Design and analysis of an isolated PV system for a house in Libya

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***Abstract*— In this research, the annual energy consumption of a private house in Libya is presented. Using the load data, the design of a photovoltaic system (PV) has been done using HOMER Pro. The designed system contains 26 PV panels of 330W each, 32, 12V, batteries and a 5.61kW inverter. The system analysis illustrates that such a system can meet all load requirements of a private house in Libya. MATLAB/Simulink has been used to simulate the dynamic model of the designed system. The simulation results show that the system can provide a stable voltage and frequency for the proposed load and its variations.**

Keywords—solar energy, photovoltaic, HOMER Pro.

I. INTRODUCTION

A. *Solar Energy in Libya*

Libya is a North Africa country that covers a total area of 1,750,000 Km². It relies heavily on oil and natural gas to produce electric power. These resources are nonrenewable and limited[1]. However, the electric energy demand increases as a result of growth in the industries and the population of Libya, which leads to more fuel consumption and more investments in energy grid from power stations, transmission lines, and substations. Also, environmental concern is one of the important issues these days. That makes progress made in the areas of renewable energy technologies that are opening the doors for an alternative source highly pertinent. Achieving this is relatively enhanced since most of the territories of Libya in the Sahara desert, which are great sources of solar radiation with a daily average direct normal irradiation ranging between 8.1 kWh/m2/day in the southern part and 7.1 kWh/m²/day in the western part with a sunshine duration hours more than 3500 for each year[2].

An analysis of the opportunities, challenges, and possibilities of renewable energy in Libya was presented[1]. The study concluded that this is an achievable objective. Given the challenges with conventional ways of power generation, the use of solar energy technology will play a pivotal role in meeting Libyan's future energy demands.

B. *Photovoltaic Energy (PV)*

In recent years, there were many research works in Libya to take advantage of the availability of solar energy to design photovoltaic (PV) systems to meet increasing the demand for energy and to provide energy for remote communities. [3] investigated the application of large scale (LS-PV) A 50MW PV-grid connected power. They carried it out by selecting a heterojunction with intrinsic thin layer (HIT) type PV module. A Microsoft Excel-VBA software for the modeling and analysis parameters of this module to determine the efficiency of this system. The results appear that the total energy output is 128.5 GWh/year, and the average module efficiency is 16.6%. Moreover, 85,581 tons of CO2 pollution would reduce each year.

An evaluation of photovoltaic technology brought out [5]. This review would be useful for people interested in this technique. The study included the capability of power generation, the various materials used to soak up light, its environmental part tied with a different application. The diverse present performance and dependability estimation modules, sizing and control, grid connection, and distribution have also been discussed. [6] conducted a comparative study on grid-connected HPS lamps and a solar-powered LED lighting system in Libya. There were illustrations and comparisons of various aspects of capital cost, maintenance, fuel, and CO2 production. The results have revealed that the use of the solar-powered LED is more suitable for street lighting due to the economic benefits and reduced loads from the electrical grid, which has difficulty in meeting the demand for energy, and it decreases the emission of carbon dioxide.

C. *Energy Consumption in Libya*

The General Electrical Company of Libya (GECOL) in 2013 stated that an electric power grid was unable to meet the growing consumption of energy. GECOL, in 2015, issued a report showing that the consumption of energy is 22.035 Gigawatts (GW) in all areas. 24% of the total amount was consumed by household loads. The problem is that cheap energy prices due to government subsidies lead to increased consumption of energy, which causes a shortage of power generation[7].

The GECOL report issued in 2010 shows that the annual demand for electricity energy increased by 9%. According to this ratio, the energy demand will be approximately 9.5 GW by 2020. This growth in energy demand is leading to the depletion of conventional energy sources and resulting in economic and environmental impacts [8].

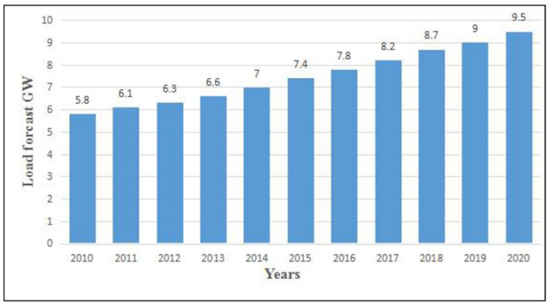


Fig.1: Libyan load growth 2010- 2020[8]

The literature reviewed shows that the photovoltaic (PV) systems are the most promising technologies that can be used as an alternative energy source to traditional energy sources. In general, the PV system is one of the most effective alternative energy sources in Libya due to the growth in the demand for energy and the large geographical area that requires big investments in transmission lines to provide remote areas. Furthermore, Libya has one of the highest daily average direct solar radiation, which reaches 7.17 kWh/m^2/day that could be used in the production of clean energy.

II. Sizing of a Photovoltaic System by HOMER Software

A. *Sizing the PV system*

In this study, a house in Libya has been considered for the load profile; the total area of the house is (7.5m*20 = 150 m²). According to the study made by The Cadmus Group, which was on three residential types in Libya: public houses, flats, and villa, as shown in table 1. Which found that the daily consumption (per m2) for public houses is 0.173kwh. Then Annual average energy consumption of a house (kWh /day), 25.95kwh/day[9].

Table 1:Residential Consumption and Demand (per m2)[9]

Sub-Sector	Consumption (kWh)	Demand (kW)		
	Daily	Average	Peak	Minimum
Flat	0.212	0.009	0.011	0.007
Public House	0.173	0.007	0.009	0.006
Villa	0.211	0.009	0.010	0.007

Upon entering data into HOMER Pro, the program will provide an optimal electrical solution. The parameters that we need to get results as follow:

- Determine the location of the proposed design, as shown in figure2 below.

Fig.2: Location of proposed the PV System in HOMER PRO

- The solar resources for the location of the proposed system, as shown in figure 3.

Fig.3: solar resource in HOMER PRO

- The house electrical load scale is 25.95kwh/day according to the calculation, as shown in figure4.

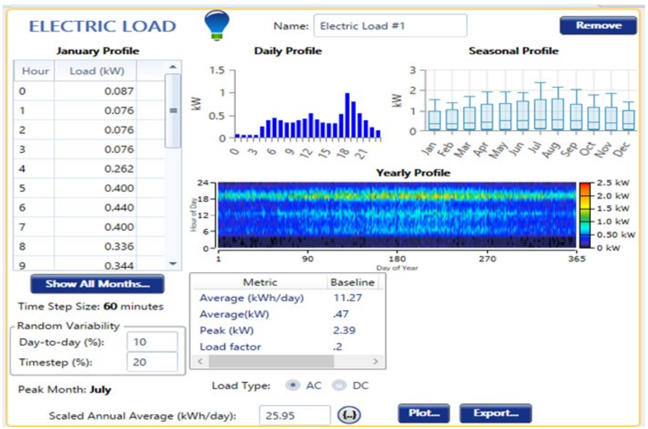


Fig 4: Hourly load profile for a typical day

- Looking at the peak load, Schneider Conext XW+ 6848 Inverter (peak is6kW, 48V) is selected. According to [10], the price is $3,975.

- As voltage is 48v in the bus of PV system panel is selected 72 cell modules type (CANADIAN SOLAR MAXPOWER2 CS6U-330P 330W POLY SOLAR PANEL). According to[11], the price is $ 170.30.

- Trojan SSIG 12 205 battery is selected, and according to [12], The price is $432.75.

The system design schematic with integrated subblocks shows in figure 5 below.

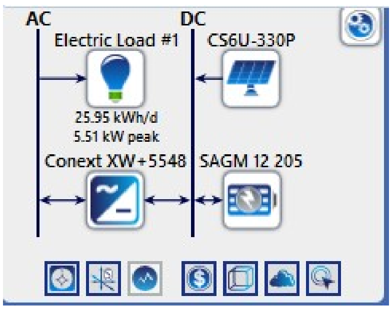
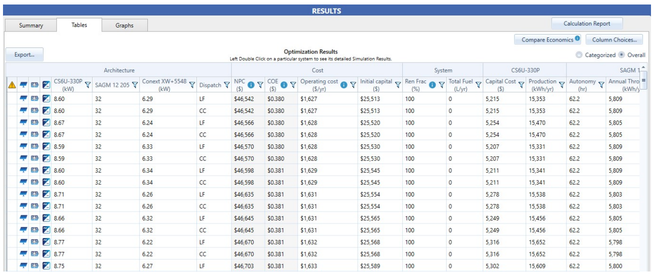


Fig.5: System schematic

B. *HOMER PRO optimization results*

By using HOMER Pro to optimized and determine the cost of the proposed system e findings are as shown in the following figure.



RESULTS

Summary | Tables | Graphs | Calculation Report | Compare Economics | Column Choices...

Export...

Optimization Results

Left Double Click on a particular system to see its detailed Simulation Results.

Categorized | Overall

Architecture				Cost				System		CS6U-330P		SAGM 1	
CS6U-330P (kW)	SAGM 12 205	Conext XW+5548 (kW)	Dispatch	NPC ($)	COE ($)	Operating cost ($/yr)	Initial capital ($)	Ren Frac (%)	Total Fuel (L/yr)	Capital Cost ($)	Production (kWh/yr)	Autonomy (hr)	Annual Thro (kWh/y
8.60	32	6.29	LF	$46,542	$0.380	$1,627	$25,513	100	0	5,215	15,353	62.2	5,809
8.60	32	6.29	CC	$46,542	$0.380	$1,627	$25,513	100	0	5,215	15,353	62.2	5,809
8.67	32	6.24	LF	$46,566	$0.380	$1,628	$25,520	100	0	5,254	15,470	62.2	5,805
8.67	32	6.24	CC	$46,566	$0.380	$1,628	$25,520	100	0	5,254	15,470	62.2	5,805
8.59	32	6.33	LF	$46,570	$0.380	$1,628	$25,530	100	0	5,207	15,331	62.2	5,809
8.59	32	6.33	CC	$46,570	$0.380	$1,628	$25,530	100	0	5,207	15,331	62.2	5,809
8.60	32	6.34	LF	$46,598	$0.381	$1,629	$25,545	100	0	5,211	15,341	62.2	5,809
8.60	32	6.34	CC	$46,598	$0.381	$1,629	$25,545	100	0	5,211	15,341	62.2	5,809
8.71	32	6.26	LF	$46,635	$0.381	$1,631	$25,554	100	0	5,278	15,538	62.2	5,803
8.71	32	6.26	CC	$46,635	$0.381	$1,631	$25,554	100	0	5,278	15,538	62.2	5,803
8.66	32	6.32	LF	$46,645	$0.381	$1,631	$25,565	100	0	5,249	15,456	62.2	5,805
8.66	32	6.32	CC	$46,645	$0.381	$1,631	$25,565	100	0	5,249	15,456	62.2	5,805
8.77	32	6.22	LF	$46,670	$0.381	$1,632	$25,568	100	0	5,316	15,652	62.2	5,798
8.77	32	6.22	CC	$46,670	$0.381	$1,632	$25,568	100	0	5,316	15,652	62.2	5,798
8.75	32	6.27	LF	$46,703	$0.381	$1,633	$25,589	100	0	5,302	15,609	62.2	5,800

Fig.6: HOMER sizing and optimization results.

Based on the Homer optimization result, the house needs 26 PV panels of 330 watts each, 32 batteries 12v, and converter 5.61kw. The battery backup to feed the house at night and the bad weather is almost two and a half days.

III. Dynamic Modeling and Control Design of a Solar System in MATLAB-Simulink

A. *The PV array Characteristics*

According to the sizing of the proposed solar system, the PV system consists of 26 CANADIAN SOLAR MAXPOWER2 CS6U-310P 330W POLY SOLAR PANEL photovoltaic modules. The PV curves for the PV array is shown in Fig.7. The model is simulated for various solar irradiations which are.

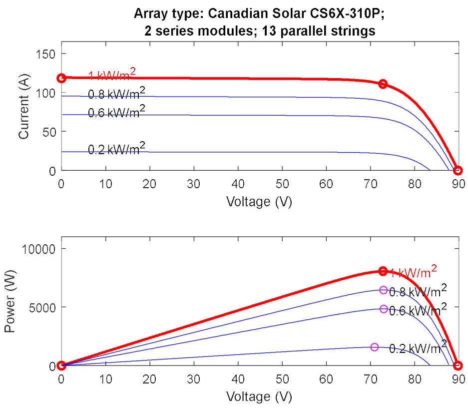


Fig.7: PV system characteristic curves in MATLAB/SIMULINK

B. *Boost converter and Maximum power point tracking for PV systems*

Control the algorithm is an important stage of an MPPT, which decides to raise or reduce the duty ratio that drives MOSFET to find a maximum power point. MPPT controller based on the Perturb & Observe algorithm is used in this system.

The PV module's output effects significantly by the temperature and solar radiations, so a DC-DC converter is connected between a PV module and the load in order the PV system is continuously operating at the maximum power point of solar radiations and temperature variations. The perturb and observe method is used for MPPT technique in this design by controlling the duty cycle of the boost converter. It is one of a widely used method, while voltage and current are applied to the function that controls the duty cycle value according to the equation given here:

$$D = \frac{1-V_i}{V_o} \tag{1}$$

The output voltage is almost constant; the differences in the duty cycle steadiness the variations in the input voltage. As this maintains the current. The algorithm detects the point at that maximum power point can be tracked, hence:

$$P_{max} = V_{max} \times I_{max} \tag{2}$$

The idea of this method is selecting a reference voltage and keep changing the output PV voltage to decrease the power variation. (MPPT) Is utilizing the available maximum power output of the PV. The algorithm is implemented according to the flow, as shown in figure8.

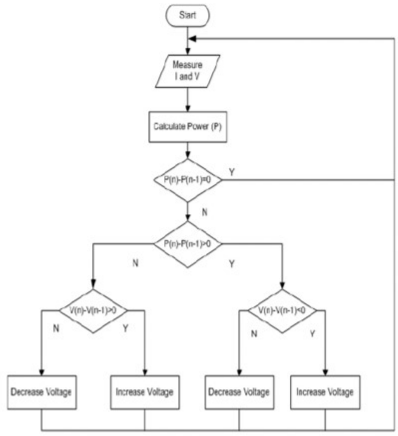


Fig. 8: Perturb and observe Algorithm [14]

The main parameters in the boost converter are MPPT, PWM, Inductor, and capacitor. The equations (3) and (4) for the boost converter is used to determine the input and output capacitors' values as follows[13][14]:

$$C_{in} \geq \frac{I_{max} \times D_{max}}{0.2 \times (1-D_{max}) \times V_{in} \times F_{sw}} \tag{3}$$

$$C_{out} \geq \frac{I_{max} \times D_{max}}{\Delta V \times F_{sw}} \tag{4}$$

Where, D max = maximum duty cycle, F sw = switching frequency, ΔV = voltage ripple.

To increase the inductor and the current, the frequency switch is performed in the model. The capacitor stores and raises the DC voltage through an electric field effect. The Pulse Width Modulation (PWM) drive is executed in the model to stabilize the converter output voltage. A capacitor is added to the system to store and smooth the voltage signal.

C. Inverter

This inverter contents of four IGBT's switches (S1, S2, S3, and S4). AC sine output voltage is generated when S1 and S4 operate under switching impulses. The transformer connection point voltage will have a positive voltage value. However, S2 and S4 operate at the same time at the connection point of the transformer, and it will have a negative polarity. The transformer is used in the model to increase the AC voltage from 48 V to 220 V, which is the normal voltage for the load. A diagram of the inverter is shown below in Figure 9[13][14].

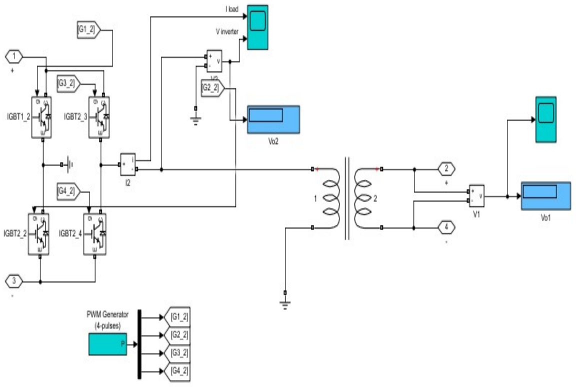


Fig.9: a diagram of the inverter in MATLAB/SIMULINK

In Figuer.10 shows the sinusoid of the voltage load.

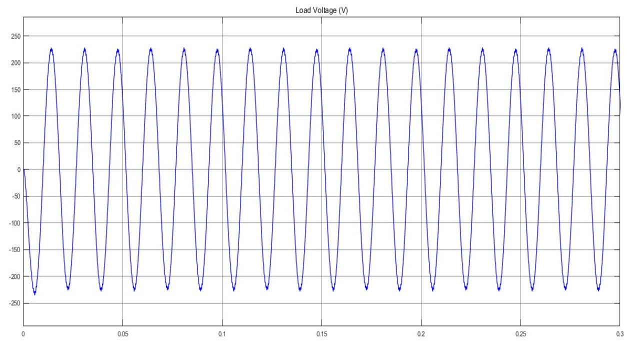


Fig.10: simulation of the load voltage in MATLAB/SIMULINK

D. The PV system protection

One of the main elements in PV system protection is a diode, which is used as a blocking diode to stop battery discharge during nighttime and bypass diode to provide Path for current when that module is shaded [15].

We also use a Fuse link in PV system protection. The system may be contents of several PV sub-arrays (each subarray consists of multiple strings) linked in parallel to achieve the desired capacity of the Photovoltaic (PV) system the fuse link is used to protect modules and conductors from overcurrent faults and help to reduce any safety risks. Also, ensure the continuation of the PV system to generate electricity by isolating the faulted string. And the circuit breaker is also used in the main panel of the load for protection [16]. the following figure shows the proposed protection of the system

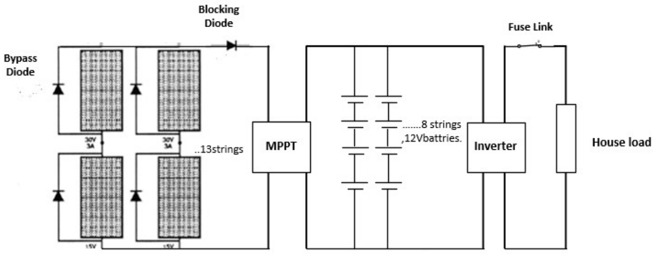


Fig.11: Protection for PV system

IV. Conclusion and Discussion

The model of the PV array, residential load, Boost Converter, MPPT controller, battery storage, and inverter is presented in this model. The performance of the system is assessed under various solar irradiance. The results show that when the output power of PV array is increased proportionally to the increase in the solar irradiance and the output voltage of the system is almost stable even though of the variation of the solar irradiance. The estimated cost by using the HOMER of this system is less than or similar by comparing it with the amount of money with the bills for 25 years. The PV system is cheaper and meets the demand of my house consumption during the year (kWh).

Moreover, (PV) systems are the most promising technologies that can be used as an alternative energy source to conventional energy sources. In general, the PV system is one of the most effective alternative energy sources in Libya due to long hours of load shedding, especially in summer, although Libya has one of the highest daily average direct solar radiation. Furthermore, that could be used in the production of clean energy and reduced the rate of carbon dioxide emission.

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