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Design of a photovoltaic system for a building in Benghazi-Libya

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ABSTRACT

A photovoltaic (PV) power system can be used to provide an alternative and inexhaustible source of electrical power to our homes through the direct conversion of solar irradiance into electricity. This study aims to present a thorough design of a grid-connected PV power system for a building in Benghazi city, Libya. The process of acquiring a PV power system involves designing, selecting, and determining the specifications of the different components involved in the system, which include estimation of load (kWh/day), size (capacity) of PV system (kW), size of the inverter (kW) and backup source such as battery bank (Ah), etc. The achievement of this process depends on various factors such as geographical location, weather conditions, solar irradiance, and load profile. As a result, an Excel-based comprehensive program to design any PV system for a specified demand is developed in this study. Finally, HOMER software is used to demonstrate the economic analysis for the designed PV system. The results obtained are believed to be useful for all players whether the Libyan government, the national grid operator, the PV system investor, and the environment.

Keywords: photovoltaic, economic analysis, power system

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I. INTRODUCTION

The worldwide demand for solar electric power or photovoltaic solar energy has grown steadily over the last two decades. Therefore, the need for reliable and low-cost electric power is the primary force driving the worldwide photovoltaic (PV) industry today. The utilization of PV systems in electrical energy generation is considered one of the most important alternative energy resources. The technological viability of solar photovoltaic systems has been proven especially for rural area applications in developing countries where solar energy is available.

Today, the Libyan energy mix consists of local resources, such as natural gas at 38%, heavy fuel oil at 20%, and light fuel oil at 42% but there is no contribution from renewable energy sources in the untraditional energy mix. Libya’s energy consumption is increasing at a relatively fast rate due to population growth and economic development. Libya’s high dependency on traditional resources and its accelerated growth of energy demand make the development of the current energy resources and the exploitation of a broader renewable supply mix one count's priorities. 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 [1], as shown in Figure (1)

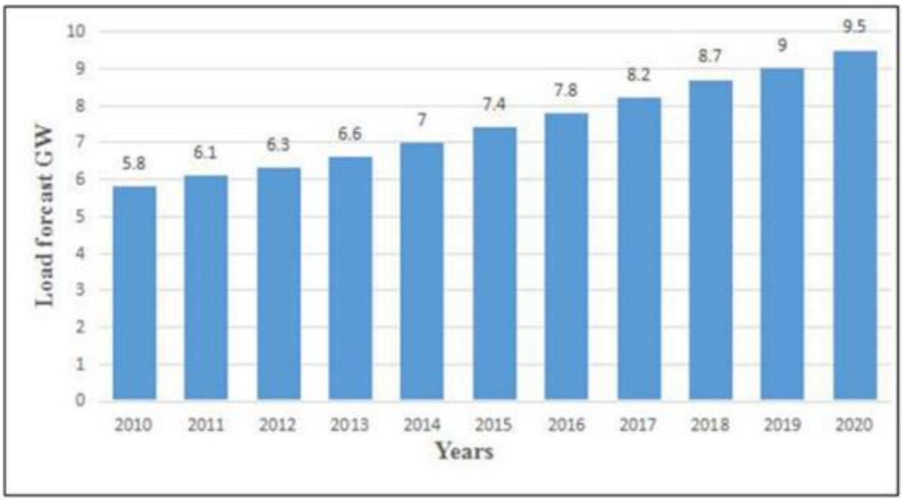

Fig. (1): Libyan load growth 2010- 2020[1].

Information on local solar radiation is essential for many applications including architectural design, solar energy systems, and particularly for design. In many developing countries, solar radiation measurements are not easily available due to the cost and maintenance, and calibration requirements of the measuring equipment. Therefore, it is important to elaborate methods to estimate solar radiation based on readily available meteorological data. The design of a solar energy conversion system needs exact knowledge at many locations around the world, while global radiation is measured at selected locations only. To overcome this defectiveness, scientists have developed many empirical equations to calculate solar radiation. Most of the sunshine-based equations built to estimate the monthly average daily global radiation are of the modified angstrom type equation. Adequate information regarding the availability of global solar radiation and its components at particular locations is essential to predict the efficiency and performance of solar PV devices. The network of solar radiation measurements usually records global solar radiation on the horizontal surface and this important quantity is mostly variable on a daily and hourly basis. Values on horizontal subsurface be used to compute the insolation received on inclined surfaces. In developing countries, the situation regarding solar radiation recording is very poor with only a few exceptions, In Libya for example, only fifteen stations recorded global solar radiation on the horizontal surface.

However, these data are not easily obtained from other locations in Libya, which depend on the satellite-based data, that are provided by NASA or by various empirical relationships between global solar radiation and other climatological parameters. So, In Libya, the functioning of instruments in the network of solar radiation measurements should be improved as soon as possible to improvement satisfy the current demand for insolation data due to the existing network being too sparse. If new stations are established, it will take several years before a reliable radiation climate can be achieved and this is due to the great natural variability of solar radiation from year to year. The existing database should be improved by utilizing climate variables that are closely correlated with solar radiation such as sunshine duration and other meteorological parameters. The climatological parameters have been extracted from the NASA database.

This study aims to improve the knowledge of exploiting and using solar energy in Libya. To reduce the oil consumption and cost of a megawatt of electricity production by using solar systems to reduce pollution of the environment arising from burning fossil fuel, the study of radiation in Libya and its use in solar energy output calculation and design of a solar PV system in Benghazi.

SOLAR RADIATION PHOTOVOLTAIC SYSTEM

Solar energy travels from the sun to the earth in the form of electromagnetic radiation. Each second, the sun turns more than four million tons of its mass mostly hydrogen and helium into energy, producing neutrinos and solar radiation, radiated in all directions. A tiny fraction of half of a trillionth of this energy falls on Earth after a journey of about 150 million kilometers, which takes a little more than eight minutes. The solar irradiance, i.e., amount of power that the sun deposits per unit area that is directly exposed to sunlight is 1368 watts per square meter (w/m2) at that distance. This measure is called the solar constant. The sunlight on the surface of our planet is attenuated by the earth's atmosphere so less power arrives at the surface about 1000W/m² in clear conditions when the sun is near the zenith. The incoming energy received from the averaged over the year and other surface areas of the globe is 342 W/m². Of these 342 W/m² roughly 77 W/m² are reflected by clouds, aerosols, and, the atmosphere, and 67 W/m² are absorbed by the atmosphere [2]. The remaining 198 W/m², which is about 57% of the total, hits the earth's surface. The solar radiation reaching the earth's surface has two components, direct or "beam" radiation, which comes directly from the sun's disk, and diffuses radiation, which comes indirectly. The sun offers a considerable amount of power about 885 million terawatt hours (TWh) reach the earth's surface in a year. Most of the electromagnetic radiation from the sun is the in the wavelength range of 0.25 to 3.0 μm. Figure (2) shows the spectral distribution of sunlight.

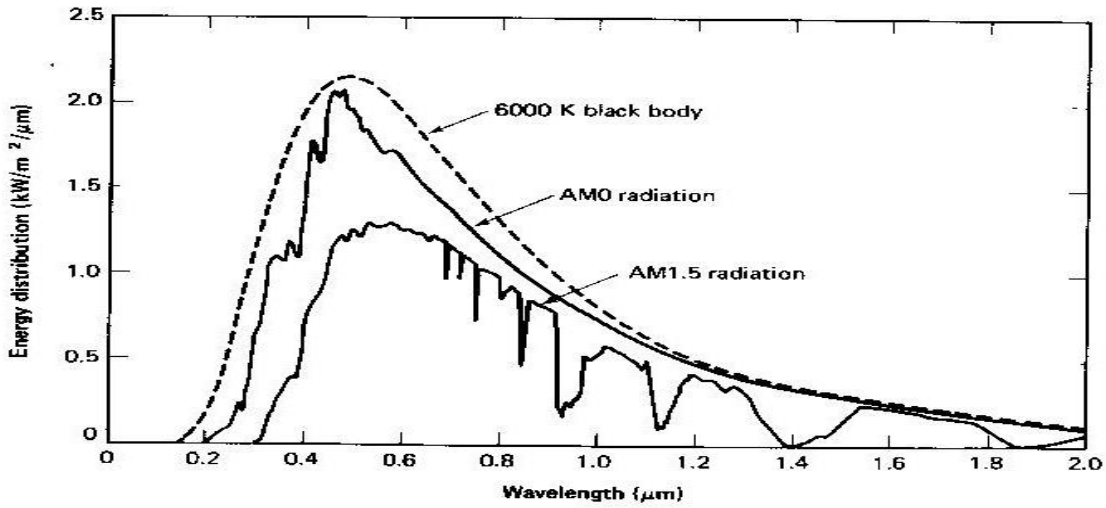

Figure (2) Spectral distribution of sunlight [3].

Photovoltaic

Photovoltaic (PV) is the most direct way to convert solar radiation into electricity and is based on the photovoltaic effect, which was first observed by Henri Becquerel in 1839. It is quite generally defined as the emergence of an electric voltage between two electrodes attached to a solid or liquid system upon shining light onto this system. Practically all photovoltaic devices incorporate a PN junction in a semiconductor across which the photo-voltage is developed. These devices are also known as solar cells. Light absorption occurs in a semiconductor material. The semiconductor material has to be able to absorb a large part of the solar spectrum.

Dependent on the absorption properties of the material, the light is absorbed in a region more or less close to the surface. When light quanta are absorbed, electron-hole pairs are generated, and if their recombination is prevented, they can reach the junction where they are separated by an electric field. Even for a weakly absorbing semiconductor like silicon, most carriers are generated near the surface. This leads to the typical solar cell structure of Figures (3), and (4).

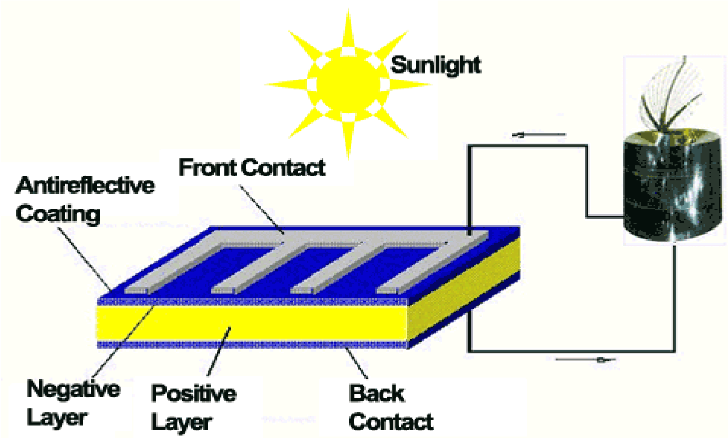

Figure (3) Typical solar cell structure.

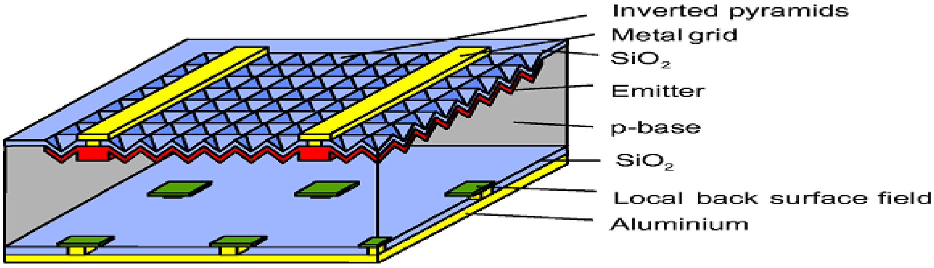

Figure (4) Structure of a high-efficiency monocrystalline solar cell [4].

The PN junction that separates the emitter and base layer is very close to the surface to have a high collection probability for the photo-generated charge carriers. The thin emitter layer above the junction has a relatively high resistance that requires a well-designed contact, also shown in Figure (4)

The design of a PV system consists of components such as a solar array, inverter, and wires connection. These components should be selected according to the load; therefore, the load should be calculated via designers, the loads consist of TV, Water Heater, Bulbs, Refrigerators, Air conditions, etc. The design of the system should cover to design of a PV system, the following criteria should be taken into consideration:

1. The losses the of system's components.
2. Determination of the load should be supplied.
3. Determination of the energy input required from the PV array or other sources (battery/charger/generator)
4. Determination of the battery storage is required for the power need of house uses equipment.

II. DATA ANALYSIS

Data for stations at different locations and climates in Benghazi were utilized. The data obtained can be divided into two main parts; the first part is the data obtained from NASA Department including the monthly average computed from the daily total values. The monthly mean ambient temperature data were obtained from NASA as in Table (1).

Table (1) The ambient temperature data(C°)(average of 22 years)

Station	**Month**												
	J	F	M	A	M	J	J	A	S	O	N	D	**average**
Benghazi	20	21.2	23.8	27.9	32.0	35.5	36.9	37.4	35.5	31.3	26.0	21.5	30

The designed system for producing power depends on the sunlight per day and as well on the quantity of solar radiation, to determine sunlight hours (peak sun hours). So, the location will affect the produced power. A daily sunlight average per month is very important information for the design. On the other hand, the latitude of the city is affecting the produced power. The average solar radiation for Benghazi city was calculated at Peak Sun Hour value, to design a solar PV system for home application and electrification in the city location. The location at 32.11° N and 20.03° E. Table (2) illustrate the sunlight per day in Benghazi city. The latitude of this city is 32.11°, The azimuth angle is a very important parameter for the PV module's position. If the azimuth is zero degrees, then the PV modules face north and if it is 180° the PV modules face south, the azimuth angle in Benghazi is 180°, which means the PV modules will face south. and we calculate later the solar radiation Peak Sun Hour (PSH).

Table (2) Sun Hours in Benghazi (kWh/m2/day)

Months	on a horizontal surface	on a tilted surface (β=32°)
January	2.87	4.01
February	3.87	5.02
Mars	5.18	5.90
April	6.56	6.55
May	7.26	6.59
June	7.92	6.84
July	7.94	6.99
August	7.26	6.98
September	5.96	6.49
October	4.55	5.74
November	3.26	4.48
December	2.63	3.82
Average	5.44	5.79

III. MATHEMATICAL MODEL

- **Photovoltaic Power Design**

The PV array will be de-rated to the manufacturer's tolerance. Most manufacturers rate their modules with h certain efficiency. the modules should be related to the manufacturer's tolerance. The actual value will be dependent on the site. In our application where the system will be installed in Benghazi. The efficiency of the solar modules is taken from the datasheet of manufacturing. The data sheet of the solar modules is mentioned in for designing the PV system some parameters should be taken into consideration, the parameter such as the load which is determined by researchers, system losses which are counted with six losses, and power sunlight hours (PSH) of Benghazi which is 5.79 Kwh/m²/day. It is known the output of solar modules is DC, and the output of PV must be calculated, that output can be calculated with Eqn. (2) to determine the needed power for Benghazi houses**.**

The equation for estimating the PV system energy output can be expressed as:

Eout =PV system capacity × Sun Hour × De-rate factor of PV module temperature × Der-ate factor of the system losses **(1)**

PV (kW) = Load (kwh) / (PSH*System losses) (2)

System losses= (Derate factor of PV module temperature × Derate factor of system losses)

The powered electricity of an administrative building in the Benghazi mechanical engineering college area is 13.70 x 37.50 = 513.75 m², and the total area of the building is 1027.50 m², which consists of two floors with several offices, a kitchen, and two bathrooms. The building loads shows in Table (3)

Place matrimonial plates on the target building' which has a group of tilted buildings with an area of 1823.74 m²
The area of each slant is 20.10 × 5.67 = 113.970 m² at an angle of about 26.5 SW
The design system of PV components for real load in Benghazi is consisting of four components as follows:
. Solar cells.
. Inverter.
. Charge controller.
. Wiring.

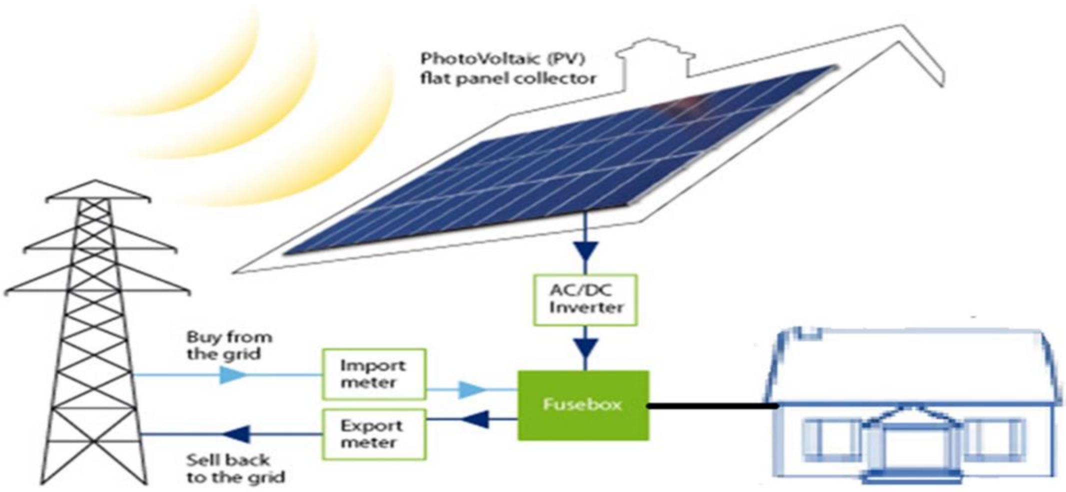

Figure (5) Block diagram of grid-connected PV system [5].

The following table represents the consumption of wattage the of most used appliances of the selected building in Benghazi. (Calculating Loads).

Table (3) Consumption of certain appliances

appliance	Load Range (watts)	Average load(watts)	No. of use appliance	Operation (wh)per hour	Operation (wh) per day
Big Florescent Lamps	36	36	39	36x39=1404	1404x7=9828
Small Fluorescent lamps	18	18	37	18x37=666	666x7=4662
Computer Desks	250	250	26	250x26=6500	6500x7=45500
printers	250	250	9	250X9=2250	2250x3=6750
photocopiers	1000	1000	4	1000X4=4000	4000X3=12000
laptops	50	50	10	50X10=500	500X4=2000
Air Conditioners	1400-2000	1800	20	1800x20=36000	36000x7= 252000
Electric Water Heater	1000-1500	1200	3	1200x3=3600	3600x2=7200
The total consumption of certain appliances per day (Wh)					339940≈340000

The angle of the solar panel is depending on the latitude of the site of the city; therefore, Benghazi latitude is the best tilt angle to observe the radiation is equal to 32°. The illustrates the tilt angle of solar modules. The location of Benghazi city will determine the facing of solar modules because Benghazi is in the north and the solar modules will face the south. That means 180° from true north.
It is advised to adjust the tilt angle to 17° in summer and to 47° in winter. This will increase san solar energy falling on installed solar panels according to the following table.

Table (4) Global solar radiation (kWh/m2/day) with tilt angle 17°, 32° and 47°

Monthly	Tilt angle		
	17°	32°	47°
Jan	3.56	4.01	4.24
Feb	4.60	5.02	5.16
Mar	5.71	5.90	5.78
Apr	6.69	6.55	6.06
May	7.10	6.59	5.75
Jun	7.55	6.84	5.79
Jul	7.65	6.99	5.99
Aug	7.32	6.98	6.28
Sep	6.40	6.49	6.23
Oct	5.33	5.74	5.83
Nov	3.99	4.48	4.71
Dec	3.35	3.82	4.08

As mentioned here three the losses of the system design must be calculated to in ensure the system will feed the load. All losses will be taken from the data sheets; the temperature loss will be calculated.
PV Temperature Losses using eq. (3)

$$T_m = T_{a.day} + 25°C \quad \textbf{(3)}$$

According to NASA, the average maximum ambient temperature around the year in Benghazi is 30°C.

$$T_m = 30 + 25°C = 55°C$$

The average PV module temperature is 55°C, and by using eqn. (4)

$$T_m - T_a = \frac{NOCT - 20}{0.8} G(kW/m^2) \quad \textbf{(4)}$$

The average solar radiation from Table (2) is 5.79 kW/m2 the module temperature NOCT is 45°C. From the aforementioned calculations, it is more sensible to consider 55°C.
Using eqn. (5) The de-rate factor due to module temperature rise is:

$$f_{temp} = 1 - (\gamma \times (T_m - T_{stc})) \quad \textbf{(5)}$$

γ is the power temperature co-efficient = -0.46%℃
With an initial estimation of inverter efficiency to be 0.97 and by taking the soiling efficiency as 0.97.

Table (5) System losses

No.	Item	Efficiency
1	Inverter efficiency	0.97
2	PV module mismatch	0.95
3	Mismatching	0.95
4	DC wires	0.98
5	AC wires	0.99
6	Soiling	0.97
7	Temperature Loss	0.87

Total losses factor = inverter efficiency *PV module mismatch*mismatching *DC wires*AC wires*soiling*temperature
Total losses factor = 0.97*0.95*0.95*0.98*0.99*0.97*0.87=0.71

Table (6) Datasheet of the solar panel used in the system design

Brand	**Kyocera KD250GX-LFB2 (Polycrystalline)**
Maximum power (Pmax)	250W
Maximum voltage (Vmp)	29.8V
Maximum current (Imp)	8.39A
Open circuit voltage Voc	36.9V
Short circuit current Isc	9.09A
NOCT	45° C

Calculation of the Required Capacity of Solar PV System
By using eqn. (2), the system capacity required = PV (kW) =load (kWh)/ (PSH x System Losses)
The power of the PV system is calculated with 83 kW, the number of solar modules will be determined, and the power of each solar module is 250 W, which is selected from the datasheets.

83 kW/250W=332 panels.

Calculating the Effect of Module Temperature on the Output Voltage of The Module.
As experienced in Benghazi, the hottest ambient temperature, reaches up to 40°C so by applying eqn. (3), the Tm can reach up to 65°C. Δt is (65-25) =40°C. From Table, the temperature coefficient of Vmp is -0.52% ℃.
As a result of the worst condition, The Vmp Would decrease to

$$(29.8\text{-}0.0052\times40) = 29.58V.$$

Knowing that the coldest ambient temperature is 4°C and by applying eqn. (3) when solar irradiance =0, the Tm = Ta = 4°C. Δt is then (4-25) =-21°C. From Table, the temperature coefficient of Voc is -0.36%/℃.
As a result of the worst condition, The Voc Would increase to (36.9+0.0036×21) = 36.98V

The role of the inverter is to convert the output of solar panel DC to AC for consumers. The type of system designed should be grid-connected because this relates directly to the inverter and its linking voltage.

Table (7) Data Sheet grid-connected the inverter

No.	Item / Type	Energy ASTRASUN 3 PH Series Three-Phase String Inverter
1	Normal AC output power	5kW
2	AC output power	5 kW
3	AC voltage Range	330V-480V
4	Nominal dc input voltage	400V
5	Operations voltage	250-720 V
6	Max. DC input voltage	900V
7	Max. Input current	20 A
8	Efficiency	97.6%

In case the system is grid-connected, the inverter voltage and current requirements are different as specified in Table 7.

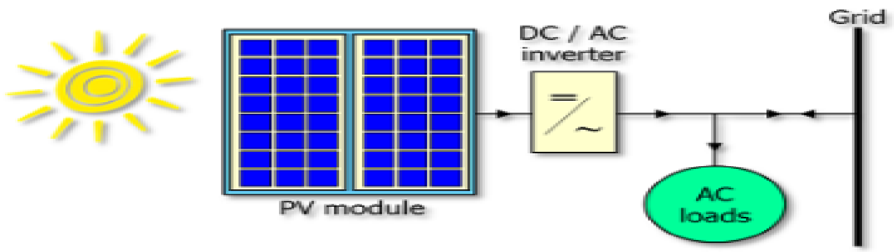

Figure (6) Grid-connected designed system

Calculate the number of solar panels in series, to determine the number of solar panels, the maximum and the minimum voltage of the inverter defined as well as the maximum and the minimum temperature in Benghazi city. The researchers have selected from the datasheet, the inverter with a max voltage is 720 V and a min voltage is 250V.
Minimum no. of panels to be connected in series= Minimum acceptable voltage of inverter/ Vmp on hottest day= 250V/29.58V=8.4 ≈ 8 panels.
Maximum no. of panels to be connected in series= Maximum acceptable voltage of inverter/ Voc on coldest day= 720V/36.98V=19.5 ≈20 panels.
Several solar panels are to be connected in series between 8-20 panels. illustrates the number of solar panels that will be connected with one inverter in series and parallel.
Since each inverter will be connected with 20 panels, that means the number of total inverters needed is 332 panels/20 = 17 inverters

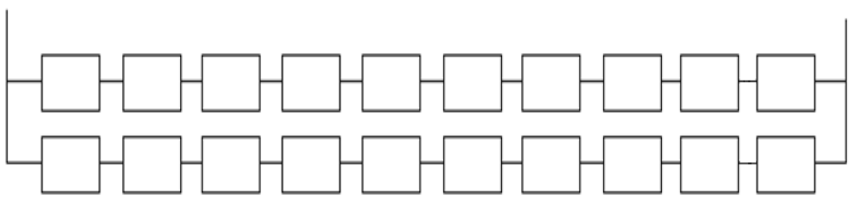

Figure (7) connects the panel in series and parallel with one inverter

The calculation of the roof area needed; the dimensions of the selected panel are 1.662 m x 0.99 m so the needed area can be calculated as follows:

The area of one panel = 1.662 m x 0.99 m = 1.65 m²

Thus, the total area required = the total number of panels x the area of one panel.

= 332 × 1.65 m² = 548 m²

Therefore, the available area is 1823 m², which means that the PV system can be installed without any obstacles. The composition of the matrimonial plates on the tilted buildings shows the structure of the mechanical engineering faculty by placing 30 panels in the front buildings and 18 in the rear buildings as shown in Figure (8). The idea of the 83 KW PV system is to have clean energy that can sell the excess energy back to the grid, particularly upon the assumption of implementing the FiT in Libya. The PV system cost breakdown as obtained from various companies, is shown in Table (8).

Figure (8) The default format for the installation of matrimonial plates on buildings.

Table (8) System components' costs of the 83 KW PV

Work of Project	Price (LD)	Rate (%)	LD/W
83 kW Polycrystalline Solar Array; 332 panels	64,000	57.8	0.77
Solar Array Mounting Structure with Installation	10000	9	0.12
5kW Inverter with System Monitoring Subsystem, 17 inverters	18750	17	0.23
Distribution Boards, Cables & Cabling Accessories	16000	14	0.2
Testing and Commissioning	2000	2	0.02
Project Price (LD)	110750	100%	1.34

Estimated energy costs per day are about 340 kW per day * 0.07 = 23.80 * 365 days * 20 years = 173740 Libyan dinars This value is the total energy costs in twenty years

The primary load input of the load type is AC. After that 24 hourly values are entered in the load table of every month. Each of the 24 V values in the load table is the average electric demand for a single hour of the day. The above Fig shows how the primary load gives the result. A converter may be a rectifier or inverter. A converter is required for the system in which DC components serve as AC load and vice versa. Here we have to also enter the cost and size value into the cost table shown in Fig including labor and hardware installation. Here we get the curve between cost and size. Its lifetime is 10 years.

IV. RESULTS AND DISCUSSIONS

The system consists of solar modules, which provide the DC volt that modules be connected through wires to DC/AC converter (Inverter). All these components are designed according to the electricity demand of the selected building in Benghazi city. In the beginning, the average of the estimated load the determined, this value of load will be used to determine the other components of the designed system. It is known each part of the design system has losses or its efficiency therefore the efficiencies have been collected and taken into consideration to cover the total electricity demand. The efficiencies of the system such as inverter efficiency, solar cell efficiency, DC wire efficiency, AC wire efficiency, soiling efficiency, and system availability are estimated to get the final efficiency of the system. However, the other purpose of this is to determine the temperature losses, system losses, number of solar modules, and roof space for grid-connected systems. Each component in the system design will be defined by using HOMER software to study the designed grid-connected PV system.

V. CONCLUSION

The system is designed to use solar energy for clean electricity. The system has been calculated with its components which consist of solar modules, and an inverter, and, that includes their losses. The maximum temperature and minimum temperature have been obtained for Benghazi to find the maximum and minimum configuration of solar panels in series to avoid the very high voltage and very low voltage and hence the failure of the operation. The roof space for installation of the designed system has been calculated to determine the needed space of the designed system to ensure that system can be installed and used in our life. All these calculations have been done to cover the electricity demand for a building in Benghazi city, which is estimated at 340 kWh/day, the purpose of the design is to get power from other sources and cheaper than the main general network and the other places that cannot support them with electricity. Such a system can be used for far places such as villages or the might cost the government a lot of money to provide it with electricity. Finally, the researchers claim the designed system of solar PV achieves the research objective, which is to produce electricity with another method than the conventional ones, cheaper, cleaner, and available at all times. It should be remembered that the system was designed so that its tilt angle is 32^{o} and accordingly produces 5.78 kWh/ m^2 /day. However, it is advised that the system's tilt angle is changed to 17^{o} in the summer and to 47^{o} in the winter to capture more solar irradiance and hence more solar energy it produces from the PV generator. The case has developed an Excel-based comprehensive program to design a grid-connected PV system for load demand. An economic investigation on a grid-connected PV system for a residential house was also conducted using HOMER simulation software and considered various PV system configurations and energy price scenarios we have obtained at different conditions to get the optimum condition for the PV installer.

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