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Design and Evaluation of Solar PV On-Grid Connected Power Plant Using PVsyst Software in Bani Walid Hospital / Libya

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Abstract:
In recent years, the production of electricity from renewable energy sources (RES) has increased due to the multiple benefits of RES: non-polluting, free of raw materials, ecologically benign, and cost-effective. In order to enhance output and efficiency, kinds of RES are associated with geographical places where they are abundant. This paper presents the design and simulation of a solar PV grid-connected electricity generation system in Bani Walid hospital. It also represents the technical and annual performance of the solar PV system. The design is validated and simulated by using PVsyst software in order to determine the optimum size, the specifications of the PV grid-connected system, and the electrical power generation. The amount of electricity that a solar PV plant generates is 7 MW. This amount could be used to reduce the load of Bani Walid city and help to minimize the annual electricity bill of Bani Walid hospital. This work can serve as a successful example of clean energy producers and a business model that encourages individuals and government utilities to utilize solar photovoltaic (PV) technology for electricity demand fulfilment and lucrative investment.

Keywords: Renewable energy, Solar Photovoltaic, PVsyst software, Bani Walid city, Libya

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1. Introduction

Energy is considered the main catalyst required in the economic and social development of every country, and as such, the lack of this beneficial commodity may severely hamper its successful development .
They are different forms and sources of energy, but electrical energy is the most important form of energy required as a root catalyst for the rapid social and economic development of a nation .
Some of the methods (but not limited to) to generate electrical energy are by use of generators, electrochemistry, and photoelectric effects.
Since a country like Libya is characterized by a sunny climate and nature, especially the city of Bani Walid which is located in the northwest of Libya, it is located about 180 km in the southeast of the Libyan capital, Tripoli. It is located on latitude and longitude (31.79_14.05) with a height of 280 meters above sea level a total area of 21517 km^2 and a population of (85425) people in 2021.

The geology consists mostly of medium-altitude mountains and flat lands, respectively There are also many open lands and vast areas in the city Where the city has many vital and administrative centers that provide services necessary for the needs of the population and like any city has a hospital located in the center of the city with a total area of 50,000 m^2 distributed over all Units inside and outside the hospital, each according to their needs of electrical energy.
The government health center that supervises the treatment and accommodation of patients within the city is distinguished by its strategic location and the spaces occupied by this health the facility in the city .
Thus, this facility needs electricity on a permanent and regular basis without interruption to continue providing its services to the residents and the executing company has connected this facility to the public network since its inception, the source of electric power that feeds this facility has become the state's public electricity with a consumption capacity of 6.15 MW.
The hospital being a vital facility in Bani Walid faces the challenge of providing an organized reliable and well distributed electric power grid not the state of the infrastructure Electricity is the best because there is a lot that needs to be done urgently to improve the generation transmission and distribution of electric power for this vital facility and as it is known frequent and long term power outages constitute an obstacle to providing health services to the population of this facility.
The Renewable Energy Agency announced Vision 2021 at the initiative of the Libyan Prime Minister through a plan to support, encourage and stimulate renewable energy projects, which clearly defines the objectives of the Renewable Energy Agency.
Therefore, there were many government policies and programs to Support and expand the source of electric power generation in 2021 and to obtain support source for the General Electricity Company to provide the hospital's need for electric power, a plan that the government hopes to complete by 2023.
Within the framework of the government's efforts to provide treatment and accommodation for residents' patients the city, as rate of expansion and maintenance witnessed a rapid increase over the past five years, and the capacity of the hospital daily to consumption of electrical energy increased from (4.11) MW to (6.15) MW.

Figure 1: Bani Walid Hospital, Libya

1.1. System design and objectives

Solar energy is used to produce electricity through photovoltaic cells systems. Energy from the sun comes in two forms, heat and light, Solar Thermal Technologies. The thermal aspect of the sun's energy is used to produce energy while solar photovoltaic technologies use light (photons) from the sun produce energy.

The demand for energy consumption after estimating the load is (6.15) megawatt. From a geometrical point of view. It is not right to produce the exact amount of energy required by the consumer and thus. We will design a photovoltaic power plant (7) megawatt; the excess energy produced will be injected into the grid.
Energy consumption will increase when energy is constantly available and affordable.
Increasing the equipment and equipment in the hospital will also lead to an increase in energy consumption and therefore the need to design a plant with a capacity of (7) megawatt.
The design of photovoltaic stations requires thousands of photovoltaic panels, and each panel produces hundreds of watts. During the PV plant design procedures, the designer needs to select and calculate the appropriate number, size and type of PV modules and converters.
Moreover, the components required to install the photovoltaic plants in order to increase the production capacity as well as improve the lifelong maintenance of the plant.
The design of photovoltaic stations with a capacity of (7) megawatt requires calculating the electrical consumption and calculating the capacity of the system and its components. Therefore, the designer will need to know more about site selection, solar energy data, components and specifications, solar PV efficiency and design optimization and efficiency analysis.

1.2. Site selection and solar data of Solar Power Plant

The hospital is located within the city of Bani Walid in the entire center area and occupies a total area of about (50,000) square meters. The city of Bani Walid is one of the areas that has enough solar radiation to support it Construction of photovoltaic power plants.
Data source from the National Center of Meteorology in Libya and Space Administration (NASA) website using geographic coordinates; longitude (14.02) And the latitude (31.75), it shows the average monthly radioactivity Horizontal radiation (6) PSH and 8 kWh/m^2 /day.

Figure 2: Bani Walid Hospital location

The day and peak hours of the sun are about 10 hours a day. The warmest annual average temperature in the city of Bani Walid is 36°C along the longitude and latitude. Figure 3 shows sunrise and Sunset in Bani Walid.

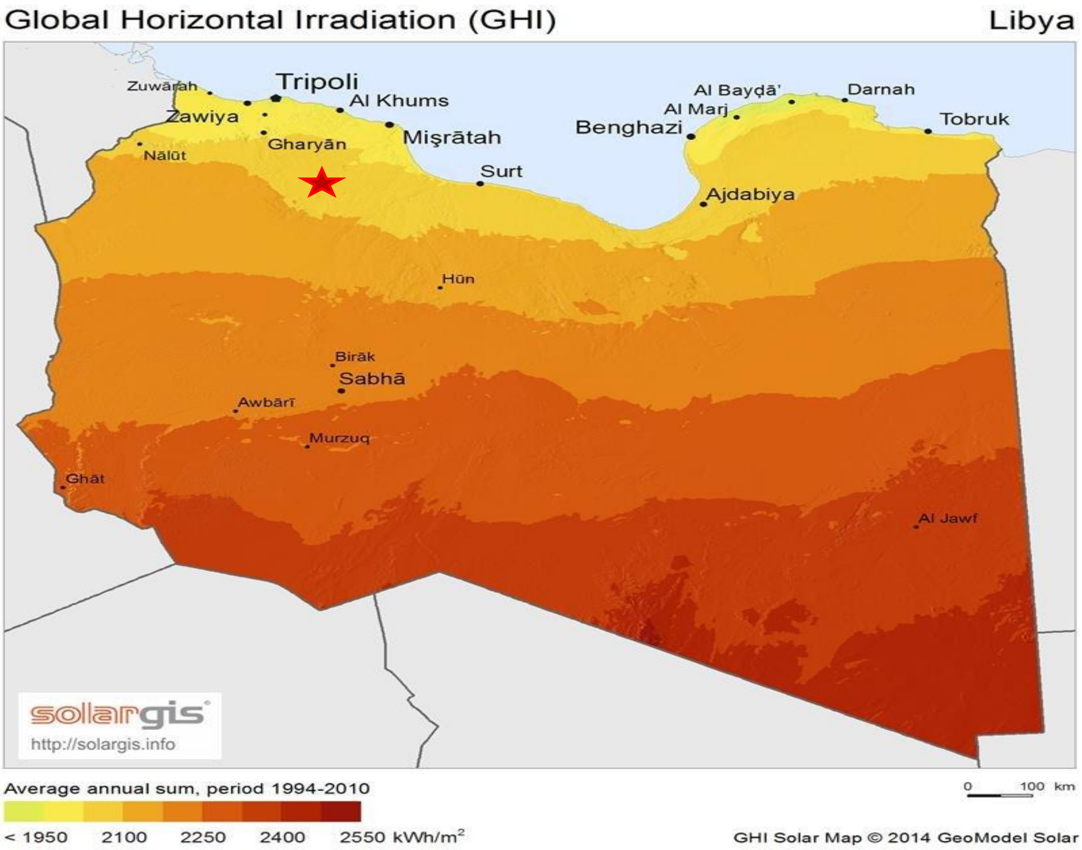

Figure 3: A Solar Irradiation Map of Bani Walid (kWh/m^2/year)

Table 1: weather and solar radiation for the year 2021

Month	Withdrawal amount Oktas 0 - 8	Avg. temperature C^O	Avg. Humidity %	Avg. Wind speed m/s	Avg. sun radiation hr/day
January	1.9	19.2	66	4.78	6.6
February	1.6	19.4	58	5.09	9.3
March	1.9	23.4	57	5.50	8.2
Apr.	1.3	27.1	53	5.04	9.9
May	1.1	29.9	54	4.88	11.0
June	1.0	36.3	49	4.26	10.9
July	0.2	37.6	47	4.01	11.8
August	0.8	36.8	53	3.44	11.3
Sept.	1.8	34.6	59	4.73	8.9
October	1.7	28.5	61	3.70	9.5
November	0.9	23.9	70	2.98	8.2
Dec	1.2	22.3	64	4.01	7.3

2. Selecting and sizing of solar PV and inverter

After studying the technical and engineering calculations of the system, the panels and reflectors must be selected in an accurate technical manner, according to the capacity and efficiency of the equipment.

Jinko solar JKM 310P-72 (310W) polycrystalline silicon solar panel is proposed for the construction of 7 MW PV power plant and also used for simulation in PVsyst software.

The datasheet specifications of JKM 310P-72 are: STC and PTC power ratings of 310W and 300W respectively, Open circuit voltage Voc is 45.90V, short circuit current Isc is 8.96A , maximum point current and voltage (Imp, Vmp) are 8.38A and 37.0V respectively ، Nominal operating cell temperature is 45C, made of 72 cells, area is 1956mm (length) x 992mm (width), weight is 26.5kg and efficiency is 15.98% with 5 years guaranty and 90% and 80% efficiency guaranty for 10 and 20 years respectively .
The following steps will help us to accurately design the required PV power plant of 7MW capacity.

$$\text{Pdc (STC)} = \text{Pac} * \frac{1}{conversation\ efficiency} = 7 * 1.3 \qquad [1]$$
$$= 9.1\ \text{MWh}$$

Conversion efficiency: 75% estimate the impacts of temperature, inverter efficiency, module mismatch, and dirt to come up with conversion efficiency from dc to ac.
Pdc (STC): is the dc power of the array obtained by simply adding the individual module ratings under standard test conditions.
Pac: AC power.

$$\text{Capacity of PV panel total WP} = \frac{pMwh}{(\frac{h}{day} of\ \text{peak sun})} \qquad [2]$$

$$\text{Capacity of PV panel total WP} = \frac{9.1\ Mwh}{6\ h/day} = 1.5\ \text{MWP}$$

$$\text{Number of PV panels needed} = \frac{total\ watt\ peak\ rating}{pv\ module\ output} \qquad [3]$$

$$\text{Number of PV panels needed} = \frac{9.1\ Mw}{310\ w}$$

Number of PV panels needed = 29354.8 modules

Energy (kWh/year) = Pac (kW) * (h/day of “peak sun”) * 365 days [4]
Energy (kWh/year) = 9.1MW *6 (PSh/day) * 365days
= 19929 MW/year

ABB Tripower pvs800-57-1000kw-c inverter is what we selected for our design.
ABB Tripower pvs800-57-1000kw-c inverter is manufactured by ABB is a Swiss-Swedish multinational group of companies headquartered in Zurich, Switzerland is a technology leader that is energizing the transformation of society and industry for a more productive and sustainable future.
ABB Tripower pvs800-57-1000kw-c has the following technical information for the dc input side: maximum dc power is 5000W, maximum input voltage 850V, maximum power point voltage range is 1100v, rated input voltage 750V; minimum input voltage 600V.
Technical specifications and sizing Nominal operating temperature is 50C, height 2130mm, width 3630mm, weight is 2600kg, Depth 708mm and efficiency is 97.80% with 5 years guaranty.
European efficiency and maximum efficiency are 97.80% and 98.42% respectively, rated power is 1000kW at 850V 50Hz frequency, nominal AC voltage at different variations: 400 nominal AC Current 1445A.
The selected inverter must be large enough to handle the total amount of watts peak
Requirement, the inverter size should be 25%–30% bigger than total watts requirement.

$$\text{Inverter size} = \text{Pac} * \frac{1}{conversation\ efficiency} \qquad [5]$$
Inverter size = 7* 1.3
Inverter size = 9.1Mw

$$\text{Number of inverter} = \frac{inverter\ size}{rated\ power\ of\ inverter} \qquad [6]$$

$$\text{Number of inverter} = \frac{9.1Mw}{1000kw} = 9.1\ inverter \qquad \approx 10\ inverter$$

$$\text{Number of modules in series} = \frac{maximum\ open\ circuit\ voltage\ of\ inverter}{open\ circuit\ voltage\ of\ each\ PV\ module} \qquad [7]$$

$$\text{Number of modules in series} = \frac{850V}{45.9V} = 18.5 \qquad \approx 19\ modles$$

Total No. of Arrays in the solar field = $\frac{total\ No.of\ modules}{number\ of\ module\ in\ array}$ [8]

Total No. of Arrays in the solar field = $\frac{30000}{20}$ = 1500 Arrays

Table 2: Array design

Planned power	7MW
Power of module	310wp
Total No. of string	1500
No. of modules in series/string	20
Total No.of modules	30000
No.of subarrays	150
No. of string/subarray	10
No.of inverter	10
Total DC power	8939kwp

PV Array Characteristics					
PV module	Si-poly	Model	**JKM 310P-72**		
Original PVsyst database		Manufacturer	Jinkosolar		
Number of PV modules		In series	20 modules	In parallel	1500 strings
Total number of PV modules		Nb. modules	30000	Unit Nom. Power	310 Wp
Array global power		Nominal (STC)	**9300 kWp**	At operating cond.	8297 kWp (50°C)
Array operating characteristics (50°C)		U mpp	655 V	I mpp	12669 A
Total area		Module area	**58211 m²**	Cell area	52566 m²
Inverter		Model	**PVS800-57-1000kW-C**		
Original PVsyst database		Manufacturer	ABB		
Characteristics		Operating Voltage	600-850 V	Unit Nom. Power	1000 kWac
Inverter pack		Nb. of inverters	9 units	Total Power	9000 kWac

Figure 4: The PV array and inverter characteristics

2. 1. The efficiency of Solar PV

This system requires an in-depth study of all factors affecting the efficiency of solar PV. Typically, the maximum solar PV efficiency is about 25%.

Studying the factors that affect the solar PV system is important because it helps efficiency improvement, as mentioned below:

*** PV module direction:** changing the direction in PV alone is not according to azimuth; it will reduce the current and lead to reduce the power.

The solar panels should be facing south. According to the Bani Walid hospital site, the north side of the land. There are two ways to find the azimuth angle .

The first is to use the solar tracker, which is conducive to the transmission of photovoltaic energy to the maximum radiation.

The second manually, using a compass, pointing south at an angle of (33^0) degrees.

*** PV module angle:** The angle is another factor to adjust after installing the PV module in the south direction. PV solar angle need to face the sun, the most suitable angle changes according to the location and seasons.

The lower slope angle increases in summer month's productivity. While in winter, higher tilt angles are used for low radiation conditions.

*** PV Module Radiation:** The input variable affects the radiation efficiency of the solar modules.

Radiation changes as the radiation increases, the shorting current of the panel increases, which increases the output efficiency of the unit. If the radiation increases, the maximum power advances, and the efficiency increases.

* **PV module temperature:** The solar PV module operates according to laboratory standard at 25°C temperature and 1000W/m^2. Current and voltage decrease as the temperature rises .Unit conversion efficiency decreases with an increase in unit surface temperature.

Therefore, choosing the right type of PV module according to the temperature and location are important.

* **Photovoltaic module cover:** The performance of solar photovoltaic energy is reduced due to shading effects such as the passage of clouds near buildings or trees .In the shading condition, the short circuit current causes a drop in the strong output. Therefore, the best performance of solar panels comes when there are no shading conditions.
* **Photovoltaic module ingress protection (IP):** IP is an indication instrument file used for water and dust protection. The tools have two numbers. The first number represents the water level and the second number represents the dust level.

3. Design based on software

The simulation aspect in our research is concerned with simulating the orientation of the fixed unit and the possible utilization of the radiation falling on the solar panels according to the possible angles in the design, and this is achieved using the PVSYST program. PVSYST 6.4.3 edition is used. André Mermoud, a graduate (1971) from the University of Geneva in Switzerland, is the author and founder of PVSYST and PVSYST SA respectively.
PVSYST consists of four sections; Initial design, project design, databases and tools. In the project design department, there are four sub-sections or systems; Network connected, stand-alone, pumped and DC network. Grid connected subsection is our area of interest as our project desire is to design grid connected photovoltaic cells. Using satellite-based meteorological data by NASA, simulations will be conducted to determine the annual energy output of the case scenario.
The steps involved in simulation design are illustrated in the form of flow chart below.
The various steps involved in designing the grid connected solar PV system in simulating platform are explained below.
Design and Estimate the results of a 7MW solar power plant by using PVSYST software version 6.4.3. The system is designed based on the above specification to provide the required energy.
Also, Figure 5 displays the system design of the solar module, inverter, and array design.

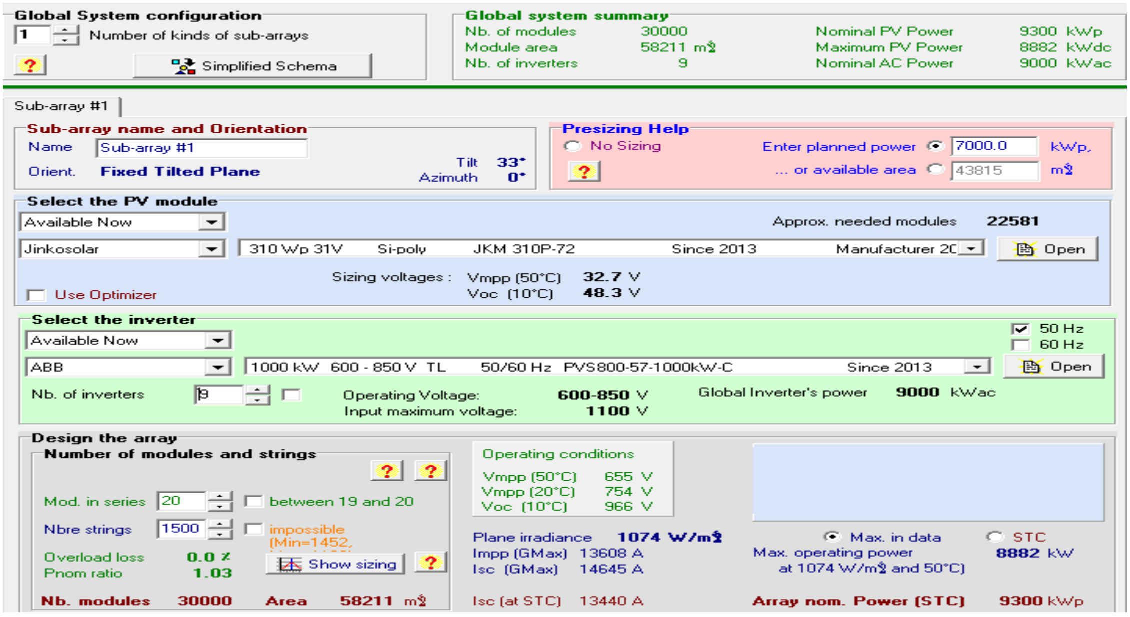

Figure 5: System Design (Solar Module, Inverter, Array Design)

4. Design layout

The generating area of the plant is an important factor in determining the amount of energy to be produced and analyzing the performance of the plant.
Size of a string is 20 Modules which are in series and 10 of such string are connected in parallel to produce one of array.
Per the technical information of the our chosen inverter, the field connection of modules to the inverter is as follows; 20 panels having voltage of 37.0V and current of 8.38A are connected in series to produce 740V voltage and 8.38A current.
Ten of such array connections are connected in parallel to produce a voltage of 740V and current of 83.8A، this produces one string of connection for one inverter.
Per the module-inverter calculations, a total of 10 inverters will be required to efficiently convert dc power to ac power.

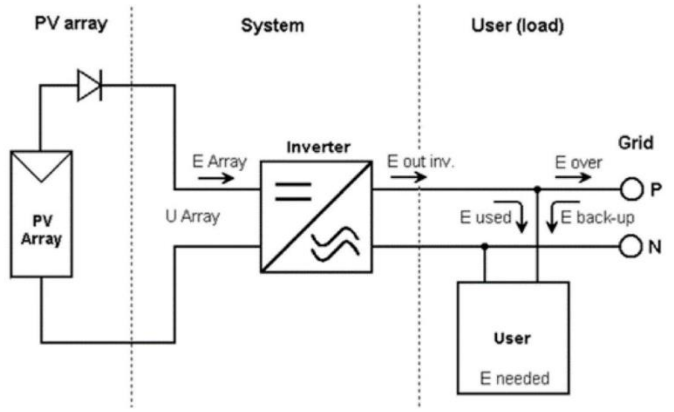

Figure 6: PVsyst Schematic Diagram of System

5. Calculation of required area

A total of 30000 panels/modules are used in the design of our photovoltaic power plant. Each module has an area of 1.940 m^2 (1.956m x0.992m) therefor the total generating area of the plant is 58211m^2 whilst the total area the plant will be bigger than the generating area of the plant.

The space between the panels needs to account (these panels need a stand) so, the total space required is estimated by dividing the total area by 0.7.

6. Results and Discussion

A simulation of the solar power plant designed to obtain the required production capacity, system efficiency, and losses from the system is carried out.

Results are drawn from the simulation software for the case and the study of the elements of the system, as a detailed report is provided on this and in the report, there are a number of main parameters that describe the system, which are:

6.1. Main simulation results

Table 3 shows the balances and main results of our simulation of the PV plant in Bani Walid Hospital from the table, the maximum monthly energy production occurred in March(1745631) kWh and lowest occurred in December (1438930) kWh Annual effective energy produced at matrix output E Array is (19224488)kwh However, it should be noted that E Array is DC power after converting DC power to AC power, we have an electronic grid, grid-connected power annual energy connected to the grid is (18922027) kWh.

The difference between the E-Array and the E Grid determines the efficiency of the inverter (97.6%).

Table 3: Balances and main results

New simulation variant

Balances and main results

	GlobHor	T Amb	GlobInc	GlobEff	EArray	E_Grid	EffArrR	EffSysR
	kWh/m²	°C	kWh/m²	kWh/m²	kWh	kWh	%	%
January	114.3	11.93	183.2	179.6	1518617	1493493	14.24	14.01
February	127.4	12.51	179.1	175.3	1473923	1449801	14.14	13.90
March	180.5	16.23	219.4	214.3	1745631	1717711	13.67	13.45
April	207.1	19.29	216.7	210.4	1700164	1673587	13.48	13.27
May	238.6	23.83	223.0	216.0	1711685	1684271	13.18	12.97
June	237.3	26.41	210.0	202.8	1595168	1569654	13.05	12.84
July	252.9	28.96	227.5	220.1	1689235	1663058	12.76	12.56
August	230.6	29.27	230.5	223.8	1703673	1678629	12.70	12.51
September	184.7	26.57	211.7	206.2	1602631	1578625	13.00	12.81
October	151.8	23.54	200.6	196.3	1555561	1531938	13.32	13.12
November	119.3	17.52	185.2	181.4	1489270	1466237	13.81	13.60
December	104.2	13.24	173.7	170.3	1438930	1415024	14.23	13.99
Year	2148.6	20.82	2460.7	2396.5	19224488	18922027	13.42	13.21

Legends:
GlobHor - Horizontal global irradiation
DiffHor – Horizontal diffuse irradiation
T Amb- Ambient Temperature
GlobInc - Global incident in collector Plane
EArray- Effective energy at array output
E_Grid - Energy injected into grid
PR – Performance ratio

6.2. Performance ratio

Performance ratio is a quantity defined as the ratio of effective energy produced at the output of the array in relation to the power output by an ideal photovoltaic system underneath Circumstances.

Standard Test Conditions (STC) are usually used with the same amount of radiation incident on a "global plane". The performance ratio of photovoltaic systems plants consists of System and group losses. Array losses are wiring, mismatches, unit quality, shading effects، photoelectric conversion rate, IAM. From Figure 7, our overall performance ratio.

The system was 83%, as there was a clear difference in the monthly performance between the summer months and the winter months, as the reason was the high temperatures in the summer months, which negatively affected the performance, and the lowest performance was recorded in the months (June-July-August), although the system's achievement was good in these months.

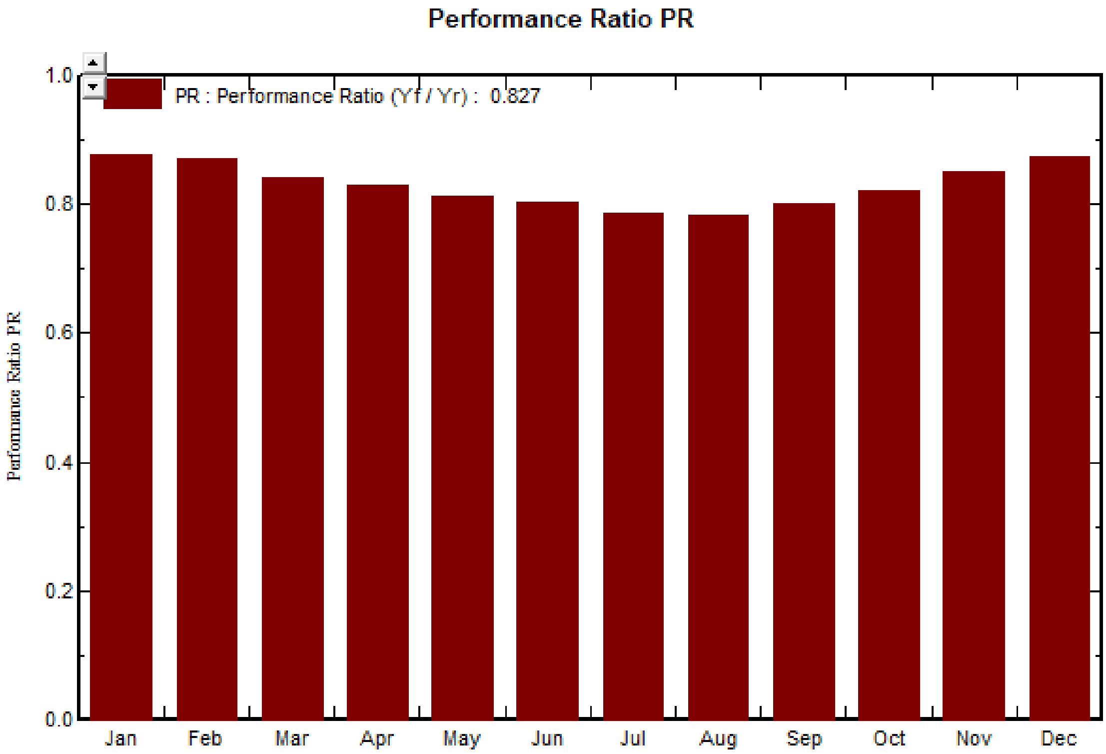

Figure 7: Performance ratio (%)

6. 3. Normalized production

Normal production (per installed kilowatt), Figure 8 shows the graph of normal production per installed kilowatt 7000kW at nominal power, It displays three other factors; System losses are marked in green, group losses are marked in blue, useful energy produced is marked in red, which are very useful indicators; Which determines the performance of the plant in terms of energy production. From the chart, the highest benefit energy produced occurred in March , April, May, June, August , September, and April recorded the highest rate؛ 5.9 kWh / kWp / day.

The highest system losses and collection losses occurred in the period August and July. Although photovoltaic systems rely on sunlight to produce electrical energ، However, the thermal energy associated with sunlight affects the performance of the photovoltaic system negatively.

This means that for every 10 degrees Celsius of temperature that exceeds the STC value, the value of the panel loss is 1 watt. Collection losses are the energy that occurs during the conversion of radiation into energy, it is relative to how much radiation is received and how much of that radiation is converted into energy. System losses

also occur in switching chain radiation but are mostly caused by mechanical losses, inverter losses etc... Losses can be greatly reduced with increasing module and inverter efficiency, quality and short cabling systems.
The percentage difference between losses (system + collection = 1.19) and useful energy produced (5. 57)is 18.09%; It is an "acceptable" loss in PV systems.

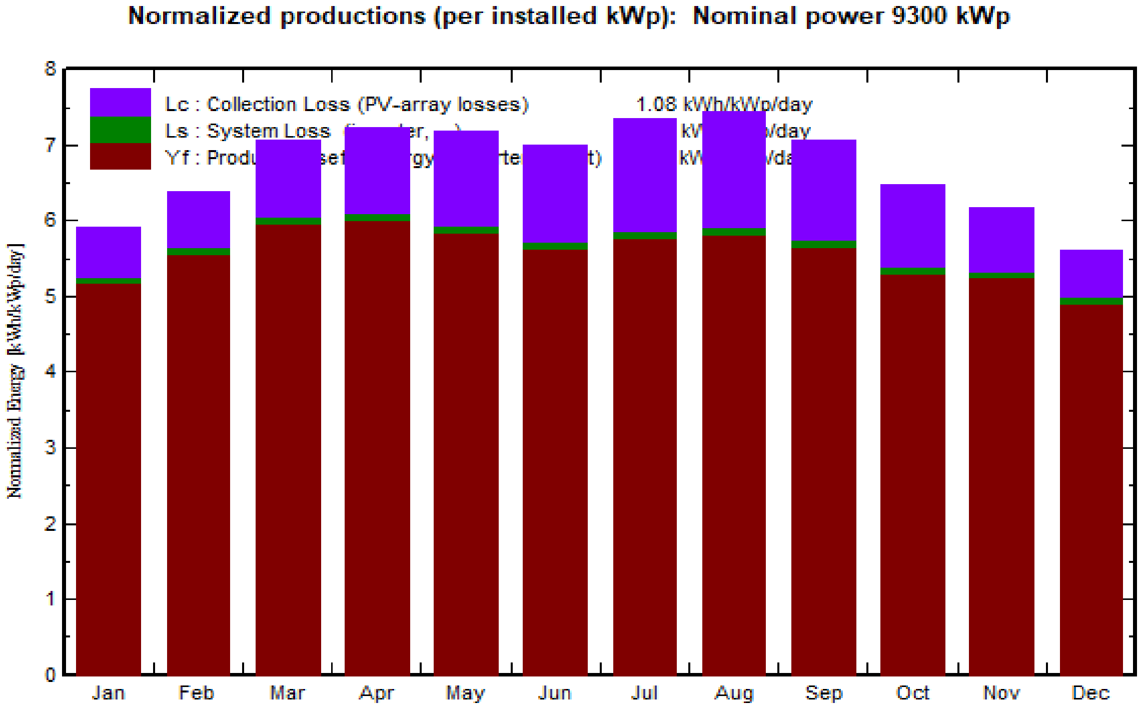

Figure 8: Normalized production

7. Conclusion

The main objective of this research paper is a proposal, which seeks to increase electric power supply and at same time reduce the huge electric power deficit of district Bani Walid thereby increasing socioeconomic development of the City. This will be achieved by designing, simulation and evaluation of a 7MW photovoltaic power plant using PVSYST software.
Simulation results acquired for the proposed Bani Walid Hospital PV power plant puts the yearly grid connected power at 18922MWh for fixed module orientation and Performance ratio of 83% for fixed module orientation case and losses of 15.3% are good indicators of PV power plants under optimal operations.

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