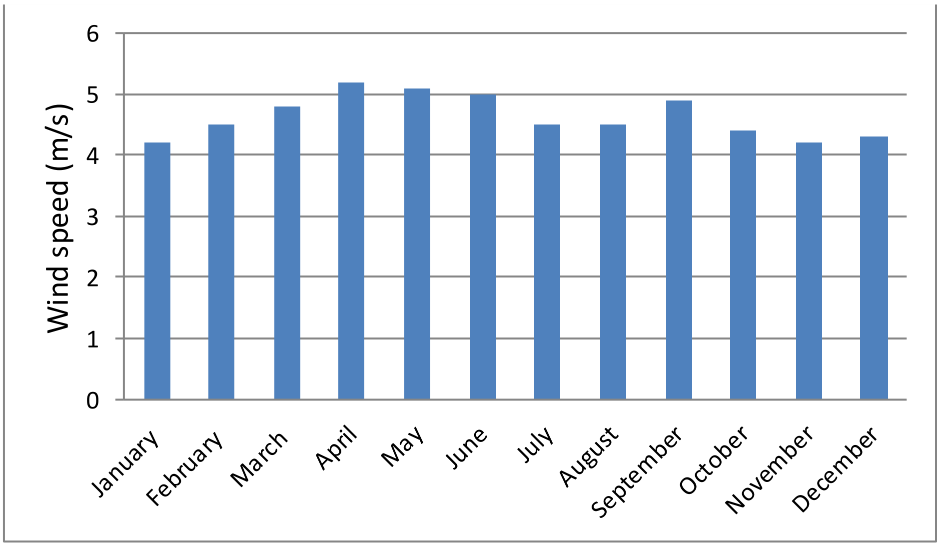

Figure 4 Monthly Average Wind Speed.

4- Solar Technology Characteristics

In this project poly-crystalline silicon solar panels have been chosen due to its conversion efficiency (refer to table 1). Although poly-crystalline silicon has a relatively high cost, it compensates for its cost by requiring less solar panels which in turn decreases the need for land and power system infrastructure (cables and mounting frames). The figure 3.8 illustrates that the poly-crystalline silicon technology is the most commonly used in solar farms over all the world within two years respectively (13).

Table 1 Characteristics for some PV Technology Classes.

Technology	Current commercial efficiency (Approx.)	Temperature coefficient (Typical)
Crystalline Silicon	13% - 21%	0.45%/ºC
Heterojunction with intrinsic Thin-film Layer	18% - 20%	0.29%/ºC
Amorphous Silicon	6%-9%	0.21%/ºC
Cadmium Telluride	8%-16%	0.25%/ºC
Copper Indium Gallium Di-Selenide	8%-14%	0.35%/ºC

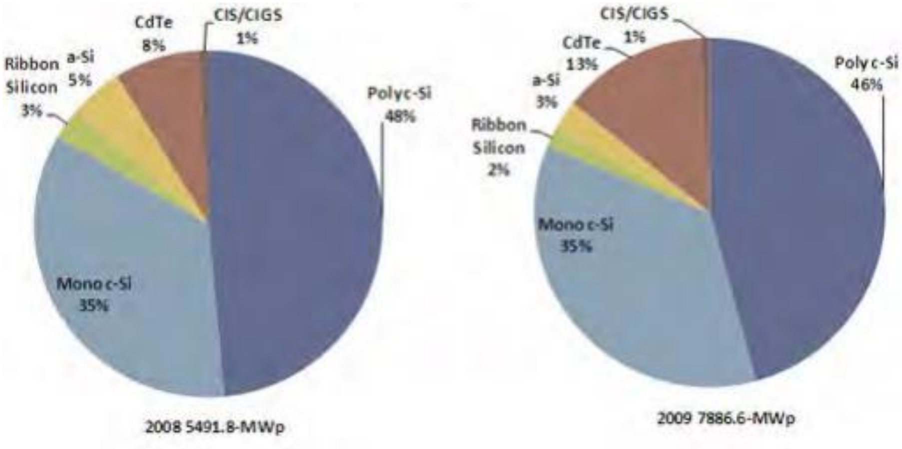

Figure 5 The global use of solar cells technologies.

A solar panel manufactured by the Canadian Solar company has been chosen due to its acceptable conversion efficiency of 15.08 percent and a power output of 165 W. The solar collector has an area of 1.2 m^2 with one axis solar tracking system. It has been decided that 11000 solar panels are needed to attain the desired power output of 1800 KW.

4.1- Tracking Systems and Mounting

The solar irradiation, trackers may increase the annual energy yield by up to 27% for single-axis and 45% for dual-axis trackers. Tracking also produces a smoother power output plateau. Figure 6 shows the proposed mounting design for each panel to prevent the shading effect.

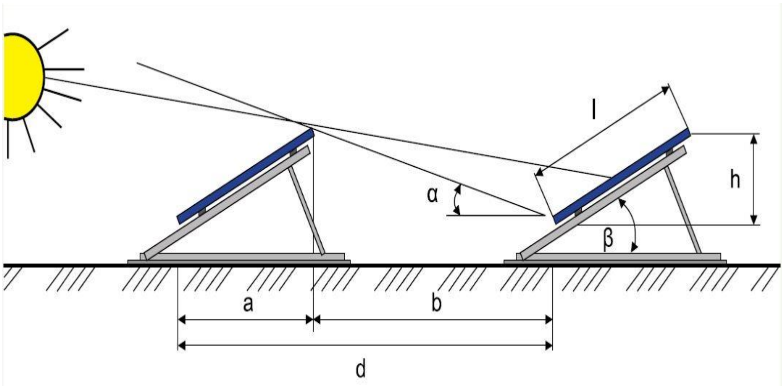

Figure 6 PV spacing and shading

Where a=1.272m; b=3.399m; d=4.671m; L=2.4 m; α=30.91^o ; β=58^o.

In order to control and move the tracking system, The Arduino Uno is a microcontroller board based on the ATmega328 was used in this project. For more details see figure 7, and table2.

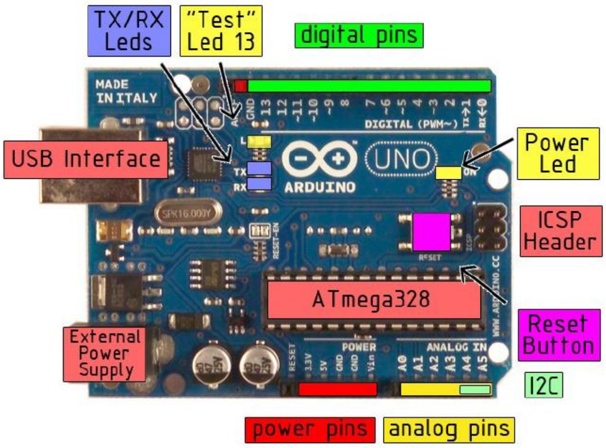

Figure 7 Arduino's board components.

Table 2: Arduino's specifications.

Microcontroller	ATmega328
Operating Voltage	5V
Input Voltage	7-12V
Input Voltage (limits)	6-20V
Digital I/O Pins	14 (of which 6 provide PWM output)
Analog Input Pins	6
DC Current per I/O Pin	40 mA
DC Current for 3.3V Pin	50 mA
Flash Memory	32 KB of which 0.5 KB used by Bootloader
SRAM	2 KB
EEPROM	1 KB

The principle of the Arduino solar tracker is illustrated in the following algorithm:

- Step 1: Read all analog voltages from analog channels
- Step 2: If all voltages are equal then Servo-motor will be in stop position.
- Step 3: If LDR1>LDR2 Then the Servo-motor will rotate clockwise.
- Step 4: If LDR2>LDR1 Then the down motor will rotate anti clockwise.

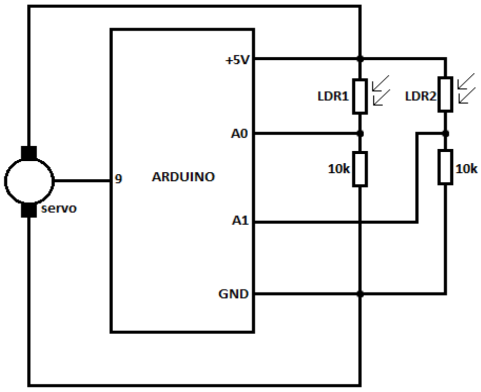

Figure 8 Schematic of Arduino solar tracker circuit.

4.2- Solar Field Layout

The aim of the layout design is to minimize cost while achieving the maximum possible revenue from the plant. Panel layout is divided into thirteen rows as shown in figure 9. The distance between them was decided to be five meters while distance between right and left rows fifteen meters for transportation. Therefore; the total solar panel area is 37740 m^2 and 8880m^2 will be utilized for other utilities (batteries, inverters and connection equipment, etc.).

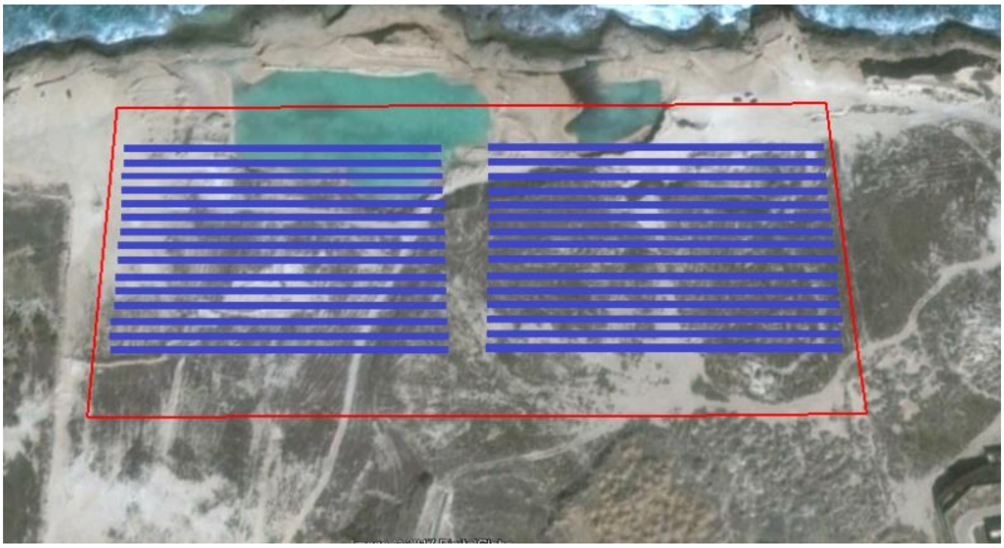

Figure 9 Solar field layout.

5- Wind Technology Characteristics.

5.1- Wind Power

the available power in wind P_w can be expressed as:

$$P_w = \frac{1}{2}\rho A u^3 \quad \text{Eq. (1)}$$

Where: ρ is the density of the air, u is the wind speed and A is the swept area.

5.2- Wind Power Parameters

a: Blade Swept Area.

$$A = \pi[(l + r)^2 - r^2] = \pi l(l + 2r) \quad \text{Eq. (2)}$$

Where: l is the length of wind blades and r is the radius of the hub.

b: Power coefficient.

$$C_p = \frac{P_{me.out}}{P_w} = \frac{P_{me.out}}{(^1/_2)\rho A u^3} \quad \text{Eq. (3)}$$

Where: 45% > Cp >30%.

c: Total Power Conversion Coefficient and Effective Power Output.

$$P_{eff} = c_p * \eta_{ele} * \eta_{gen} * \eta_{gear} * p_w = \eta_t * p_w = _{1/2}(\eta_t \rho u^3) \quad \text{Eq. (4)}$$

Where:

η_{gear} Gearbox efficiency.

η_{gen} Generator efficiency.

η_{ele} Electric efficiency.

d: Tip Speed Ratio.

$$\lambda = \frac{(l+r)\omega}{u} \quad \text{Eq. (5)}$$

Where: w is the angular speed of blades .

e: Optimal angular speed and optimum TSR.

$$\omega_{opt} \approx \frac{2\pi u}{nL} \quad \text{Eq. (6)}$$

$$\lambda \approx \frac{2\pi}{n}\left(\frac{l+r}{L}\right) \quad \text{Eq. (7)}$$

Empirically, the ratio $(l + r)/L$ is equal to about 2. Thus, for three-blade wind turbines (i.e. n = 3), $\lambda = {}^{4\pi}/_3$. If the aerofoil blade is designed with care, the optimal tip speed ratio may be about 25–30% higher than the calculated optimal values above. Therefore, a wind turbine with three blades would have an optimal tip speed ratio:

$$\lambda_{opt} = \frac{4\pi}{3}(1.25 \sim 1.30) \approx 5.24 \sim 5.45 \quad \text{Eq. (8)}$$

5.3- Wind Turbine Choice

According to a late project of “Design a wind turbine for the administration bulding of engineering faculity at university of zawia”, which used number of software in order to design the desired turbine. MATLAB, QBlade and ANSYS were used to achieve a final design of a three bladed upwind wind turbine with a rotor diameter of 21.5 m, hub height of 24 m and rated wind speed of 8.874 m/s with the stain-less-steal hallow taper tower dimensions were obtained. In addition, E-Glass Fiber blade design and wind turbine specifications. Those specifications are the cut-in, rated and cut-out wind speed which are 3 m/s, 8.9 m/s and 18 m/s respectively all that in a goal of generating 65kW of electricity power. Starting from the recommendations of the mentioned project, six wind turbines were used in this project to generate 0.39 MW which will be the desired power from the wind part of the hybrid system. Table 4.1 bellow presents the main factors of the chosen wind turbine.

Table 3 Wing Turbine Regions

State	Wind Speed (m/s)	Pitch Angle (º)	Rotor Speed (rad/s)	Power Coefficient Cp	Power (kW)
I	3 – 9	constant	variable	constant	< 65
II	9 - 18	variable	constant	Variable	65

A wind turbine manufactured by Endurance Wind Power company has been chosen since it satisfies the required power output and complies with urban noise regulation. The wind turbine according to the RETScreen database has a power output of 50 KW, a hub height of 24m and rotor diameter of 19.2m. To satisfy the 300 KW output requirement, six of the chosen wind turbines are needed.

5.4- Wind Farm Design:

In this project sex wind turbines have been placed in one row taking into account the layout concept shown in figure 10.

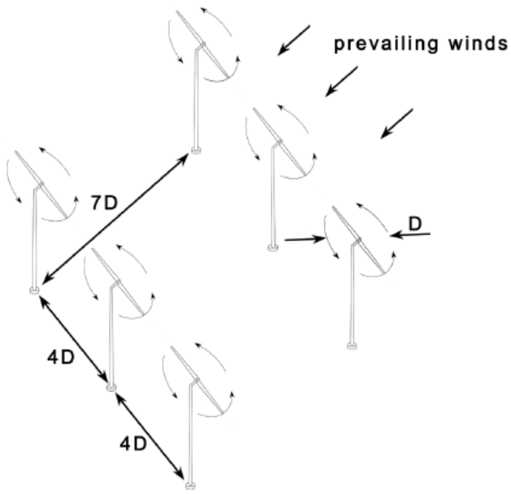

Figure 10 Wind farm optimal placement.

6. Performance and Financial Analysis.

6.1- Performance Analysis

The performance of the hybrid PV-wind energy system has been evaluated and simulated according to the energy potential for each source. The electricity gained from the solar field and the power output and electricity generated by the wind farm are shown in figures 11 and 12 respectively.

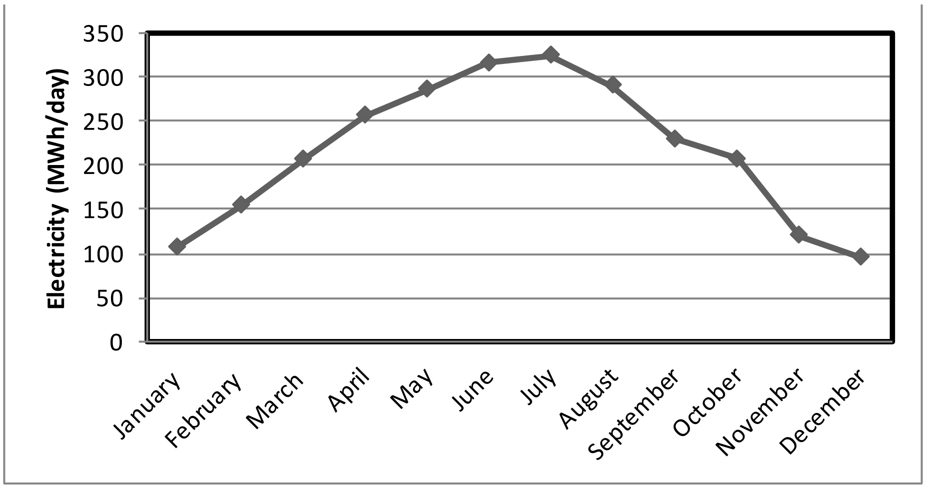

Figure 11 Electricity gained from the Solar Field.

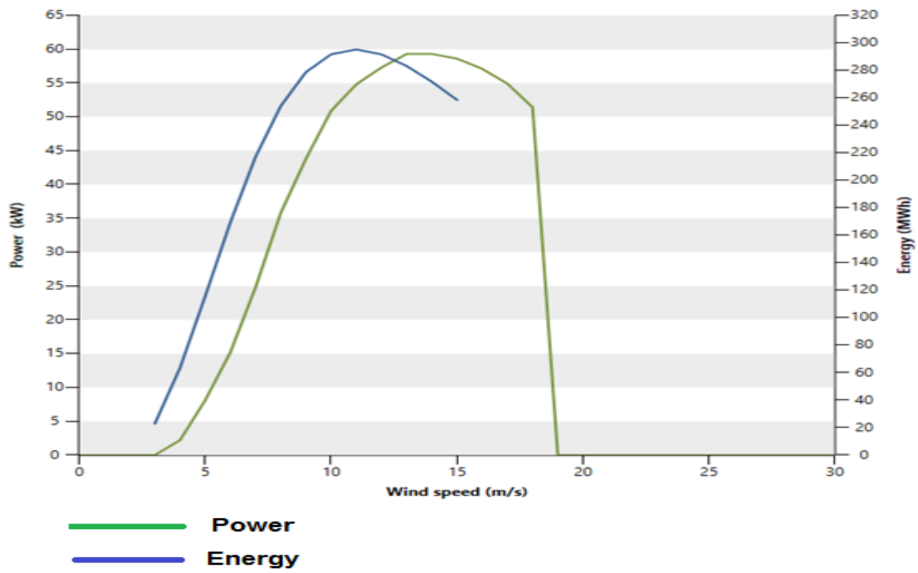

Figure 12 The electricity generation of the wind turbine.

6.2- Financial Analysis

a. Levelized Cost of Electricity (LCOE):

$$LCOE = \frac{\text{Sum of costs over lifetime (\$)}}{\text{Electrical energy produced over lifetime (kWh)}} \quad \text{Eq. (9)}$$

The hybrid system costs including the initial costs, operation and maintenance costs have been calculated using RETScreen software. It is assumed that the project life is about 20 years and annual revenue of 1’582’056 $/yr see figure 13. An initial cost of 12’103’000 $, operation and maintenance costs of 115’038 $/yr and the sum of costs over lifetime = 14’403’760 $. Also, the electrical energy produced over lifetime = 367’920’000 KWh. Thus; the LCOE = 0.0391 $/KWh.

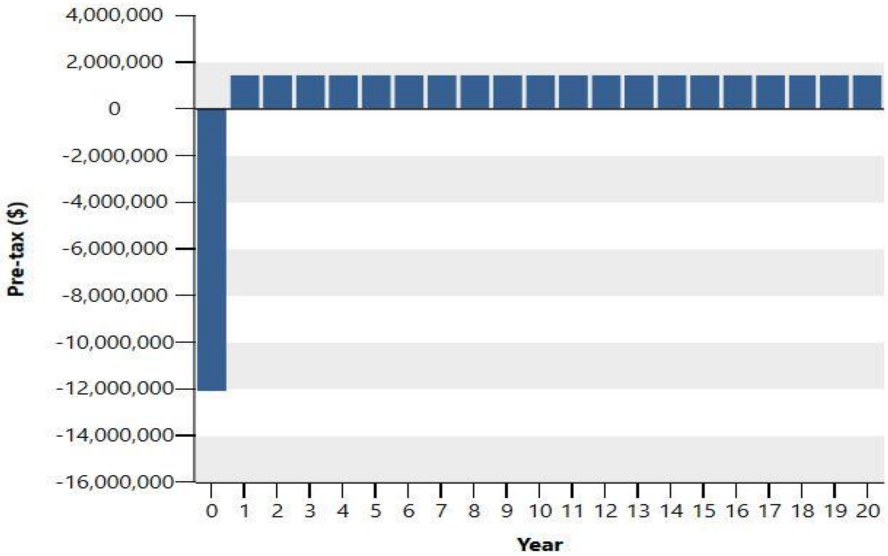

Figure 13 The initial cost and the annual revenue for each year.

b. Payback Period (PBP):

The Payback period is the year in which the net present value of all costs equals with the net present value of all benefits. Hence PBP indicates the minimum period over which the investment for the project is recovered. the formula to calculate payback period is:

$$\text{Payback Period} = \frac{\text{Inintial cost}}{\text{Cash inflow per period}} \qquad \text{Eq. (10)}$$

According to the general electricity company, the electricity is supported by government and reaches the citizens with price of 0.0143 $/KWh. The electricity price without supporting is 0.086 $/KWh. From a financial stand-point, about 1.5 m $/yr will be Saved to the state treasury after the payback period (during the last 11.7 years of the project life).

Figures 14 and 15 illustrates the payback period which belongs to the governmentally supported electricity (26.9 years) and the governmentally unsupported electricity respectively (8.3 years)

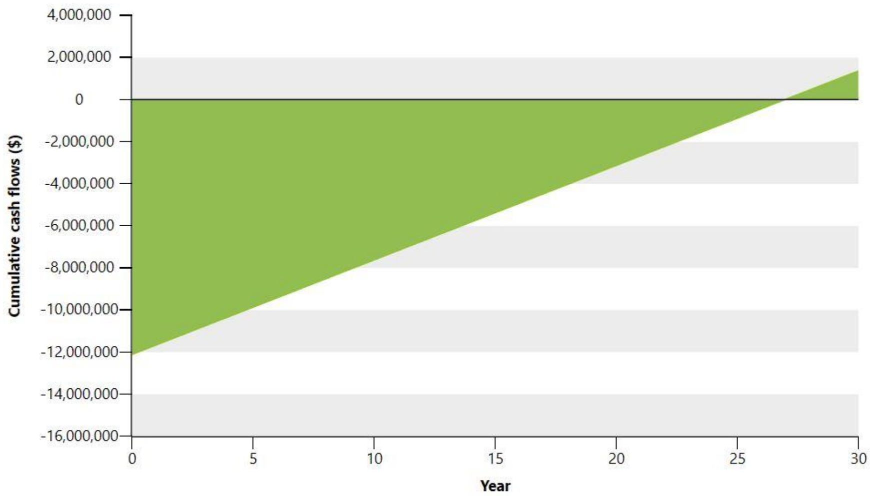

Figure 14 The payback period for the governmentally supported electricity.

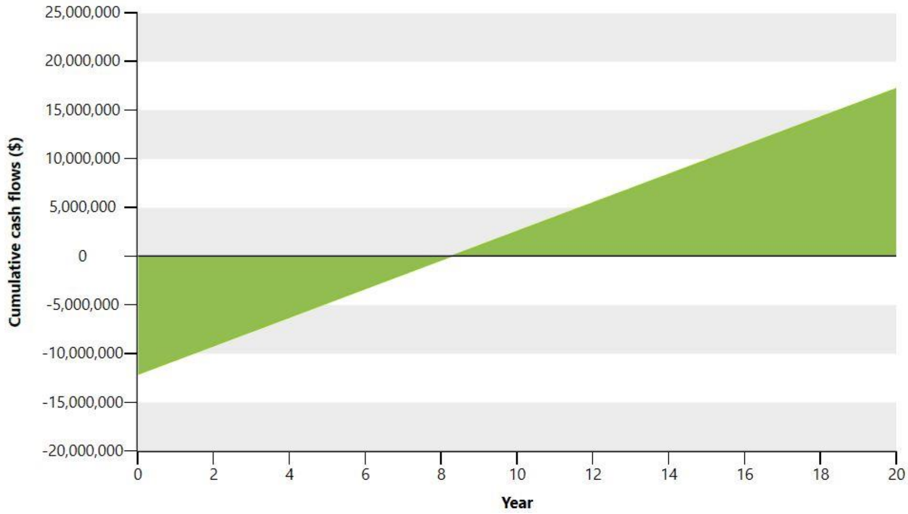

Figure 15 The payback period for the governmentally unsupported electricity.

7- Conclusion.

The work of the proposed project could be concluded as following:

1- The main goal of this project is to design a Hybrid system consists of solar field and wind farm to generate the electricity power for the proposed residential are of Deela.

2- The total load of the residential area 'was estimated to be 2.1 MW' could be achieved by designing a hybrid system consists of 0.3 MW of wind farm and 1.8 MW of solar field based on the available wind and sun energy data for the proposed location.

3- A solar PV system was chosen as a suitable technology for the solar field using a poly-crystalline silicon solar panels with a one axial tracking system which programed with and Arduino program based on the different solar angles throw the year.

4- Six upwind wind turbines with three E-Glass pitched blades were designed should be installed to generate the needed electricity from the wind farm, which may stand the weather conditions such as stream wind speed and the high humidity.

5- Performance and financial analysis of the proposed project were done by using the RETScreen and in order to estimate the LCOE and PBP which turned out to be 0.0391 $/KWh and 27 Yrs respectively. This LCOE is very competitive to the unsupported electricity price which is 0.086 $/KWh, and the PBP is considered as a good period comparing to the other hybrid systems' life times.

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