The Economic Feasibility of Photovoltaic Systems for Electricity Production in Libya

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Abstract— **The increased energy demands will result in more oil and gas consumption in Libya. This could lead to a decrease in the country revenue and more CO_2 emission. Hence, Libya should use its alternative energy sources. In this paper the photovoltaic systems are proposed to share in the electricity energy mix in Libya. As the electricity is subsidized in Libya it results to inefficient and irrational use of electricity. Additionally the corruption and the bad management results in an extra cost for electricity generation. A photovoltaic system model is proposed and used to estimate the energy output of a PV system installed in Libya. The results show that moving toward photovoltaic systems could result in large energy and cost saving. Worthless to mention a reduction in CO_2 emission.**

Keywords—Libya; photovoltaic; solar energy; renewable energy; electricity

I. INTRODUCTION

As the largest oil producer in North Africa, the Gas and the Oil contribute to most of the country revenue. Libya relies on the oil and the gas for electricity production. Libya is producing now around 33 TWh of electricity mainly from gas and oil [1]. The demand on energy will substantially increase in the near future as a result of the economic development in order to build new infrastructure in Libya after the massive destruction that happened during the last four years. This will lead to more consumption of oil and gas which causes a reduction in the national economical revenue and more carbon dioxide emission. Therefore, Libya should use its alternative energy supplies to cover some of its load requirements. Depending mainly on fossil fuel without paying attention to alternative renewable energy could lead to more irrational use of the country resources.

However, the renewable energy has been used in Libya back to the seventies, the main applications are for powering small remote loads such as communication repeaters, rural electrifications, water pumping and Cathodic Protection for the oil pipelines in the desert. Libya has high potential of wind and solar energy. The average solar radiation in Libya is around 7.5 $kWh/m^2/day$ with about 3000 to 3500 sunshine hours per year [2]. The average wind speed is roughly between 6 m/s and 7.5 m/s at 40 m height [2]. This huge amount of sunshine and wind distributed over an area of 1,750,000 km^2 can provide the future electricity needs for Libya and its neighbors.

Although is blessed with such a huge renewable energy resources, their share in electricity production is negligible. Libya currently depends mainly on the oil and natural gas for electricity production which are limited and depleted. The expected energy demands increase in Libya could affect the oil and natural gas production. This no doubt will lead to decreasing the country revenue. The decision makers in Libya should initiate an urgent plan to diversity its energy sources. According to the REAOL (Renewable Energy Authority of Libya) the renewable energy share is expected to reach 10% of energy demand in 2025 [3].

The residential load and the street lighting forms around 50% of Libya electricity consumption. The irrational use of electricity has increased dramatically in the last few years. This will lead to more consumption for the precious gas and oil. Renewable energy is one of the alternatives that could play great role especially in street lighting and home systems which can create awareness among people and may help to reduce the irrational use of electricity. In this paper the economic feasibility of using photovoltaic systems for electricity production is addressed. The paper starts with a description to the current energy situation in Libya followed by a brief on the solar energy resource. Then the model of PV system is presented and a simplified model is derived to estimate the energy output from a PV system installed in Libya. Finally the economic feasibility of PV systems is discussed.

II. ELECTRICITY PRODUCTION IN LIBYA

Libya has installed twelve power plants which are capable of supplying 8.347 GW while the available capacity is 6.357 GW. The energy sector relies on the natural gas, heavy fuel oil and light fuel oil with the percentages shown in Figure 1. The General Electricity Company of Libya (GECOL) increased the dependence on the natural gas in order to reduce the CO_2 emission. The energy consumption is distributed among several load types as shown in Figure. 2. The residential load is the most dominated load with 31% of the total consumed energy. The street lighting is around 19% of the energy consumption. The load growth study is one of the essential subjects with regard to load demand prediction. Figure 3 shows the energy consumption in Libya over the last ten years.

The regression equation has been derived and then used to predict the load growth at about 9% for each consecutive year.

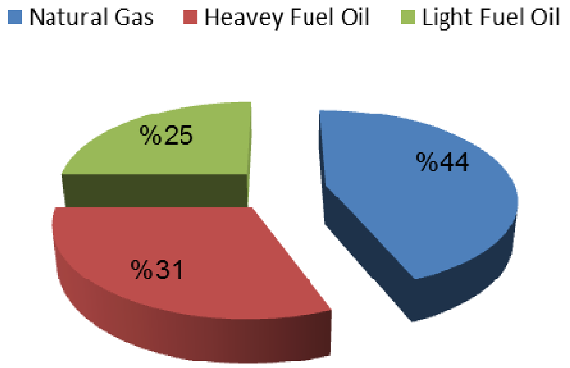

Fig. 1. Types and percentage of gas and fuel used in electricity generation in 2012

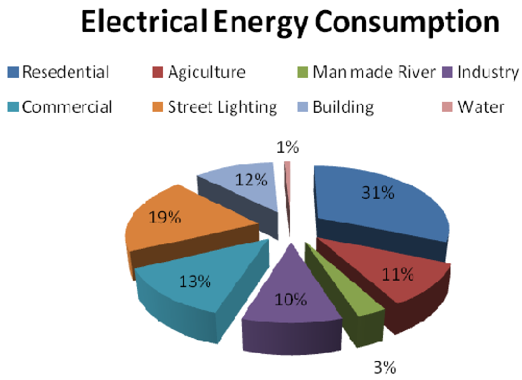

Fig. 2. Types and shares of customers of Libyan electricity generation in 2012

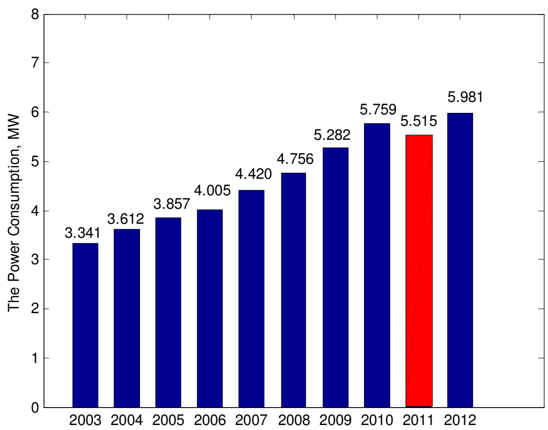

Fig. 3. The energy consumption over the last 10 years

The demand on energy will substantially increase in the near future in an exponential growth as shown in Figure 4 as a result of economic development. This will lead to more consumption of oil and gas which causes a reduction in the national economical revenue and more carbon dioxide emission. The expected increase in electricity demands is shown in Fig. 4.

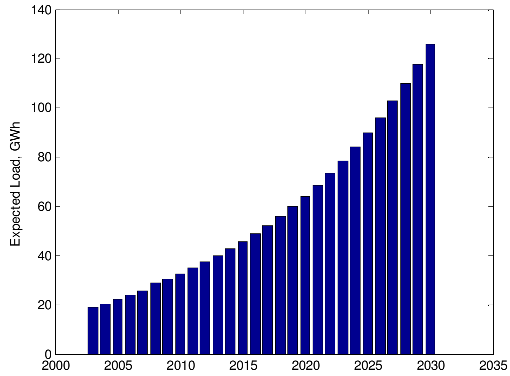

Fig. 4. Expected load demand for the next 20 years

As can be expected from Figure 4, The load demand for the electricity consumption will be increased for the long term with 9%. This means that, in the future, the amount of oil used for electricity generation will be substantially increased. The price of electricity generation from oil can performed in two steps.

First the expected load demand for any prospect time can be figured out from Figure 4. Second this amount of oil can be converted to no of barrels by dividing it over 1628 KWh. Finally, this number of barrels is multiplied by its price predicted by OPEC [4,5]. Another method is to convert from kWh to dollars directly. For instant, in 2030 the expected load demand will be 120 TWh and the number of barrel to cover this generation per day is 202 thousand barrels (bbl/d). This number will be subtracted from the daily Libyan oil export which is about 1.3 million barrel on average. The energy demands in 2030 is expected to be 120 TWh multiplying this figure by 0.176$ the cost of the energy is found. This will cost the country around 21.12 billion a year. As the street lighting forms around 19% of the electricity consumption then will cost the country around 4.013 billion. This means that there will be a substantial reduction in oil exportation as a result of electricity usage unless the renewable energy technology is adopted. The use of clean energy such as wind and solar in electricity generation will also lead to the reduction of carbon dioxide emission to some extent. The saving in Libya oil and gas resources is not beneficial only to Libya but to the whole world. The electricity in Libya is subsidized because the country adopted a communist economical system since 1969. By the time, the consequences of this policy are clear in the irrational use of electricity by most of the Libyans.

The expected increase in the load demands can be compensated by putting the renewable energy train on the track. Based on 100$ price for the crude oil price per barrel the cost of the kWh produced by oil is 0.176$ the average cost of the kWh produced by PV in Libya is around 0.123$ which is much cheaper than burning the precious crude oil. What the country needs is stability, security and political well. The electricity in Libya is subsidized and it is better for the

GECOL to spend on emerging the renewable technology into the country.

It worth noting that around 19% of the loads are street lighting. The GECOL relies on very old and inefficient street lighting systems. Replacing these old fashioned inefficient technology with LED solar street light system can achieve energy consumption and reduce CO_2 emission.

III. The Solar Energy Resource

The Geographical location of Libya makes it one of the countries blessed with high Solar Energy. Solar energy is believed to be the most important and feasible renewable energy source in Libya. Libya lies within the most favorable sunny zone (between 15^0 N and 35^0 N). The rain falls is below 150 mm in most of the country. For example, the average solar radiation in Libya is around 7.5 kWh/m^2/day with about 3000 to 3500 sunshine hours per year [1]. The solar radiation in different cities in Libya is shown in Figure 5.

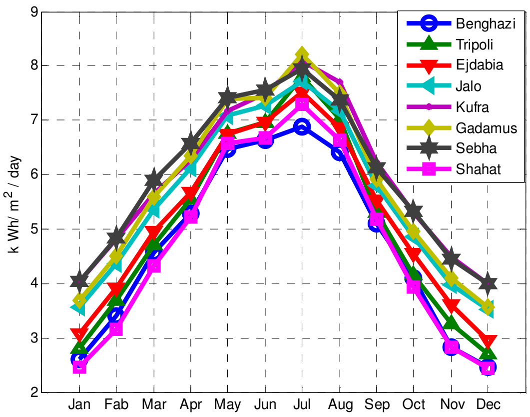

Fig. 5. The monthly solar radiation in different cities in Libya

IV. The Model of PV System for Energy Prediction

The basic PV system is shown in Fig 6. The main components are: the PV module, the charge controller, the loads and the battery. A mathematical model of each component is derived and implemented in Matlab/Simulink. Then a simplified model of the system is developed to estimate the energy output of the system.

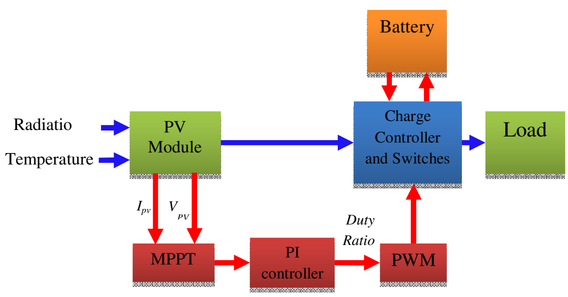

Fig. 6. The basic PV system

A. PV Module

PV solar cells are made from semiconductor material and rely on the photoelectric effect to generate electricity. The most widely used semiconductor for terrestrial applications is the silicon. The basic PV cell is the p-n junction shown in Figure 7. In the dark the characteristics of the PV cell is similar to the normal diode. When sunlight with energy greater than the semiconductor energy gap hits the cell, electrons becomes free and a considerable current flows in the external circuit.

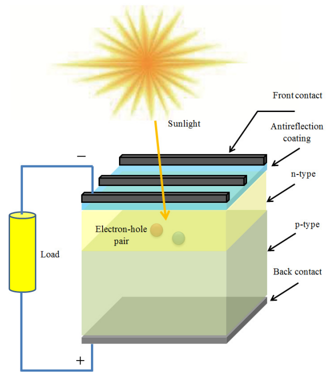

Fig. 7. A pn-junction silicon solar cell.

Many studies focus on modeling the PV cell instead of the PV module [6,7]. This is not practical because the manufacturer provides the module data not the cell data. In order to obtain the IV and PV curves a mathematical model must be derived. There are many methods for modeling PV modules in the literature [7]. The model derived in this paper is based on the single-diode model [8] and extracting some of the parameters from the manufacturer data sheet [9]. The electrical circuit model is shown in Figure 8.

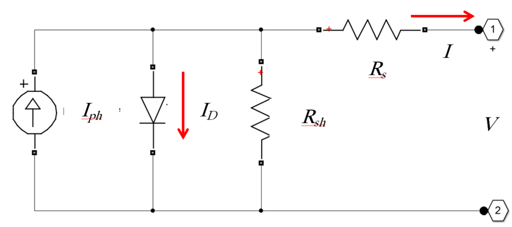

Fig. 8. Circuit model of a solar cell

The model is with middle complexity where the temperature dependence of I_0, I_{ph}, and V_{oc} are included. Also the parasitic resistances R_s and R_{sh} and their temperature dependence are considered. The ideality factor is used as a variable to match the simulated data with the manufacturing data. The mathematical model of a solar cell based on the single diode model is given as [7]:

$$I(T,G,V) = I_{ph} - I_0(e^{(V+IR_s)/nV_{th}} - 1) - (V + I \cdot R_s)/R_{sh} = I_{ph} - I_D - I_{sh} \quad (1)$$

where the variables in (1) are given by;

$$I_{ph} = I_{ph0} \cdot G / G_{nom} \quad (2)$$

$$I_{ph}(T) = I_{ph} + K_0 (T - T_{meas}) \quad (3)$$

$$K_0 = [I_{ph}(T_2) - I_{ph}(T_1)]/[T_2 - T] \quad (4)$$

$$I_0 = I_{SC(T_1)} \cdot (T/T_1)^{3/n} \cdot e^{-\frac{E_g}{V_t}(\frac{1}{T}-\frac{1}{T_1})} \quad (5)$$

$$I_0(T_1) = I_{SC(T_1)} / \left(e^{qV_{OC(T_1)}/nkT_1} - 1\right) \quad (6)$$

$$R_s(T) = -dV/dI_{V_{oc}} - 1/(I_{0(T_1)} \cdot q/nkT_1 \cdot e^{qV_{OC(T_1)}/nkT_1}) \quad (7)$$

$$R_{sh} = V_{OC} / [I_{ph} - I_0 \left(e^{\frac{qV_{OC}}{nkT_{meas}}} - 1 \right)] \quad (8)$$

$$R_{sh}(T) = R_{sh} \cdot (T/T_{meas})^{\alpha} \quad (9)$$

The parameters in the model are explained briefly. I_{ph} is the photo generated current in Amperes. I_{ph0} is the photo generated current at the nominal radiation. I_0 is the diode dark saturation current. I_D is the diode dark current. I_{sh} is the shunt current. R_s is the series resistance. R_{sh} is the shunt resistance. G is the solar radiation in W/m^2. The G_{nom} is the radiation the PV module is calibrated at. n is the ideality factor. e is the electron charge. k is Boltzmann's constant. E_g is the semiconductor energy gap. K_0 is the short-circuit current temperature coefficient. The manufacturer provides the following: N_s: the number of cells in series, N_p: the number of cells in parallel, I_{sc} is the short-circuit current, V_{oc} is the open-circuit voltage, K_0 is the short-circuit current temperature coefficient. V_{th} is the thermal voltage and given by $V_{th}=nkT_c/e$.

B. Maximum Power Point Tracking

The maximum power point (MPP) changes with the temperature and the radiation. The voltage at the maximum power point is plotted as function of the radiation and the temperature and shown in Figure. 9. Applying this voltage on the PV module will achieve the maximum power. Figure. 9 will be used later to derive a simple model for the PV system.

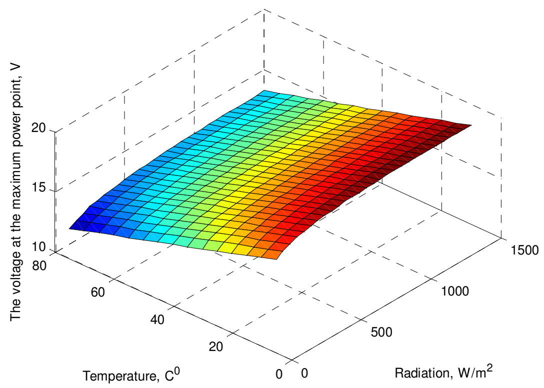

Fig. 9. The voltage at the maximum power point

In this paper we present a simplified model for the PV panel, the MPPT, the battery and the DC/DC converter. From Figure. 9 and a look-up table is used to generate the voltage at the maximum power point and the duty ration. From the PV model the current at the MPPT is derived. For the ideal DC/DC Buck converter the following equations hold:

$$V_{out}/V_{in} = I_{in}/I_{out} = D \quad (10)$$

C. The Battery Model

The battery is one of the crucial elements in PV systems. The batteries are used because of the intermittent nature of the renewable energy sources. During the day where there is a sufficient energy the battery is charging and during the night or very cloudy days where there is a deficit in the energy the battery is discharging. The general model of the battery is shown in Figure 10. The battery is simplified an internal voltage source in series with internal resistance R_0 [10, 11]. The terminal voltage is given by:

$$V = E - IR_0 \quad (11)$$

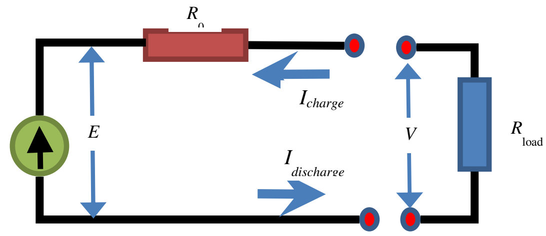

Fig. 10. Schematic diagram of the battery

The battery is viewed as energy source so the charging current is negative and the discharging current is positive. Battery capacity in both charging and discharging is known to decrees with increasing the charge and discharge rates. This behavior can be modeled by assuming that some of the charge is available, that is immediately accessible, and some of it is bound [10].

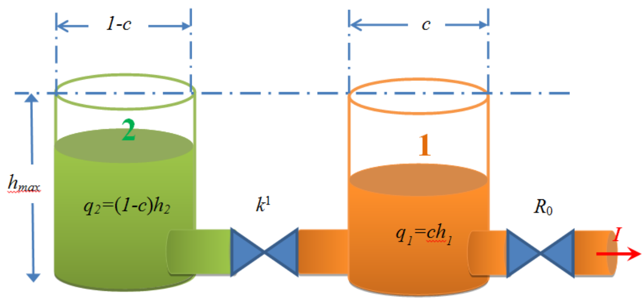

Fig. 11. Schematic battery model KiBaM

The total charge is then given by:

$$q = q_1 + q_2 \quad (12)$$

The bound and available charges are related to the charging/discharging current by the following two equations:

$$dq_1/dt = -I - k(1-c)q_1 + kcq_2 \quad (13)$$

$$dq_2/dt = k(1-c)q_1 + kcq_2 \quad (14)$$

The capacity as a function of the current is given by:

$$q_{\max}(I) = \frac{q_{\max} kcT}{1 - e^{-kT} + c\left(kT - 1 + e^{-kT}\right)} \quad (15)$$

The voltage nonlinear model is given by:

$$E = E_0 + AX + \frac{C_1 X}{D - X} + \frac{C_2 (D - X)}{X} \quad (16)$$

Where the constants k, c, q_{max} and R_0 are provided by the manufacturer. The charge or discharge time, T, is defined by $T = q_{max}(I)/I$. A, C_1, C_2 and D are found from the manufacturing data. X is the normalized capacity. The simulations are carried out test the behavior of the model under charge and discharge conditions. At the beginning the battery is fully charged. Then the battery is discharged every 48 minutes and retrieves in the next 72 minutes. After 10 hour the battery is then charged at the same rate. The voltage of the battery is shown in Figure 12 it clearly shows the nonlinear behavior during charging and discharging.

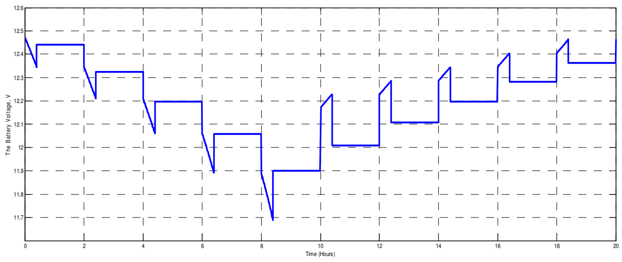

Fig. 12. The voltage of the battery

The simplified model with the PV module model and an approximation to account for the efficiency of the DC converter and the battery is shown in Figure 13. Using (10) the output current and voltage are derived.

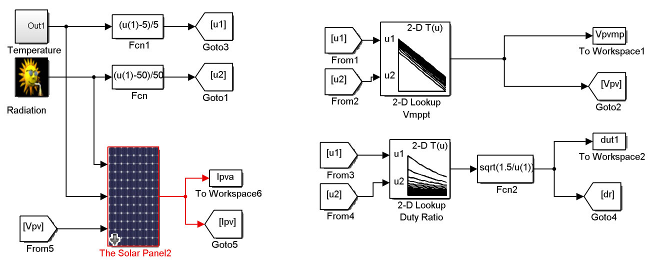

Fig. 13. The simulink implementation of the simplified PV system model

For the output current and the output voltage a correction factor to accommodate the efficiency of the converter and the battery is introduced in the approximate model. The good agreement between the results of the full detailed model and the approximate model is clear from the Figure. 14 where the output power are matched. It worth noting that the transient is neglected in the approximate model and this is because for simulating the PV system with storage devices their response is larger than the response of the MPPT and the DC/DC converter.

V. Economic Feasibility of PV System in Libya

The PV module power and the output power for a clear sky day in Benghazi (Libya) is shown in Figure 15. The simulation takes very small time because there no switching devices and the simulation does not involve solving the nonlinear time varying equation for the DC/DC converter in Matlab/Simulink. The solar radiation for the average months of the year is shown in Figure 16. Using the proposed model the output power of the PV system are shown in Figure 17.

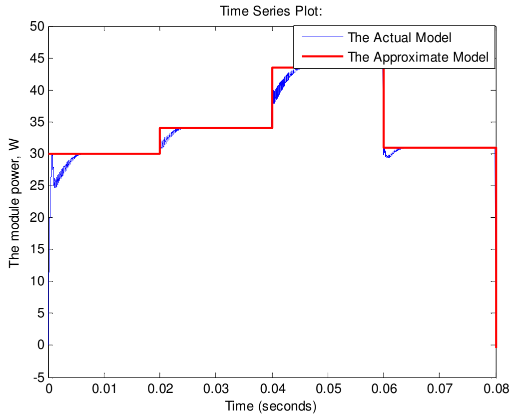

Fig. 14. The PV module power

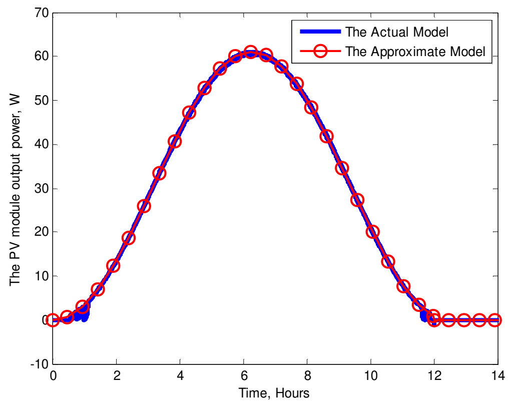

Fig. 15. The output power of the PV module in clear sky day in Benghazi

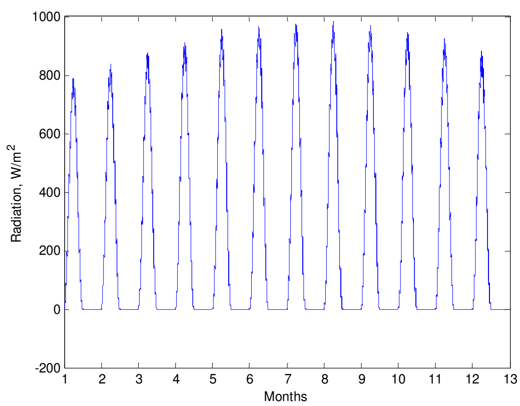

Fig. 16. The radiation of the average months through the year

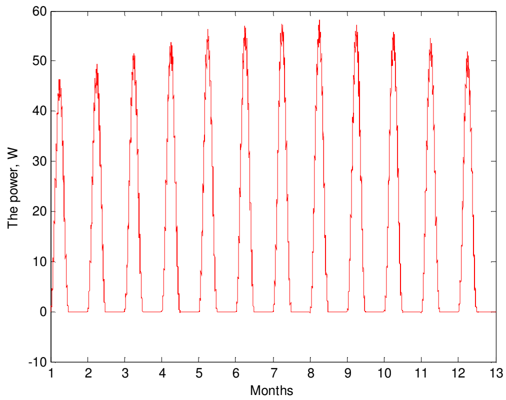

Fig. 17. The output power of the PV system

From Fig. 17 the 60 Wp module is expected to generate 112.15 kWh/year. A 1 kWp system (around 16 modules rated 60 Wp) is expected to generate 1,896 kWh/year. Libya relies on fossil fuel for electricity production. The energy density of the oil is around 10 kWh/l and the efficiency of the fossil fuel power plants is 40% in addition to 15% losses in the transmission and distribution. Due to the lack of the maintenance in the power plants and the transmission losses the losses in Libya will be higher. To generate 1,896 kWh/year we need to burn around 3.5 barrels of the precious oil and this will cost 450$ under the assumption that Brent oil prices remains at 100$. The cost of electricity production in Libya is 0.176$. To install the 1 kWp system the cost will be around 2100$ and if we assume a life time of 10 years the energy produced will be around 18,690 kWh which makes the cost of the kWh produced from the sun 0.111$. Then the energy saving is 0.065$ per kWh. If Libya starts a plan to reach 1 GWp from PV this will save around 132.24 million dollars for the ten years period. Additionally this will create social awareness and reduce the irrational use of electricity and CO_2 reduction.

In this analysis we assumed the following:

- The price of crude oil remains at 100$ and it is expected to rise and the cost of 1 kWp PV system is around 2100$ which is expected to decline.
- We also neglect the cost of installing new fossil fueled power plants in addition to the distribution and the transmission infrastructure cost.
- Additionally we did not consider the savings from CO_2 reduction.
- We do not take into consideration the impacts of reduction in Libya revenue resulting from relying on the oil and the gas for electricity production.

The aforementioned reasons triggers the alarms for an urgent need for Libya to accelerate its plans for adopting the renewable energy. One of the main issues faced by the electrical company is the irrational use of electricity. Installing PV system in Libya could help in creating awareness among people for the rational use of electricity. Furthermore initiating the PV technology in Libya will create new jobs which will improve the country economy.

However the PV system technology is being developed from the decades it is still does exist in Libya form electricity production. There are many obstacles facing this technology in Libya [12]. Among these obstacles is the unawareness among local people toward this technology and even among the responsible people in the authority it still viewed suspicious. To make PV convincing the government could start installing PV on roofs to support the grid in the peak time in the summer. The Libyan is connected to Egypt and Tunisia grid that can absorb the extra energy and even it can exported to Europe in the case the planned High Voltage DC link between Libya and Italy is achieved.

The simple direct coupled PV systems can be used in Libya for water pumps, ventilation fans, and circulation pumps designed for water heating the following reasons: the system is simple, cheap compared with system with storage, and does not require maintenance.

VI. Conclusion

In this paper a proposed PV model is used to estimate the energy output of PV system installed in Libya. The results show that with PV system energy saving could be achieved Libya. As Libya relies on the oil and gas for electricity generation, these will reduce the country revenue when the load demands increase in near future. Furthermore the adoption of the PV system in Libya could help in creating awareness between people for the rational use of electricity in addition to reducing the CO_2 emission.

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