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Enhancing and Designing A Solar Photovoltaic System in A Tent City (Mina)

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Abstract: *Currently, existing technologies of energy generation based on fossil usually accompanied by burning of gases resulted in excessive amount of CO_2 emissions. The national oil consumptions of kingdom of Saudi Arabia (KSA) is increasing by 7% annually. If this growth rate continuous, the local demand will tremendously increase in a decade. This study has covered a solar photovoltaic system in a Tent City (Mina) during Al Hajj period. The Al Hajj is an important to every Muslims since it needs to be performed only one time in their life. Al Hajj ritual is performed in Makkah city, Saudi Arabia. A part of this ritual is staying in the tent city (Mina) for a few days, which has approximately 160,000 tents for sustaining around 3 million pilgrims. During Al Hajj period, Saudi Arabia is feeding the Mina with high amount of electrical energy to serve pilgrim's need such as air-conditioning, lighting and external outlets. In this research work,solar energy is used to supply electricity to tents by using solar panels. Each Tents can be fitted with solar panels to cover the electrical needs. The design aspects of supplying the accurate amount of energy are studied. The design of solar PV system, such as design and selection of panel, inverter, and battery,are investigated. In this article, the calculation of the tent area, arranging panels, actual capacity of the battery is performed. The result shows how the solar PV system is used to increase efficiency, reduce power consumption, cut cost, reduce the demand of fossil fuel and eliminate carbon emissions. The primary function of this article is to use solar photovoltaics on-grid system in order to reduce the energy consumptions of the tent city (Mina) during Al Hajj period.*

Keywords:*Solar energy, Solar Photovoltaics; Renewable energy; Solar on-grid system; PV efficiency.*

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I. INTRODUCTION

The Sun is the primary source of renewable energy that could provide a limitless source of energy supply in many parts of the world. Lack of Sun can easily end life. Without the Sun, the Earth's temperature will drop suddenly, and Earth will be cold and dark. The Sun considered the origin of many energy sources, such as fossil fuels and wind energy. Most renewable energy comes either directly, such as solar energy or indirectly from the Sun, such as wind energy. Solar Energy used for generating electricity, water heating, solar cooling, and a variety of commercial and industrial uses. Solar Energy provides a lot of benefits that make it one of the most promising energy forms. Renewable, non-polluting, and available planet-wide are contributing to sustainable development and job creation where it is installed. Therefore, Saudi Arabia has announced Vision 2030 by Crown Prince Mohammed bin Salman, and the National Transformation Plan (NTP) clearly outline ambitious renewable energy goals under the King Salman Renewable Energy Initiative. In fact, Saudi Arabia will install 9.5 GW of renewable energy capacity by 2023 [1].

Solar Photovoltaic (PV) is the most important type of renewable energy, therefore, improving the PV solar energy since its clean for the environment considered a moral mission. In this mission, the Sun will provide not only the light but the energy for pilgrim's comfort by producing enough energy for supplying the air conditioning system. Two-thirds of the total energy is used for buildings, where 30-50% of electricity consumption in buildings is dominated by air conditioning systems [2]. Solar Photovoltaic Air-Conditioning System is used to convert the solar into electrical by using photovoltaic cells, which are then used to operate a vapor-compression air conditioning system. There are many types of research related to Solar Photovoltaic System have been studied through this paper to compare, improve, develop the study of a Solar Photovoltaic System in a Tent City (Mina).

Dragza, B. (2008) discussed the history of Solar Photovoltaics applications. Moreover, explained the future application of the PV system and expressed different technology. Clearly showed how Solar power had come a long way in the past 200 years, from observing the properties of light to finding new ways to convert it into power [3].

Reinders, A., Verlinden, P., Sark, W. V., & Freundlich, A. (2017) were explained the fundamental and application of Photovoltaic solar energy. They presented, in chapter 1 & 2, the basic functional principle of photovoltaics, including the introduction to semiconductor materials and topics related to solar cells device in general. Also, the second half of the book was focused more on the application of photovoltaics technologies. In details, Chapter 9 explore PV technologies that are applied in space, and chapter 10 presented PV modules and their manufacturing processes. While, in chapter 11, PV technologies applied in systems, buildings, and various products are placed in the spotlight [4].

Reinders, A., Verlinden, P., Sark, W. V., & Freundlich, A. (2017) were explained the fundamental and application of Photovoltaic solar energy. In chapter 3, they explained the design aspects and the actual function of crystalline silicon solar cells, the most dominated solar technology in the current PV market. Thin-film solar cells in chapter 4 were discussed while in the chapter, they discussed the thin film silicon-based PV technologies. Also, organic PV cells and their application demonstrated in chapter 6 and 8 [4].

Giges, N. (2014) expressed the improvement of the solar panels and made them more efficient, according to the American Society of Mechanical Engineers. The report expressed and showed the result of improving the cost and efficiency of PV in a different method and technology [5].

Mostafa R., Ahmed, E. (2015) provide a review on Photovoltaic Solar Energy Technology and its Efficiency. The review explained the types of technologies and classification of the PV system. Also, he compared each type in order to calculate efficiency. The efficiency played a significant rule in selecting the technology based on the price and maintenance of the Photovoltaic system that has been used [6].

Saudi Arabia Solar Industry, "Country Focus Report." (2017) Provide a detailed report about Solar Energy in Saudi Arabia. The report discussed the capacity of solar by 2023, which is around 9.5 GW. Also, it gives a description of solar energy Beyond 2017, Vision 2030, and change of direction from traditional fossil fuel energy to renewable energy [7].

Shahzad Ahsan and co-authors present designing aspects and assessments of a solar PV system based on field and actual performance. The study of designing a solar PV system based on cost analysis of 1.0 kW off-grid photovoltaic energy system installed in India. The calculation of monthly and weekly of 1kW is performed to save money and improve the investment [8].

Andreas Jossen and co-authors described the requirements for batteries in solar systems. They discussed the essential storage systems, such as lead-acid, NiMH, and Li-ion batteries. They clearly present in this paper the operation conditions, performance, and lifetime in photovoltaic systems. The result expresses the idea that the operation conditions strongly influence the battery lifetime [9].

Akash Kumar Shukla, K. Sudhakar, and Prashant Baredar examined the design, simulation, and economic analysis of standalone rooftop solar PV system in India. They discussed that the selected inverter must be able to work with the maximum expected power of AC loads. The paper represents that the inverter output capacity more than the total AC loads wattage. They explained that the output would be either single-phase or three phases compatible with the AC loads [10].

B. Pakkiraiah and G. Durga Sukumar are discussed many important topics related to the solar system in the Research Survey on Various MPPT Performance Issues to Improve the Solar PV System Efficiency. They represent different types of PV panel systems, power electronic converters usage with control aspects, filters to reduce harmonic content, maximum power point tracking control algorithms, usage of battery system for the PV system, and various controllers [11].

Ramakrishna Kappagantu, et ll. They performed a survey and study with electricity consumers in the paper of analysis of rooftop solar PV system implementation barrier in Puducherry smart grid pilot project. They discussed questions regarding space availability for the rooftop PV system, consumption over a different period, and experience of the users with this solar technology. The paper clearly shows the result that helps to improve and enhance the development of a rooftop solar PV system [12].

Mohammad Al-Najideen and Saad S.Alrwashdeh have studied the Design of a solar photovoltaic system in order to cover the electricity demand for the faculty of Engineering- Mu'tah University in Jordan.

They produce more than 50 kW grid-connected, which efficiently and effectively reduce energy bill due to dropping the energy consumption as well as the electricity generation [13].

Sandor Bartha discusses the importance of saving energy by using photovoltaic street lighting systems instead of traditional street lamps. The aim of his article is describing the design and simulation of the solar street lighting photovoltaic system with LED Energy Lamp. He successfully discussed the optimal type of battery for PV lighting system. The result clearly presents and evaluate the application site solar energy potential to ensure a continuous operating of a street light system without brooking down of the technical unit [14].

In this article, a Solar Photovoltaic System in a Tent City (Mina) proposed because energy plays a significant rule in civilizations therefore many studies are discussed on the use of solar energy in order to increase efficiency, reduce power consumption, cut cost, reduce the demand of fossil fuel and eliminate carbon emissions. The primary function of this article is to use solar photovoltaics on-grid system in order to reduce the energy consumptions of the tent city (Mina) during five days of Hajj period.

II. METHODOLOGY

This section introduces the data generation, PV system, PV module specification, and load calculation in order to select the proper Solar PV system in the Tent City (Mina). The methodology procedures divided into three parts. The first part is the components of the Solar PV system. The second part is the design of the Solar PV system. The third part is the mechanicals design structure of the solar PV system.

2.1 Components of the Solar PV system

The main component of the solar PV system in this article are:

- **Solar Panel:** The primary function of the panel is to absorb the solar to generate electricity or heating.

A PV module is a packaged of connected solar cells. There are two electrical connections made in series to achieve the proper voltage and/or in parallel to provide a desired current capability [15].

- **Charger Controller:** A charge controller or charge regulator used to regulate the voltage and/or current from the panels to the battery. If the system has no regulation, the batteries will be damaged from overcharging. When battery banks used, the charge controller is a required device [16].
- **Solar Inverter:** The function of an inverter is to convert the variable direct current (DC) of a photovoltaic (PV) solar panel into frequency alternating current (AC) [17]. Inverter maintains the required output voltage and frequency.
- **Battery Bank:** Batteries convert chemical energy into electrical energy. They store electrical energy in the form of DC and retrieve it for later use. Batteries reduce the efficiency of the solar plants by ten percentages, so in grid-connected applications batteries are not used. In this situation, the loads are 24/7 loads during the night the battery bank is used for supplying power. The general types of batteries used in solar power systems are as follows [18].
- **Load:** The load is any components that consumed power or energy. In this project, the load is air-conditioning, light bulbs, and USB charging phone socket, as shown in Table 1.

Table 1 Loads that used in the tent and the electrical power (watt)

Load	Type	Power consumed (watt)	Quantity	Total power (watt)	Operating time/day(hours)
Light Bulbs	LED(400 Lumens)	7	4	28	12
Air Conditioners	Evaporative coolers	1200	1	1200	24
Charging	USB charging Phones socket	3.68	4	14.72	2

2.2 Design of Solar PV System

Designing of Solar PV system is one of the essential procedure to select the proper PV system. This section presents the design and selection of proper panels, inverters, and batteries.

- **Panel design and selection:**In every tent, there will be a specific Load that will provide the output required for powering a single tent as describes in the table below.

Table 2Details of devices that used in the tent and the total electrical power (watt)

Load	**Type**	**Power consumed (watt)**	**Quantity**	**Total power (watt)**	**Operating time/day(hours)**	**Totalpower (watt)/day(hours)**
Light Bulbs	LED (400 Lumens)	7	4	28	12	336 = 0.336
Air Conditioners	Evaporative coolers	1200	1	1200	24	28800 = 28.8
Charging	USB charging Phones socket	3.68	4	14.72	2	29.44 = 0.02944
Total		1210.68	9	1242.72	38	29.16

Table 1 is clearly showing the total power required for the tent is 29.16 KW/day.

The operating time of the panel with complete efficiency is assumed to be from 9 Am to 3 PM, the total operating hours with full efficiency is 6 hours.

Numbers of Panels = Daily Load / Daily one panel output *hrs.

= 29165.44 / (250×6) = 20 Panels (4 set of panels)

The power produced by each set of panels = 1250W

The minimum power generated by the sets of panels = 4×1250×6 = 30,000 $watts$

There will be an extra power that comes from the solar panels during the time from 6 am to 9 am in morning, and evening from 3 pm to 6. This time is called the partial generation time, which will provide approximate of (250W×5×0.6) = 750Watts.

Partial power generation during this period = 4×750×6 = 18,000 $watts$.

Therefore, the total power generated per day = 30,000+ 18,000 = 48,000 $watts$.

Designing the panels need to be done for the available site (Mina Tent) to chick how much area is available for the panel to be installed. Also, it is essential to know the tilt angle of the panel in order to have maximum efficiency. Generally, winter tilt angle latitude is plus 15 degrees while in summer it is minus 15 degrees. In this case, we are using the fixed tilt angle to keep it equal to the latitude. The tilt angle used in this study is 38 degrees.

- **Calculations of the area:** It considers a really important to keep the tents in a place without anyshadow in order to avoid any losses in energy. Therefore, the whole roof is used to install the PV panels.

Length of each tent = 8m

Breadth of each tent= 8m

Total area= 8×8= 64m2

The panels are used in this study is a 250 W panel from Kyocera.

The dimensions of the panel = 1.662 × 0.99 m.

The area of each panel = 1.65m2

Total number of panels that can fit onto 64m2 roof top area

Keep in mind that there will be a 0.85 as a ventilation factor to keep a gap between panels.

The total number of panels = (64/1.65) × 0.85 = 33 Panels

The maximum load of 33 panels= 33 × 250 = 8.25 kVA

The even number of panels are used therefore we are using 32 panels in order to maintain an even number in connection= 32 × 250 = 8 kVA

Clearly, the annual average sunshine hours are about 5 hrs. So, the total number of units that can be generated everyday = 8 × 5 = 40 kVA

Since the total power required is 30 kVA, then the extra 10kVA is used to charge the batteries.

- **Arranging Panels:** The most important part after calculating number of panels is to arrange the panels in the circuit in order to come up with the appropriate voltage and current. So, we select 4 panels of 30V as a string in series to get 30V. After that, we connect each 4 strings in parallel with each other to get the appropriate amount of current. Therefore,

The voltage on each string = 30 V

The total voltage of all strings = 4 × 30 = 120 V

- **Inverter design and selection:** Inverter/charger is used to converts DC power from the batteries into AC that can power standard loads. Also, converts AC into DC energy that can charge deep cycle batteries.

A charge controller sends power in one direction to charge batteries from the power generated by solar modules and prevent the current from draining back into the PV array at night.

The selected inverter for this project is 2 Luminous inverters with 4 kVA capacity for each.

The following Fig. 1. shows the connection of panels in series and parallels as well, also it clearly showsthe inverter and batteries.

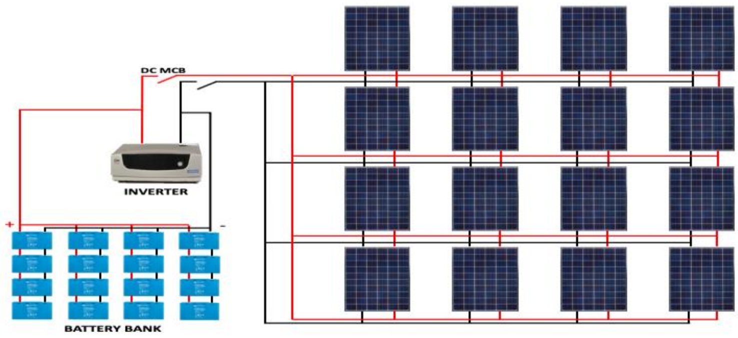

Fig. 1. Schematic Diagram of Panels among with inverters and batteries

- **Battery design and selection:** The Battery is considered one of the most important part of Solar PV project since it saves the energy and discharge it whenever it needs to do so.
  Total Watt-hours of operation of the equipment = 29,165.44 watts.
  Efficiency of the battery = 90%.
  Depth of Discharge (DOD) of the Battery = 0.80 (Lithium Ion Battery).
  Nominal Battery voltage = 12 volts.
  Hours of operation of battery = 120 hours (6PM of day 1 to 6PM of Day 5).
  Battery Capacity (Ah) can be determined as follows:

$$= \frac{\text{Total}\frac{\text{Watts}}{\text{hours}}\text{of operation of the equipment} \times \text{Hours of Operation}}{\text{efficiencyoftheBattery} \times \text{depth ofdischarge} \times \text{Nominalbatteryvoltage} \times 24}$$

$$= \frac{29{,}165.44 \times 120}{0.90 \times 0.80 \times 12 \times 24} = 168.78 \text{ Ah.}$$

The battery capacity should be around 200 Ah, and the available battery in the market is between 200 and 250 Ah. The recommended battery is around 200 Ah to cover the losses and the surge capacity of the system.

- **Calculation the actual capacity of battery:** Since, the total voltage of strings is 120 V, which indicate that the voltage is within the range of charge controller.The energy of the maximum load is 8 kVA, but during the day the only power consumed is air-conditioner which is 1200 VA = 1.2 kVA. Therefore, during the day it considers important to save the rest of energy in the batteries in order to use it later in night.
- **The calculation of the rest of energy:**

  The energy of Maximum load – $\frac{\text{Air-conditioner power consumed}}{\text{efficiency of panels}}$

  = 8 – (1.2/0.8)
  = 6.5 kVA

  The next step is to store the rest of energy from the panels during the day in the appropriate amount of batteries. Since average sunshine is 5hrs.
  Therefore, the total kVA needs to store in the batteries = The rest of energy × Sunshine hours
  = 6.5 kVA × 5hrs
  = 32.5 kVAh

- **Calculation of the Ampere per hour**
  The battery voltage = 48 V
  The total kVAh = 32.5 kVAh = 32500 VAh.
  Ah of battery = The total kVAh / the battery voltage
  = 32500 / 48
  = 677 Ah

  Since we need 700 Ah, then we will use a set of 12 batteries of 48V,200Ah. And a set of 4 batteries of 48V, 100 Ah. In order to cover the required voltage and Ah needed for the project as shown in Fig. 2.

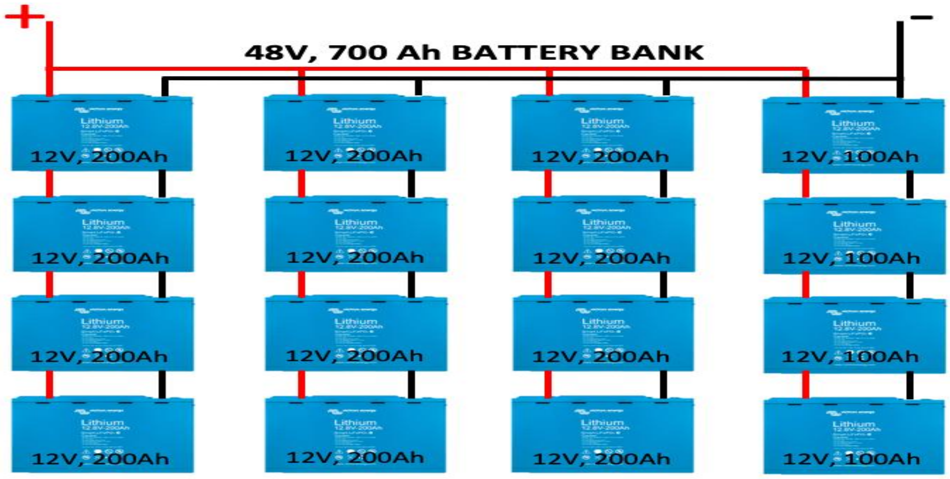

Fig. 2. Schematic Diagram of battery bank connection

- **DC Miniature Circuit Breaker (MCB) selection:**It is a mechanical switch whenever continuous overcurrent flow through it, that will cause to open the MCB contact in order to stop the current to slow in the circuit. It used as short circuit protection or overload protection [19]. It generally located where the parallel connection of PV is performed in the combiner box. The MCB helps to trip of 120V DC supply in case of maintenance. In this project, the rated current of PV strings = 8.39A, since four strings are connected in parallel, so the total current = 8×4 = 32A. The DC MCB that used in this project is 32A, 120V DC.

2.3 The mechanicals design structure of the solar PV system.

The design of the solar PV system plays a significant rule in reducing the power consumptions as well as the electricity generation. Photovoltaic systems can be generally divided into two primary groups:

- **Stand-alone Photovoltaic systems (off-grid):** This system is designed to operate independently without electric utility grid to supply certain DC and/or AC electrical loads [20]. The off-grid system consists of solar panels, charge controller, inverter, and battery, as shown in Fig. 3.

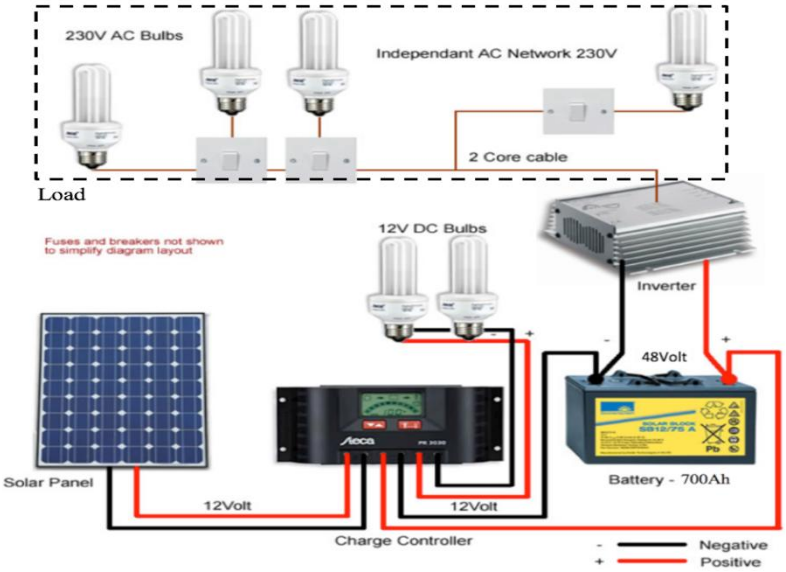

Fig. 3. Stand-alone PV system (off-Grid)

- **Photovoltaic systems (on-grid):**On-grid PV system is an electricity generating PV system connected to the grid. On-grid system consists of solar panels, one or several inverters, charger controller, Main breaker box, meter, and grid connection equipment [21]. AC and DC coupled are two types of grid connection discussed in this project; both of them has advantages and disadvantages to be used in the Tent city (Mina).

- **AC coupled PV system:** AC-coupled systems require a grid-tied inverter and a battery-based inverter [22]. The energy used in batteries may be inverted three times. The first inverting is from solar PV panels (DC) to the critical load panel (AC) through Grid-tied inverter. The second inverting is to batteries (DC) through the battery-based inverter, while the third inverting back to AC again, as shown in Fig. 4.

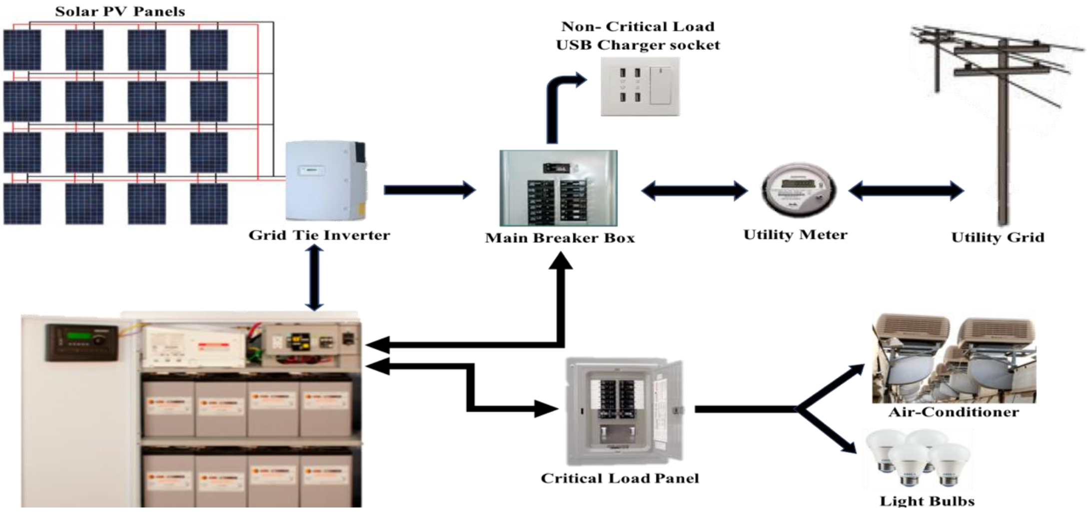

Fig. 4. AC-coupled PV system

- **DC-coupled PVsystem:** DC-coupled systems use a charge controller to charge batteries with solar generation directly and a battery-based inverter to power the critical loads (AC) as shown in Fig. 5. From the previous chapter, the DC and AC-coupled are considered a really logical choice to use in the solar PV system. After studying the two types, it clearly appears that the DC-couple systems are slightly more efficient and more regulated charging than AC coupled systems due to the power is not inverted multiple times [22]. DC-coupled is considered ideal for new installed on-grid system.

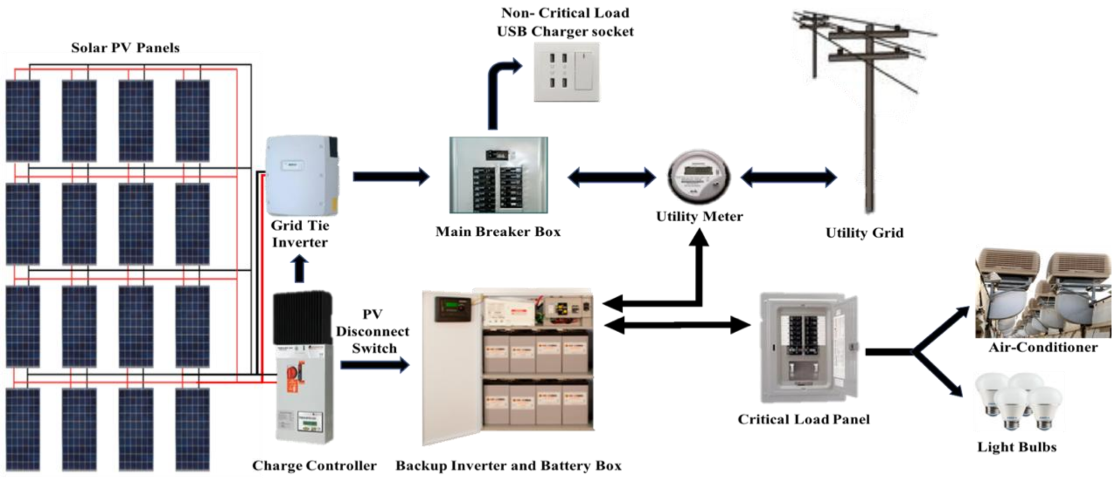

Fig. 5. Dc-coupled PV system

III. RESULT AND DISCUSSION

- **The amount of energy of solar PV system In the Tent City (Mina):** After designing the system of solar PV in the tent city (Mina), it appears that the amount of energy produced is too high in a short period of time. So, the project focuses on how to save this energy by using the proper system during AL Hajj. As mentioned, Al-Hajj period is considered a significant time for pilgrims as well as for the Saudi government, so it needs more concern. Therefore, the result of this project shows how much saving in electrical energy can help to reduce the cost and pollution.

- The following Table 3 presents the quantity of the components for the whole project in the Tent City (Mina), which help to clarify the exact save energy amount from the solar PV system.

Table 3. The quantity of the components in the solar PV system

Components	Quantity per tent	Number of tents	Total Quantity
Panels (250W)	32	160,000	5,120,000
Grid-tied inverter	1	160,000	160,000
Charger controller	1	160,000	160,000
Battery (12V,200Ah)	12	160,000	1,920,000
Battery (12V,100Ah)	4	160,000	640,000
LED bulbs	4	160,000	640,000
Air-conditioner	1	160,000	160,000
USB charging Phones socket	4	160,000	640,000

The energy of the solar PV system that the project will produce in the Tent City (Mina) is discussed based on the load and the total number of tents.

The total panel per tent = 32 Panels

The power of each panel = 250W

The PV load supplied per tent = the total per tent × the power of each panel = 32 × 250 = 8kVA

The total amount of energy that will be produced from solar PV in all tents = PV load × No. of tents

= 8kVA × 160,000

= 1.280,000kVA

= 1280 MVA

It can clearly be seen that the amount of energy produced is huge; this amount not only will help to cover the needs of pilgrims during Al-Hajj period. Moreover, it will be a really effective method to be used and definitely will support country power usage, which will save energy, money, and reduce emissions

- **The efficiency of Solar PV:** This system requires an in-depth study of all the factors that affect the efficiency of solar PV. Usually, the maximum solar PV efficiency is around 25%. The PV module of 250W can produce 1000watts, which considered one of the factors that affect the solar PV system efficiency. In this section, the idea is to discuss the other factors affecting the efficiency of the solar PV system, as mentioned below:
  - The direction of the PV module.
  - The angle of the PV module.
  - The irradiance of the PV module.
  - The temperature of the PV module.
  - The shade of the PV module.
  - The load of the PV module.

- **The direction of the PV module:** The direction of the PV module is important because any change in direction module not according to Azimuth, then the current will reduce, which reduce the power [23]. According to the location of the Tent City (Mina), which considered in the northeast side of earth then the solar panels should face the south. There are two methods to find Azimuth angle. The first is manually by using a compass to south direction with a 15-degree angle. The second is to use the solar tracker, which help to move the PV to the maximum radiation.
- **The angle of the PV module:** After placing the PV module in the south direction, the angle is another factor to adjust. The solar angle of PV needs to set towards the sun. The best angle changes throughout the year, depending on location and seasons. In general, higher tilt angles prefer lower irradiance

conditions in the winter months, whereas a lower tilt angle helps increase productivity in the summer months.

- **The irradiance of the PV module:**Solar module efficiency depends upon the input variable irradiance, as the irradiance is changed from 400W/m2 to 800W/m2 the output efficiency of a module changes [24]**.** As the irradiance increases, the number of photons incident on the module produces maximum power and leads to increase in the efficiency.
- **The temperature of the PV module:**The solar PV module operates according to a laboratory standard at 25°C temperature and 1000W/m2. When the temperature increases, the current and voltage decreases. The conversion efficiency of the module decreases with an increase in module surface temperature [25]. If the temperature increases, then generated electrons to increase the rate of phonon vibrations. This increase is leading to a decrease in voltage [26,27]. In this case, it is essential to select the right type of PV module according to the temperature and location.
- **The shade of the PV module:**The shading effects such as trees, passing of clouds, and close building to solar PV system affect the performance of PV module [28]. Therefore, the better performance of solar panels exists when there are no shading conditions. During shading, a current short circuit is existing, which will lead to a decrease in power output.
- **The load of the PV module:**When the solar system installed, then load calculation is an essential part of adjusting for the reliability of the solar system because the PV system needs to adjust the battery capacity according to load. The load calculation is the factor which makes the system reliable. So, if the load more than the battery capacity, then battery life and PV module efficiency reduce.

IV. CONCLUSION

Saudi Arabia starts to think in deep in transferring the energy from traditional fossil fuel to renewable energy. Solar energy, as mentioned before, is the primary type of renewable energy since the sun shines every day and everywhere, whether it used or not. This paper discusses the importance of using the solar PV system to power up the Tent City (Mina) by its needs of electricity during Al-Hajj period. In this research, the design and selection of the right solar PV system are investigated. The research work discusses the components of solar PV system with its design such as panels, batteries, inverters, charge controller, etc. The area of Mina's tent has studied in order to select the exact number of panels that could produce the maximum power out of them. The batteries are well investigated in order to choose lithium-ion battery as the proper type of battery as well as calculating the actual capacity of batteries that cover the needs for storing enough power. Then, provide the system with protection from overcurrent by using Minatare Circuit Breaker (MCB). After that, the paper discusses the mechanical design structure of solar PV system in both on-grid and off-grid system. It appears that the proper system to be used in Mina is the on-grid DC-coupled PV system since it is slightly more efficient and has better regulation. Finally, the result shows how important to use the solar PV system in the Tent City (Mina) due to the enormous saving energy during a short period time of Al-Hajj. The system saves 1280 MVA of power, this amount not only will help to cover the needs of pilgrims during Al-Hajj, but it will be a really effective method to be used to support the country power which will consider one of the aims of visions of 2030 in Saudi Arabia.

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