World Academy of Science, Engineering and Technology
International Journal of Electrical and Computer Engineering
Vol:8, No:6, 2014

Optimal Design and Simulation of a Grid-Connected Photovoltaic (PV) Power System for an Electrical Department in University of Tripoli-Libya

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Abstract—This paper presents the optimal design and simulation of a grid-connected Photovoltaic (PV) system to supply electric power to meet the energy demand by Electrical Department in University of Tripoli Libya. Solar radiation is the key factor determining electricity produced by photovoltaic (PV) systems. This paper is designed to develop a novel method to calculate the solar photovoltaic generation capacity on the basis of Mean Global Solar Radiation data available for Tripoli Libya and finally develop a system design of possible plant capacity for the available roof area. MatLab/Simulink Programming tools and monthly average solar radiation data are used for this design and simulation. The specifications of equipments are provided based on the availability of the components in the market. Simulation results and analyses are presented to validate the proposed system configuration.

Keywords—Photovoltaic (PV), solar energy, solar irradiation, Simulink.

I. Introduction

RENEWABLE energy sources offer great potential for reducing the green house gases emission and other environmental impacts of electricity production. Each kilowatt-hour (kWh) generated from renewable resources saves the environment from the burning of fossil fuels. The coal fired and the natural gas fired power plants produce 1.05Kg and 0.75Kg carbon respectively [1]. The sun is a glint ball of gas that sends out huge amount of rays every day. However only less than 50% of solar radiation reaches the earth, where 20% is absorbed by atmospheric gases and 30% is reflected back to the space [2].

The sun radiates its energy at the rate of about $3.838 \times 10^{23}\ kW/sec$ [3]. Most of this energy is transmitted radially as electromagnetic radiation, which comes to about; $1.4kW/m^2$ at the boundary of the atmosphere. After traversing the atmosphere, a square meter of the earth's surface can receive as much as 1 kW of solar power, averaging to about 0.5 over all hours of daylight.

There is significant potential for the use of the photovoltaic solar energy in countries like Libya which receive abundant amounts of solar radiation around the year. Libya is an oil producing country located in the middle of North Africa, with 6 million inhabitants distributed over an area of 1,750,000 Km^2, and with sun duration of more than 3500 hours per year [4].

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Grid-connected PV systems have many technical advantages such as flexibility, simplicity to install in any area where the solar irradiation is available, as non-polluting, emitting no noise and requiring little maintenance [5], [6]. Therefore, many countries are encouraging customers to install PV systems in order to generate their own power, to reduce electricity bills and to increase the contribution of renewable energy to limit carbon dioxide (CO_2) emissions.

Generally the PV system comprises of PV generator which is a set of series-parallel electrically interconnected solar panels. PV panels are delivered by the manufacturers and are given in terms of the nominal peak power of the panel at standard test conditions (STC). PV generator gives the total installed power. It is the sum of nominal peak power of each solar panel present in the PV installation [7].

A grid-connected system comprises of the modules and an inverter. The inverter converts the direct current (DC) electricity generated by the PV array into alternating current (AC) electricity that is synchronized with the mains electricity. Excess electricity generated at any time is fed into the grid. The grid-connected inverter must be designed for the peak power and must obey conditions that deal with issues like power quality, detection of islanding operation, grounding; MPPT and long-life [8].

Inverter maximum power is exactly referred to the total installed power of the PV generator and has to optimize the energy injected to grid. Since the expected irradiance in the physical location of the PV installation is lower than the nominal or standard one, a current practice is to select the inverter maximum power than the nominal peak power of the PV generator. This practice is known as under sizing of the inverter and has been discussed [7], [8].

The nominal power of the PV generator corresponds to standard irradiance conditions. However this irradiance is unusual. Under low irradiance, a PV array generates power at only a part of its nominal capacity and the inverter thus operates under part load conditions with lower system efficiency [7].

This paper presents design and analysis for a grid-connected photovoltaic system for a case study Department of Electrical Engineering in University of Tripoli. Possible plant capacity of 162 kW PV strings is analyzed by using MatLab/Simulink programming. The effect of the temperature and irradiance are are also analyzed by using Simulink/ programming.

II. Design Methodology

The methodology for this study includes the preparation of the inputs and calculations required for the simulation process. Determination the possibility of solar photovoltaic generation potential, based on the annual solar radiation is taken over Tripoli Libya. Also for calculating the output efficiency of the PV module is taken as 17%. In addition it is in the design that the solar energy assumed to be available for 6 hours during the normal day. Finally a grid connected PV system is designed with the available technology for the calculated plant capacity on the available area.

III. Site Characteristics

Libya is located in the middle of North Africa and its capital Tripoli is located at 32° 54' North latitude and 13° 11' East longitude. The area of Libya is characterized by a vast plain area i.e an ideal location for solar energy utilization. Libya is exposed to the sun's rays throughout the year with long hours during the days [9]. It has an average daily solar radiation rate of about 7.1 kilowatt hours per square meter per day (kWh/m²/day) on a flat plane on the coast and 8.1kWh/m²/day in the south region [4].

IV. Load Profile

The load profile is essential for the designing process because the variation of the load during the day and night would affect the number of PV panels, and hence the inverter size. The load profile for EE Dep, seen in Table III, was based on the fact that EE Dep as to provide services for more than 1000 student, 60 staff members and 30 employees and technicians.

The department electricity consumption consists of various electronic devices, lighting and air conditions. There are different loads for different seasons and power consumption does vary according to the daily activities. The total load demand of the department is about 270 kW as shown in Table I. The roof area of the Electrical Engineering Department building is about 1500-m^2.

TABLE I
TYPICAL ELECTRICAL APPLIANCES USED IN THE ELECTRICAL ENGINEERING DEPARTMENT

Floor	Lights 40W	Air-conditions W			Other loads
Ground floor	351	2500	3750	5000	-
Second floor	427	2	6	-	-
Third floor	531	2	-	7	-
Fourth floor	341	15	-	-	-
Sum	1650	13	-	-	-
Total load power(W)	66000	137500			66500
Total load power (W)					**270000**
Total roof area of electrical department					**1500 m^2**

V. Energy Calculation

Using the value for average annual solar insulation, on Tripoli, the available roof area for the possible plant capacity is estimated by considering the PV module efficiency as 17%. By assuming that the solar energy is available for about 6 hours during the normal day, the average solar insulation in Tripoli [10]:

$$= 5.48\text{kWh/m2/day} = \frac{913W}{m2}/day$$

After estimating the potential, the design of grid as connected to solar PV power plant is made.

The energy generated from photovoltaic solar system installed in the roof of the building is estimated as shown in Table II.

TABLE II
ENERGY GENERATED FROM AVAILABLE ROOF-TOP AREA ON THE EE DEPARTMENT BUILDING

Available area (m^2)	Effective area (m^2)	Average peak output (W/m^2)	Possible plant capacity (kW)	Energy generated /d(kWh)	Energy generated /month (kWh)
1500	$1500 \times 0{,}70 = 1050$	913	162	972	29160

VI. Sizing of the PV-Grid Connected System

Generally, PV-Grid-connected systems are designed to supply electrical power from 10 to 70% of the power demand with the difference being supplied by utility power. In this paper the ratio of about 60% of the needed energy is covered by the PVs. So, the total power of the PV system is 150kW.

A. Sizing Pv Panel

Photovoltaic (PV) modules are sized using wattage determined under Standard Test Conditions (STC). This is the manufacturer's specified nameplate wattage and represents module output as measured under very controlled factory conditions. Specifically, STC are 1,000 W/m2 solar irradiance and 25oC module temperature. STC wattage provides a good relative comparison between module and system sizes, but not a good real world output measure.

The design criteria for PV module are based on the manufacturer's data [11]. Specifications for used solar panels are listed in the Table III.

TABLE III
SPECIFICATIONS FOR SOLAR PANELS [11]

Rated Power (P_{max})	W	200
Maximum Power Voltage (V_{pm})	V	55.8
Maximum Power Current (I_{pm})	A	3.59
Open Circuit Voltage (V_{oc})	V	68.7
Short Circuit Current (I_{sc})	A	3.83
Minimum Power (P_{min})	W	180.0
Max System Voltage (V_{sys})	V	600
Series Fuse Rating	A	15
Temperature Coefficient (P_{max})	$\%/^0C$	-0.29
Temperature Coefficient (V_{oc})	$V/^0C$	-0.172
Temperature Coefficient (I_{sc})	$mA/^0C$	0.88
Electrical Tolerance	%	+/-10
PTC Rating	W	188.7
Cell Efficiency	%	19.7
Module Efficiency	%	17.0
Module Area (m^2)	1.18m^2	

From the results obtained it is found that a 162 kWp solar photovoltaic power plant can be developed on $1050m^2$ area.

The required numbers of PV modules are obtained as follows:

$$No._{PV}\ modules = \frac{P_{PV}}{P_{mpp}}$$

$$No._{PV} = \frac{162000}{200} = 810 \text{ PV modules}$$

Using the effective area and the module area

$$No._{PV}\ modules = \frac{effective\ area}{module\ area}$$

$$No._{PV} = \frac{1050}{1.18} = 889 \text{ PV modules}$$

Now to form a solar photovoltaic power plant 810 modules are connected in series-parallel combination.9 in series and 90 parallel.

B. Inverter Sizing

An inverter is used in the system to meet the need for AC power output. For grid connected systems, the inverter must be large enough to handle the total amount of Watts is needed at one time.

The inverter is chosen based on the selected PV modules. For 162 kW rated output PV, the inverter is rated at 172 kW to fully supply the power from PV. Therefore, the supplied power would be less than the rated power. Inverters currently available are typically rated for:

- Maximum DC input power. i.e. the size of the array in peak watts;
- Maximum DC input current; and
- Maximum specified output power. i.e. the AC power they can provide to the grid;

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VII. System Sizing Specifications

The designed system sizing and specifications are provided for 162kW power plant and shown in Table IV.

TABLE IV
PV POWER PLANT SPECIFICATIONS

Solar photovoltaic power plant specifications	
plant capacity	162 kW
voltage output	502V
Current output	323A
No of modules	810
Effective area	1050 m^2
Solar panel specifications	
type	polycrystalline
Rated power	200W
Voltage	55.8V
Current	3.59A
Efficiency	17%
Temperature	25deg c
Dimension (mm)	Area of single panel 1.18 m^2
Inverter specifications	
Type (SUNFOREST)	Model 150KT
Max. DC Input Power	172KW
Max DC Voltage	1000Vdc
Max. Input Current	380A
Nominal Output Power	150KW
Max. Output Power	165KW
Nominal Output Current	216A
Max. Output Current	238A
Nominal AC Output Voltage	400Vac
AC Output Voltage Range	360~440Vac
Power Factor (cosφ)	0.9 (lead)~0.99 (lag)
Max.efficiency	>97.4%
Operating Temperature	-25°C~+50°C
Operating Consumption	<100 W
THDI	<3% (at nominal output power)
grid specifications	
Number of phases	3-phases
Voltage rating	380 volts
Frequency	50 Hz

VIII. Simulink Output of Designed Grid-Connected PV Panel

A general block diagram of the PV model using Simulink is given in Fig. 1. The block in Fig. 1 contains the sub models connected to build the final model. Variable temperature (T), and variable solar irradiation level (G) are the inputs to the PV model. The equation of the PV output current I is expressed as a function of the array voltage V as given by (1).

$$I = I_{ph} - I_D = I_{ph} - I_{sat}\left[e^{\frac{q(V+IR_S)}{nkT}} - 1\right] \quad (1)$$

where: I_{ph} the light current [A], I_{sat} the diode reverse saturation current [A], R_s, the series resistance [Ω], V the operation voltage [V], and I the operation current [A]. q = charge of one electron$(1.602 \times 10^{-19} C)$, $n =$ Diode idealising factor, and $k =$ Boltzman's constant $(1.38 \times 10^{-23} J/K)$. T=Junction temperature in Kelvin.

The modeling of the PV array for Matlab/Simulink environment is discussed in [12], [13].

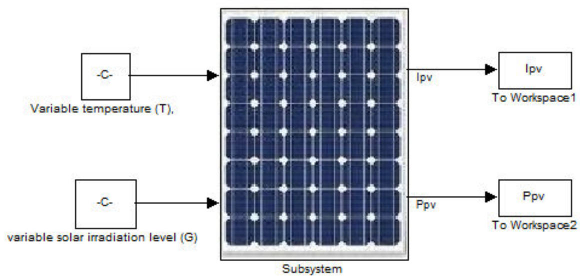

Fig. 1 Simulink model of PV module

The final model consists of 9 modules connected in series and 90 module connected in parallel with manufacturer's specified nameplate as shown in Table IV. It takes irradiation, operating temperature in Celsius and module voltage as input and gives the output current Ipv and output voltage Ppv. With the developed model, the PV module characteristic is displayed as follows:

The I-V output characteristics of PV module with varying irradiation at constant temperature are shown in Fig. 2. The P-V output characteristics of PV module with varying irradiation at constant temperature are shown in Fig. 3. When the irradiation increases, the current output increases the voltage output also increases. This results in net increase in power output with increase in irradiation at constant temperature.

The I-V output characteristics of PV module with varying temperature at constant irradiation of 1000W/m^2 are shown in Fig. 4. The P-V output characteristics of PV module with varying temperature at constant irradiation are shown in Fig. 5. When the operating temperature increases, the current output increases marginally but the voltage output decreases drastically results in net reduction in power output with rise in temperature. The results are verified and found matching with the manufacturer's data sheet output curves.

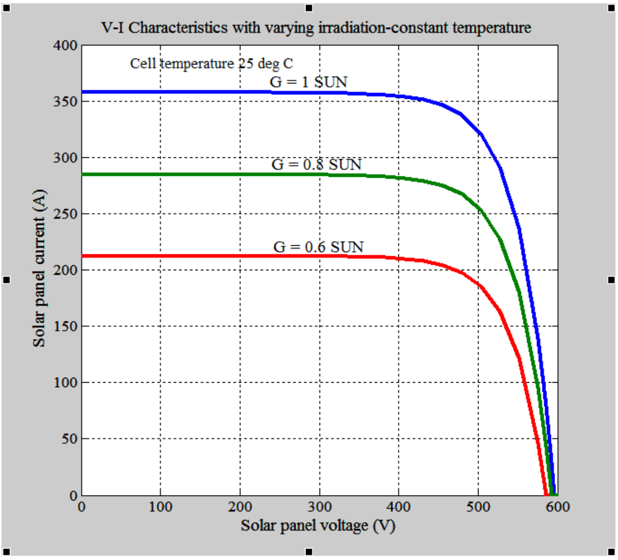

Fig. 2 Simulink model of Solar panel (810 strings) I-V Characteristic curves at different insolation levels (HIP-180BA3, G= 0.6 Sun, 0.8 sun, 1 sun)

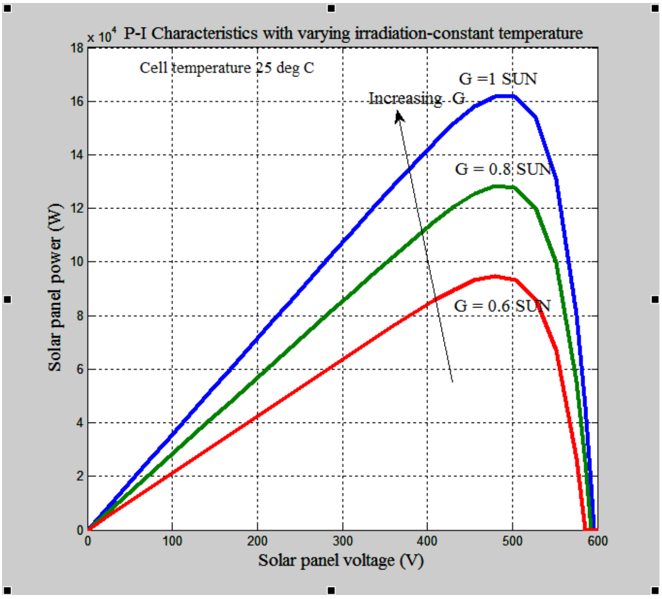

Fig. 3 Simulink model of Solar panel (810 strings) P-V Characteristic curves at different Insolation levels (HIP-180BA3, G=0.6 Sun, 0.8 sun, 1 sun)

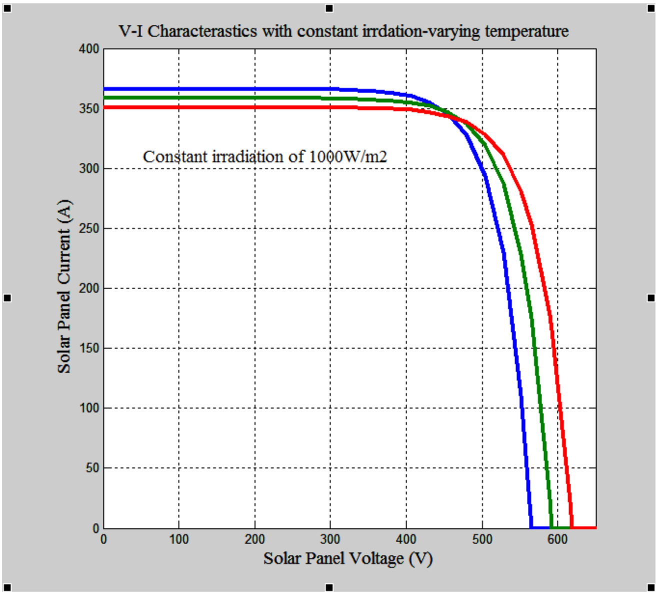

Fig. 4 Simulink model of solar panel (810 strings) I-V Characteristic curves at different cells working temperature (HIP-180BA3, Tc =25^{o}C, 50^{o}C, 75^{o}C

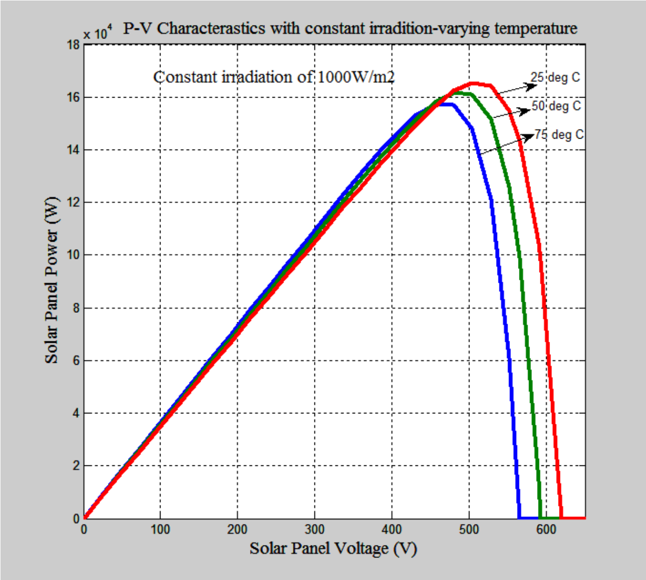

Fig. 5 Simulink model of solar panel (810 strings) P-V Characteristic curves at different cells working temperature (HIP-180BA3, Tc = 25°C, 50°C, 75°C

IX. CONCLUSIONS

Libya is very rich in the solar resources and has a great potential for PV powered projects. In this paper proposes PV-grid connected system as designed and simulated to supply a large part of the electrical load for EED building as case study in Libya. The designed solar panel (810 modes) is modeled using MATLAB/SIMULINK. The P-V characteristic curves at different insulation levels and at different cells working temperature are shown in Figs. 4 to 5. Finally the designed PV system modules are sized and simulated using Simulink, the resulting system as developed is composed of 162kW of PV and 172 kW inverter.

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