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ISTANBUL AYDIN UNIVERSITY
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DESIGN OF A 50 kW SOLAR PV POWERED CHARGING STATION FOR EVs

MASTER'S THESIS

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DEDICATION

I hereby declare with respect that the study “Desıgn of A 50 Kw Solar Pv Powered Chargıng Statıon For Evs”, which I submitted as a Master thesis, is written without any assistance in violation of scientific ethics and traditions in all the processes from the project phase to the conclusion of the thesis and that the works I have benefited are from those shown in the bibliography.

Yazan A. R. Aloqaily

FOREWORD

First of all, I would like to thank the Almighty ALLAH for his support, help, and generosity to complete this thesis.

Second, I would like to thank my family, especially my mother Adilah for supporting me throughout my life. My mother constantly pushed me to be the best person that I can be, and I would not be the person I am today without you in my life. I wish my father Ali Aloqaily could be here who passed away on 20 September 2020. I missed you, Dad. I would like to thank my brothers: Yanal, Mohammed, Yazed, Yaser, Akthim, for all the support and encouragement.

I would like to express my special gratitude and thanks to my advisor Prof. Dr. Nedim Tutkun, head of the Electrical and Electronic Engineering department at Istanbul Aydin University, for his continuous support, patience, motivation, and immense knowledge that helped me successfully carried out this thesis. I am also grateful to all my teachers for their kind guidance and encouragement. Finally, I would like to thank all my friends, colleagues, and my family in Jordan, especially Bashar, Moath, Mahmoud, and Ghaith for the support I have received during these years.

June 2021 Yazan A. R. Aloqaily

DESIGN OF A 50 kW SOLAR PV POWERED CHARGING STATIONFOR EVs

ABSTRACT

This study investigates to design a 50-kW solar photovoltaic (PV) charging station for plug-in hybrid electric vehicles (PHEVs) to mitigate problems encountered in renewable energy utilization processes and to cope with the increasing power demand by PHEVs for the near future, because solar energy the among the cleanest source of energy which does not contribute to carbon emission as in the case of thermal or nuclear power plants hence, it is an essential connection to solving the environmental problems of how to charge PHEVs from renewable energy. The purpose is to create a highly powerful, intelligent charging network that is powered by solar energy for charging PHEVs at workplaces. This study further reduces the operating cost of PHEVs in long run makes the whole setup of the charging station more economical than conventional sources of energy. With the help of online commercial tools along with a global solar atlas, the available solar energy for one year in king hussein business park (KHBP) is calculated along with the required PV modules, maximum power point tracker, inverter, and battery bank. The annual variation in solar insolation is analyzed to determine the energy available for PHEV charging and the necessity for grid connection and PV modules are selected for the worst irradiance level. MATLAB/Simulink is used to design, integrate, and simulate the solar PV system as well as to determine the system stability and performance. The system works satisfactorily under the given conditions and can be modified by adding protection and other components to obtain a more realistic result. This study will help in commercializing the renewable energy charging station of electric vehicles and keep the environment clean.

Keywords: PV charging station, hybrid electric vehicles, power demand, renewable energy, maximum power point tracker.

ELEKTRİKLİ ARAÇLAR İÇİN 50 kW'lık GÜNEŞ ENERJİLİ ŞARJ İSTASYONU TASARIMI

ÖZET

Bu çalışma yenilenebilir enerji kullanım süreçlerinde karşılaşılan sorunları azaltmak ve yakın gelecekte “plug-in” hibrit elektrikli araçların artan güç talebini karşılamak için 50 kW'lık solar fotovoltaik (PV) şarj istasyonu tasarlamayı araştırmaktadır. Solar PV kullanımı ile “plug-in” hibrit elektrikli araçların uzun vadede şarj maliyetini düşürerek şarj istasyonunun tüm kurulumunu geleneksel enerji kaynaklarından daha ekonomik hale getirmek çalışmanın esas amacı olarak ele alınmaktadır. Çevrimiçi ticari araçların yanı sıra küresel bir güneş atlası yardımıyla, King Hussein Business Park'ta bir yıllık mevcut güneş enerjisi, gerekli PV modülleri, maksimum güç noktası izleyicisi, invertör ve batarya bankası ile birlikte hesaplanır. “Plug-in” hibrit elektrikli araçların şarjı için mevcut olan enerjiyi belirlemek için güneş ışınımındaki yıllık değişim analiz edilir ve şebeke bağlantısı gerekliliği ve en kötü ışınım seviyesi için PV modüller seçilir. Bu çalışmada, solar PV sistemini tasarlamak, entegre etmek, simüle etmek, ve sistem kararlılığını ve performansını belirlemek için MATLAB/Simulink kullanılmıştır. Elde edilen sonuçlar tasarlanan sistemin verilen koşullar altında tatmin edici bir şekilde çalıştığını göstermiştir.

Anahtar Kelimeler: PV şarj istasyonu, hibrit elektrikli araçlar, güç talebi, yenilenebilir enerji, maksimum güç noktası izleyici.

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ABBREVIATIONS

EV's : Electric Vehicles

PV : Photovoltaic

DG : Distributed Generations

RES : Renewable Energy Sources

SPCS : Solar Powered Charging Stations

DC : Direct Current

AC : Alternating Current

STC : Standard Test Conditions

C-SI : Silicone Crystalline

P-Si : Polycrystalline

MC-Si : Multi-Crystalline Silicon

CdTe : Cadmium Telluride

OPC : Organic photovoltaic Cells

A-Si : Amorphous Silicon

CIGS : Copper Indium Gallium Selenide

MPP : Maximum Power Point

V_{oc} : Open circuit voltage

I_{SC} : Short circuit current

HEV : Hybrid Electric Vehicle

PHEV : Plug-in Hybrid Electric Vehicle

PEV : Plug-in Electric Vehicle

CCS **:** Combined Charging System
GCPV **:** Grid-Connected Photovoltaic system
GCPV **:** Grid-Connected Photovoltaic system
ESD **:** Energy Storage Device
TOU **:** Time of use
EVCS **:** electric vehicle charging station
PWM **:** Pulse Width Modulated
AGM **:** Absorbed Glass Mat
SOC **:** State of Charge
DG **:** Distributed Generations

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I. INTRODUCTION

A. Scope and Literature Review

There is emerging definition related to EVs technologies. Many primary ideas in the manufacture of EVs predate internal combustion engines for fuels. There were several EVs on our world's highways in the 19th century than gasoline cars. There are now many other sales designs in world and their existence is estimated to rise dramatically in the next thirty years. Developments in energy storage, design flexibility of vehicles, electric grid mechanization moreover the value of EVs for Customers, companies and government organizations would improve and encourage long-term moves to improved transportation alternatives (Awasthi, et al., 2017). EVs are much more effective energy than petrol/diesel-powered motor cars and do not release carbon from engines. They are much smoother, less annoying and need limited maintenance (Mouli & Chandra, 2018).

EVs are therefore sustainable mainly if they are charged by energy from renewable sources and not by power stations dependent on fossil fuels (Messagie & Boureima, 2014), (Nordelöf, Messagie,, Tillman, & Söderman, 2014). If EVs are supplied from a network primarily driven by fossil fuels such as carbon or gas, in comparison to common opinion, emissions are substantial and not negligible.

On the other hand, if EVs are charged from a grid which is mostly powered by renewable power plants, net emission then is almost zero. The obstacle is therefore to use sustainable energy sources to fuel electric cars in future. The best renewable energy sources to electric vehicles would be wind, geothermal, biogas, solar, hydropower and tidal energy. Including the use of photovoltaic solar panels for charging EVs, is an appealing option for several purposes:

- The price of solar photovoltaic (PV) sharply dropped during last decade, and it is around 1$/Wp (Obi & Bass, 2016).

- High accessibility PV power for EV users is available since Photovoltaic cells can be attached to rooftop and as solar parking lots near the location of EVs. There is a huge amount of unusable PV capacity of top of buildings or parking lots, and this should be taken advantage of in the future.
- The power demand and energy on the grid is decreased due to electricity charging because the charge energy is provided locally "green" by solar panels (Denholm, Kuss, & Margolis, 2013), (Li, Lopes, & Williamson, 2009, July). This decreases/reduces the need to strengthen the network (Birnie III, 2009).
- PV systems provide low noise, no moving components and are virtually free of maintenance.
- The price of charging the electric vehicle from photovoltaic panels is lower than the grid and limits the effects of low tariff feed-in PV (Mouli, et al., 2016, June), (Tulpule, Marano, Yurkovich, & Rizzoni, 2013).
- PV devices typically use a battery to store solar energy to handle the fluctuations in solar activity both daily and seasonal (Mouli, G; Bauer, P; Zeman, M, 2015, June). When charging EVs from PV, the EV battery can be used as power storage for the PV, and no extra battery is needed (Carli & Williamson, 2013).

B. Literature Review

1. Charging an EV from Grid

Although charging EV via grid can seem easy and comfortable, it is difficult method has different consequences on the grid infrastructure that runs today. The power demands can vary from 1kW to 50kW for peak to nonpeak hours, based on the type of charging station, which creates higher power demand and strains grid infrastructure. According to Zeming Jiang, Hao Tian, Mohammed J Beshir, Surendra Vohra and Ali Mazloomzadeh demand growth is expected during the daytime if EV users come and start charging at their specific workplace. Further, the research carried out in it suggests that the peak energy demand measured in the network was between 3 pm - 5 pm on a normal working day because of the EV activity (Jiang, Tian, Beshir, Vohra, & Mazloomzadeh, 2016, September). Salman Habib, Muhammad Kamran, and Umar Rashid were carried out the amount of entry and discharge or charge techniques of vehicles can affect the economy, pollution and grid stability greatly. Also, the loading of these vehicles may affect grid stability without suitable scheduling or coordination of the charging of EV batteries. Additional influential effects on grids since EVs will be used (Habib, Kamran, & Rashid, 2015):

- Higher generation costs with higher demand.
- Overcrowding transmission line.
- Overloading of distribution transformers.
- Excessive damages and losses in transmission line.
- The variations in voltage of EV charging sites.
- Grid infrastructure wear.

Saadullah Khan and Aqueel Ahmad worked on the creation of a systematic charging technique using clean energy sources for the use of distributed generations (DG). The above impacts could largely be reduced, which would make EV a viable and economical prospect (Khan, et al., 2018).

Table 1 Uncoordinated and Coordinated EV Charges electrical Characteristics

	No load electric vehicle	Coordinated Charging	Uncoordinated Charging
Peak Load (kVA)	23	25	36
Line Current (A)	105	112	136
Power Loss (%)	1.4	2.1	2.4
Node Voltage (V)	220	220	217

EV charging from grid also has no Positive effect in the atmosphere. It is a wrong assumption that people assume that EV-associated Carbon dioxide emissions are negligible. However, energy generation from other carbonizing sources (coal, gas, etc.) produces higher Carbon emission used to charge these EVs. According to Joyce McLaren, John Miller, Eric O'Shaughnessy Eric Wood and Evan Shapiro there is no major achievement in achieving decreased CO2 emissions from the United States, in the areas with high carbon intensity networks (McLaren, Miller, O'Shaughnessy, Wood, & Shapiro, 2016). This is because the emission decrease advantages of charging stations decrease with the increased grid CO2 level. Further, Joyce McLaren, John Miller, Eric O'Shaughnessy Eric Wood and Evan Shapiro suggests that grid carbon capacity has a far larger benefit than charging situation to overall EV-related emissions, it is a complex and tedious interchange method. Nesimi Ertugrul studied about the establishment of further charging stations, in particular renewable sources, would have a significant environmental effect with CO2 reduction (Ertugrul, 2016, November). In the previous year’s group of authors like (Peter Kelly-Detwiler's) and (Ghanim Putrus and Pasist Suwanapingkarl) have information and thoughts exchanged on how to charge electric cars using power generation produced by conventional sources of energy such as coal, gasoline, and hydropower (Kelly-Detwiler, 2013).

2. Charging EV through Renewable Energy Sources

Renewable energy technologies have increasingly become an alternative to traditional fossil fuels. According to Mohammed Hadi Amini, Mohsen Parsa Moghaddam and Orkun Karabasoglu says that as these sources of electricity can be found near the power station, system efficiencies can be significantly increased with minimized losses, voltage changes, and cost of power infrastructure (Amini, Moghaddam, & Karabasoglu, 2017). The mixture of renewable energy sources (RES) with electric vehicle provides a wide variety and low environmental impacts for sustainable growth. Shaaban et. Al presents the systemic design method to reduce emissions of GHG and system costs by evaluating the optimum level of EV penetration for RES units in addition to their position, volume, and year of operation (Shaaban & El-Saadany,, 2013). In addition, through multiple research (Jeongkyun Roh, Wencong Su and Jianhui Wang), (Mohammad E. Khodayar and lei wu) and (Jenni Gunter, Khurram Afridi and David Perreault) the variable nature of renewable energy sources (RES) over grids of power systems has been developed to reduce through Intelligent coordination and storage capabilities of PHEVs (Gunter, Afridi, & Perreault, 2013). Balasubramaniam Natarajan and Anil Pahwa proposed the creation of solar photovoltaics has been shown across a clean, safe and alternative charge station infrastructure-based charging stations or solar powered charging stations (SPCS), usually for producing electricity of electric vehicle charging also to support the grid in parking areas. 25% to 33% of USA total energy can be generated by coverage 200 million parking lots with roofs made of solar panels (Jhala, Natarajan, Pahwa, & Erickson, 2017). For instance, Envision Solar International Inc., developed electric vehicle autonomous renewable charger (EV ARC) a standalone SPCS system with battery storage built to be autonomous without interference with the grid (2020; ENVISION SOLAR," EV CHARGING, OUTDOOR MEDIA, ENERGY SECURITY, 2006. , 2020).

The places of the SPCS will mainly focus on the terms of operation of the EVs:

- Electric vehicles at work areas (parking the car more than one hour).
- Electric vehicles at house.
- Electric vehicles over the road.

In most cases, Balasubramaniam Natarajan and Anil Pahwa studied about the users have SPCS at home on their roof of a building solar panels or solar panels over carport. In other cases, EV suppliers provide their consumers with premium charging facilities. For instance, Tesla company has a US and Europe-wide network of SPCS. This is a typical example of charging the EVs along the way. In fact, SPCSs in public spaces like malls, convention centers, gyms, public parks are becoming more popular. Ratil H. Ashique, Zainal Salam, Junaidi Abdul Aziz, and Abdul Rauf Bhatti drawn simple scheme of a SPCS with energy storage unit (ESU) in Figure 1 (Ashique, Salam, Aziz, & Bhatti, 2017).

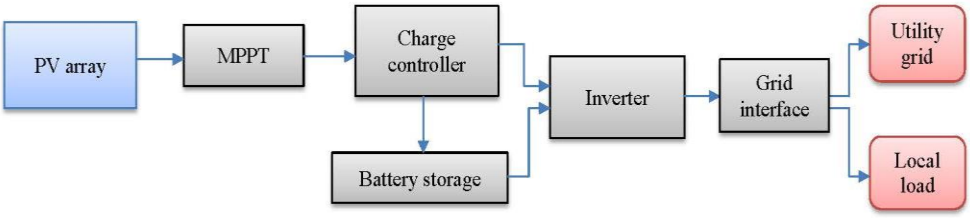


Figure 1 Simple scheme of a SPCS based EV charging.

Quanhua Liu and Mark Jacobson these researchers work on the way electric vehicles can be charged with wind and solar energy in past years. Their conception is primarily based on obtaining multiple energy sources, depending on the temperature and time of one place. They said that they will be given an idea about what electricity they would produce and save in the future to use the vehicle by predicting future weather conditions. However, climate-related estimates are generally not reliable or accurate. This could affect the availability or no electricity to operate the car (Delucchi & Jacobson, 2011).

However, few researchers like Zhang, Weige, et al have introduced academic papers on how to use the best daytime charging method to charge electric vehicles using renewable energy since the daytime have the best solar irradiance, they try to develop a strategy to increase the energy dropping at peak times on the ground surface. The energy combining technique using PV cells is environmentally, but they did not describe how extra energy is provided and how energy is generated during times of small or no solar irradiance (Zhang, Huang, & Jiang, 2015). Our research attempts to understand how solar energy from photovoltaic cells can be used to charge electric vehicles from parking areas and roofs of the buildings, thus providing room for unused power at peak hours, and energy reuse during lower power times.

Also, some authors wrote on plug-in hybrid electric cars like B. Kramer and Sudipta Chakraborty these vehicles are shown to use (consume) both fuel and electricity at evaluation techniques depend on the miles travelled and route topology. Not only do these vehicles increase emissions, but they are pricey because of their dual motorships. Solar power is not only good for the environment but safe for charging electric vehicles (Kramer, Chakraborty, & Kroposki, 2008, November).

C. Thesis Purpose

The purpose of this thesis is to create a highly powerful, intelligent charging network that is powered by solar energy for charging electric vehicles at home and workplaces. The research focuses on charging EVs from solar panels at workplaces such as companies and schools. The purpose of this behind. Firstly, there is a relatively wide space in workplaces for Photovoltaic module installations. Secondly, during the day the working hours of workers mostly match the hours to the sunshine. This gives enough time to recharge an electric vehicle EV battery from photovoltaic panels. Finally, the use of 8 hours of car parks at the workplace enables lower charging energy thus decreasing the price and complication of the EV chargers required. The long parking periods allow smarter charging to still be applied, which helps to further minimize the costs.

D. Problem Statement

These days, with worldwide concern for greenhouse gases and environmental pollution, EVs are being produced in speed for commercial and personal uses. Users must charge the battery of the vehicle when they run out of their battery at the charge station when these vehicles are used every day. It does not take short to charge your car fully. Besides, few drivers of electric vehicles do face the issue of charging their electric vehicles at some charging stations as their car batteries are not matched with the adapter. Therefore, it is an essential and critical connection to solving the environmental problems of how to charge electric vehicles from renewable energy.

II. PV SYSTEM

A. Introduction

In 1839, Edmund Becquerel figured out how sunlight is used to generate an electric current in a solid object, but about a century after scientist actually discovered that such materials were transformed to light energy by photovoltaic effect into electrical energy. At the beginning 1950s, PV cells were developed as a spin-off of transistor technology.

A photovoltaic array (PV) is a power system planned to transform sunlight into electrical energy using semiconductor materials that show photovoltaic effect. There are many parts of photovoltaic technologies such as solar cells, inverters, wires, batteries, electric metering, charging controller and other electrical equipment's. Photovoltaic systems provide electricity that is effective, affordable, and secure. Photovoltaic systems produce reliable, affordable, and clean energy. It can be used in many products such as embedded photovoltaic systems in building solar vehicles, and standalone systems.

Figure 2 Solar PV system used for electricity generation.

Figure 3 shows various types of photovoltaic module separated primarily into standalone photovoltaic module (off-grid) and a grid-connected photovoltaic module. (On-grid).

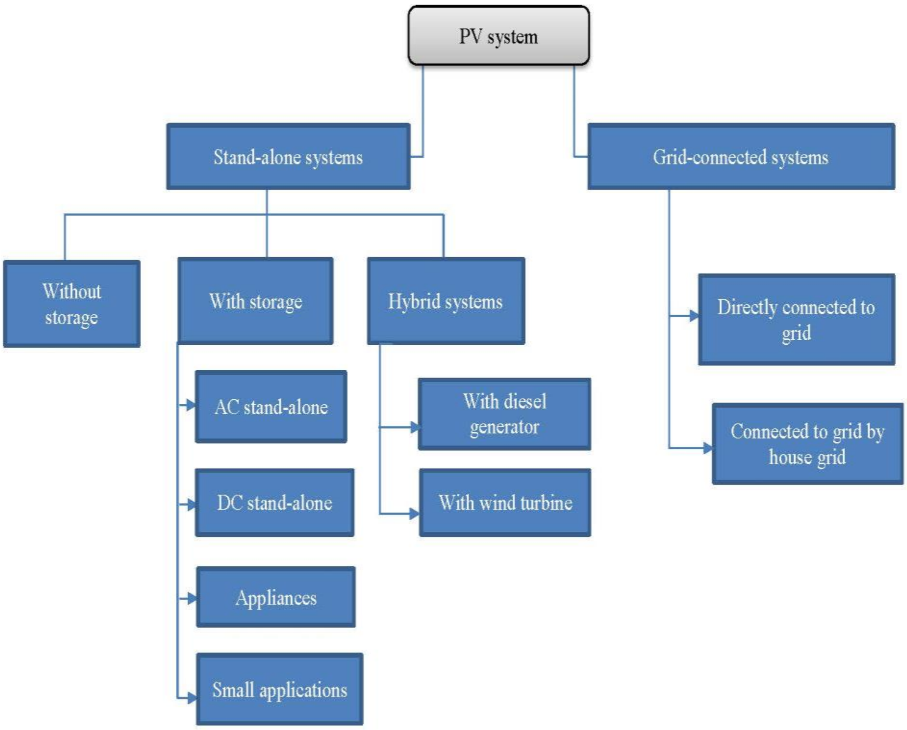


Figure 3 Photovoltaic module types.

B. Solar PV System

1. Solar PV Cell

A single PV cell is a thin semiconductor chip composed of two sheets of high purity silicon (PV cells are made of several semiconductors, however the most used crystalline silicone). As sunlight pummels the chip, photons knock out excess electrons in the sunlight. This differs between these sides by the voltage as excess electrons are attempting to travel into the deficit part. This voltage is 0.5 volts in silicone.

On either side of the semiconductor are metallic contacts. For an additional connecting circuit, Electrons will return to their origin and the circuit moves with a current. It actually functions as an electron pump, but this PV cell has no storage space. The sum of electrons that knock off solar photons measures the quantity of current. More electrons are produced by wider cells, more powerful cells or by cells exposed to more focused sunlight.

2. Solar PV Module

A PV module made up of multiple PV cells connected in parallel to improve current and in series to get a higher voltage. For massive energy generation, thirty-six cell modules are the industry norm.

The module is enclosed across the front cover with tempered glass (or any other translucent items) and on the rear surface it is covered and waterproof. The sides are weatherproofed, and sometimes there is an aluminium frame that keeps everything in one storage structure. There is a connecting box or wiring pipes at the back of the module to provide electrical control.

3. Solar PV Panel

PV panels contain one or even more PV modules installed as a pre-wired, field-installable package. The modular design of photovoltaic panels permits structures to expand with changes needed. Various manufacturing modules can be combined without any difficulty since all modules have an estimated output voltage of 1.0 volt.

4. Solar PV Array

PV array consists of a variety of separate PV modules or panels which are connected in a series and/or in parallel to transmit the current and voltage that any system's needs. The larger the array surface area, the more solar energy would be produced in overall.

Figure 4 From cell to array.

PV systems and array efficiency in conformity with their peak DC output is usually tested under standard test conditions (STC), the temperature of the solar cell itself 25℃ (77 F), solar irradiance level 1 kW/m^2 and mass of the air 1.5. Although since way photovoltaic systems or arrays operate on the field is not always popular, actual execution is usually between 85 and 90% of the STC level.

C. Solar PV Types and Efficiency

From (Bagher, Vahid, & Mohsen, 2015), Details of various types of solar cells are mentioned (combining several cells results in PV module), and sequential order and overall field performance of all solar cell types is shown in Figure 5. From (Henning, 2020), the development of a multi-crystalline PV module in recent years has been seen to have controlled the industry, PV module is the major element for the solar irradiance conversion for electrical energy. ‘Maxpower CS6U-320P’it is one of the most operated modules for EV charging station in Canada.

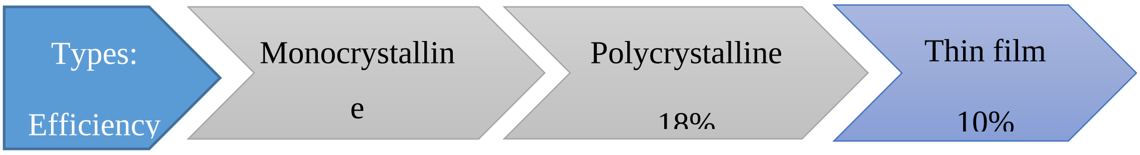


Figure 5 Evolution of solar cells.

Various PV cell types support multiple roles and purposes. PV cells are commonly divided into three categories with an emphasis on fundamental materials and solar cell performance.

1. Silicone Crystalline Cells (c-SI):

These cells were originally developed in the 1950s and are generally used in most solar cells, very popular and powerful semiconductor material (This Month in Physics History, 2020). Crystalline silicone solar cells consist of multiple types but vary in their respective levels of purity. That is, when the silicon atoms are well matched, this special silicon is better than most since the solar cells produced of that species are able to transform solar energy into electricity efficiently (Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film, 2017). Two forms consisting of crystalline silicone; monocrystalline and polycrystalline.

Figure 6 Monocrystalline Solar Panel.

Monocrystalline Silicon solar cells are made of cylindrical ingots and four sites cut to produce silicon wafer. Not only does this reduce prices but also optimizes ingot efficiency. However, the crystals have a higher performance capacity of up to 20%, a small size, so area efficient and lifetime is more than 25 years (Monocrystalline silicon, 2020). While they have an essential advantage over other silicone solar panels, their performance is easily influenced by drastic weather changes and relatively expensive.

On the other hand, polycrystalline (p-Si)/multi-crystalline silicon solar cells (mc-Si) consist of squared ingot wafers (Which Solar Panel Type is Best? Mono-, Polycrystalline or Thin Film?, 2014). They are less brittle, and less heat resistance than monocrystalline solar cells. But the energy efficiency is less than 20%, the efficiency of space is less and less favorable prices in markets.

Figure 7 Polycrystalline Solar Panel.

String Ribbon seems to be another type of Evergreen Solar Company's multi-crystalline silicon cell production. The cost of manufacture is lower than monocrystalline, since production requires half the quantity of silicone in comparison to monocrystalline. However, this is ineffectual, because of reduced power performance compared to polycrystalline and due to its lower space efficiency.

2. Thin-Film PV Solar Cells (TFPC/TFSC):

This solar cell is made up of: Cadmium Telluride (CdTe), Organic photovoltaic cells (OPC), Amorphous Silicon (a-Si), and Copper indium gallium selenide (CIS/CIGS). Basically, they are the second version of solar panels produced by depositing thin layers on a substratum of solar cell. Around the same time power output is decreased in favor relative to monocrystalline cells combined with shorter life makes it lower in terms of preference.

CdTe has been found the only thin-film solar panel can overrun cost efficiency silicone solar panels with a solar panel performance of 9-11%. The power payback period is also shortest. While it has high performance and lower time in the energy pack, it is unclear about its high costs to produce a tellurium element and its high toxicity to cadmium makes its preference uncertain.

Figure 8 Thin-Film Solar Panel.

Furthermore, Amorphous Silicon (a-Si), essentially used in limited power combining, the substrate is low-cost with has little non-toxic silicon. It consumes a full variety of light spectrums and thus works well in nearly any hour of the day, independent of the differences of temperature. The output power is very poor, however (though can be improved by stacking) and still less than one year's efficient lifetime (Sahaya, Sethia, & Tiwarib, 2013).

Copper indium gallium selenide (CIS/CIGS) is a solar cell with a thin film used for turning sunlight into electricity. CIGS is one of three key techniques thin film (PV) technologies, the other two is cadmium telluride and amorphous silicon. Due to the high absorption coefficient and high absorption of sunlight the material requires a much thinner film than in other semiconductor elements. With a laboratory efficiency exceeding 20%, a copper, indium, gallium, and selenide absorber is used in this product (Green, et al., 2017).

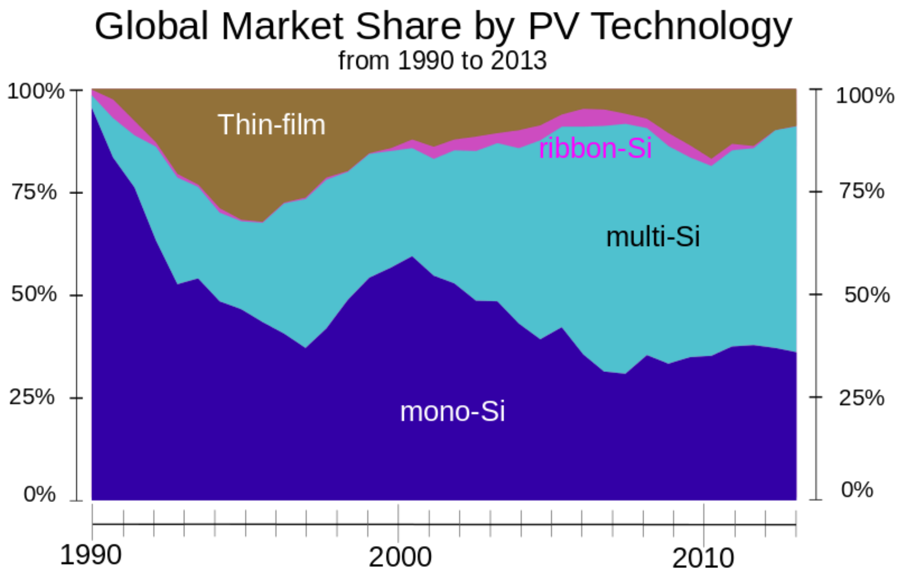


Figure 9 Global market share for photovoltaic technology from 1990 to 2014.

In 2010, when the traditional PV systems were in short supply, thin film it represented 15% of the total market. In 2014, it decreased to 8%, and could stable at 7% from 2015 to 2020.

3. Emerging PV Solar Cells:

This is a photovoltaic unit of thin films that use organometal as well as inorganic materials. Presently they still possess lower efficiencies and lifespan still shorter as well. This contain; Copper Zinc tin sulphide solar cell (CTZTS), Dye-sensitized solar cell, Polymer solar cell, Quantum dot solar cell, Perovskite solar cell, between all that mentioned above, the best solar conversion efficiency is the Dye – sensitized solar panel with around 11 percent since only thin layers are constructed and conductive plastic in front layer, this helps them to radiate some heat away effectively and rapidly. Suitable therefore for slightly lower temperatures (Ultrathin, Dye-sensitized Solar Cells Called Most Efficient To Date, 2020).

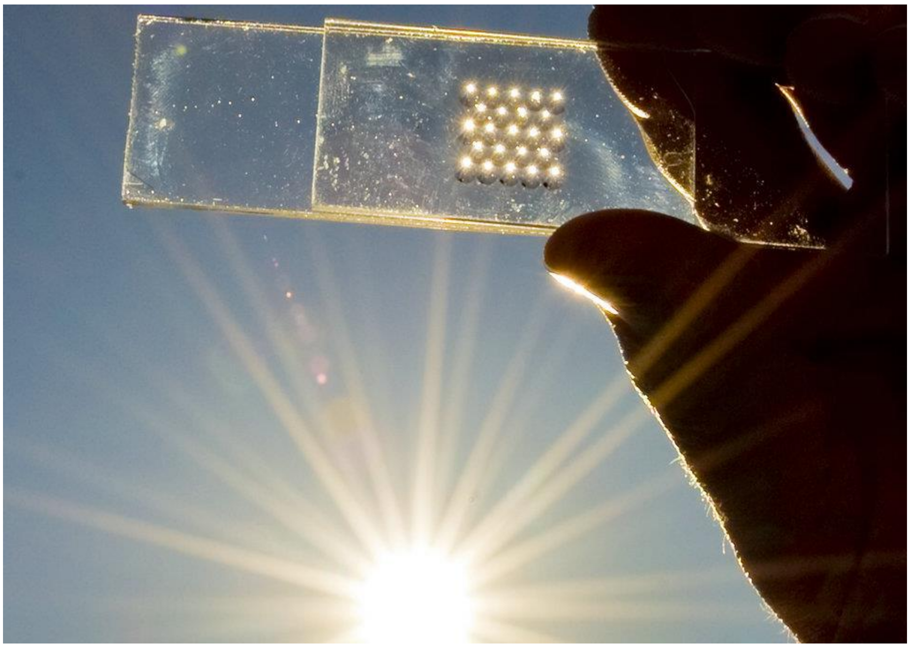


Figure 10 Emerging Photovoltaics Solar Cells.

Based on the data obtained from Table 2 as shown below, we decided to choose the silicon crystalline solar (Specifically 1STH-435-WH solar panels) panel to design the solar panel. this is since it has an efficiency of more than 23%. Furthermore, with a fill factor of over 80 % (that is ratio of the solar cells actual power output to its dummy output) over an area of 778 da.

Table 2 Confirmed terrestrial module efficiencies measured under the global at temperature 25℃ (77 F), irradiance 1 kW/m^2 and mass of the air 1.5 (Green1, Jul, 2014).

Classifications	Effic. (%)	Area (cm²)	Voc (V)	Isc (A)	FF
Si (crystalline)	22.9 ± 0.6	778 (da)	5.6	3.97	80.3
Si (large crystalline)	22.4 ± 0.6	15775(ap)	69.65	6.34	80.1
Si (multicrystalline)	18.5 ± 0.4	14661(ap)	38.97	9.14	76.2
GaAs (Thin film)	24.1 ± 1	858.5(ap)	10.89	2.25	84.2
CdTe (Thin film)	17.5 ± 0.7	7021(ap)	103.1	1.55	76.6
CiGs (Thin film)	15.7 ± 0.5	9703(ap)	28.24	7.25	72.5
Organic	8.7 ± 0.3	802(da)	17.47	0.57	70.4

Effic. = efficiency.

(ap) = aperture area.

(da) = designated illumination area.

FF = fill factor.

Characteristics of a PV Module

In the relation between output current and voltage the electrical parameters of a solar cells array are summarized. PV systems or panels usually have a current-voltage (I-V) or a power-voltage (P-V) characteristic. As we can see Figure 11 represented characteristics curves of a PV cell. We usually use power-voltage (P-V) curve to figure out maximum power point tracking (MPPT) and (I-V) to see the relationship between the current and voltage under Stander Test Condition (STC).

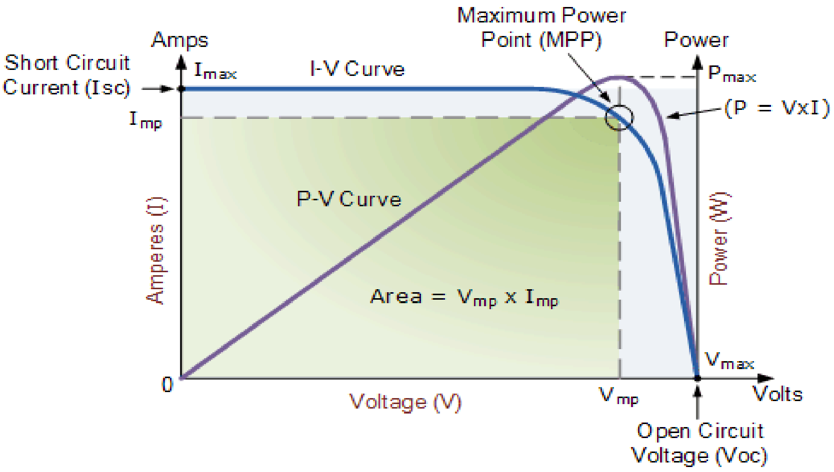


Figure 11 I-V and P-V characteristic curves of a PV array.

The parameters related to the PV cell are (Electrical4U, 2020):

Open circuit voltage (V_{oc}): Solar panel output voltage at standard test conditions if no load is connected to the terminals of the systems Voc will be the maximum voltage that the array provides, and the current will be equal to zero. This solar module performance is primarily dependent on the technologies used to manufacture photovoltaic panels. This open circuit voltage of a photovoltaic systems also depends upon operating temperature. This value is significantly greater than Vmax which concerns the operation of the photovoltaic panels which is fixed by the load.

$$V(\text{at } I = 0) = V_{oc} \quad \textbf{(2.1)}$$

Short circuit current (I_{SC}): The maximum current supplied by the photovoltaic panels when the output connectors are shorted together (as short circuit) the voltage across the panels will be zero. This value is even greater than Imax for the standard circuit current. The current also depending on the panel areas exposed to sunlight.

$$V(\text{at } I = 0) = V_{oc} \quad \textbf{(2.2)}$$

Maximum power point (P_{max}): This refers to the level at which power is provided by the panels connected to load (batteries, inverters) at its maximum value. Maximum power point of a PV panels estimated in Watts (W) or peak Watts (Wp).

$$P_{max} = I_{mpp} \times V_{mpp} \quad \textbf{(2.3)}$$

Where, Im maximum current and Vm maximum voltage.

Fill Factor known as the ratio of maximum power (Pm = Vm x Im) to product of open circuit voltage (Voc) and short circuit current (Isc). This value for the full factor provides an indication of the array performance and the closer the fill factor to 1 (unity), the more power the cells can provide. Typical values are between 0.7 and 0.8.

$$FF = \frac{P_{max}}{I_{sc}V_{oc}} = \frac{ImVm}{I_{sc}V_{oc}} \quad \textbf{(2.4)}$$

Efficiency: The ratio of maximum power at standard test condition, to the input power. As we know that input power is solar radiation for solar cell considered as 1K w/m2

$$\eta = \frac{P_{max}}{P_{in}} = \frac{ImVm}{1000A} \times 100\% \quad \textbf{(2.5)}$$

Where, A is the exposed area of the solar systems, Im maximum current, Vm maximum voltage, Pmax maximum power at standard test condition and Pin input power.

D. Effect of Tilting and Tracking in Panels

From (U.S. Energy Information Administration, 2020) through various times and times of the day, sunlight angles are variable, the solar tracking system is a device to adjust position or angles of the photovoltaic systems to face sunlight to optimize irradiation to achieve optimum efficiency. It is quite clear that the production of solar power from the Photovoltaic panels rises as the direction of the sun's location can be either tracked or tilted. Figure 2.12, 2.13 full information is available on photovoltaic panel direction, i.e., fixed tilt, monitoring and seasonal tilt mechanisms.

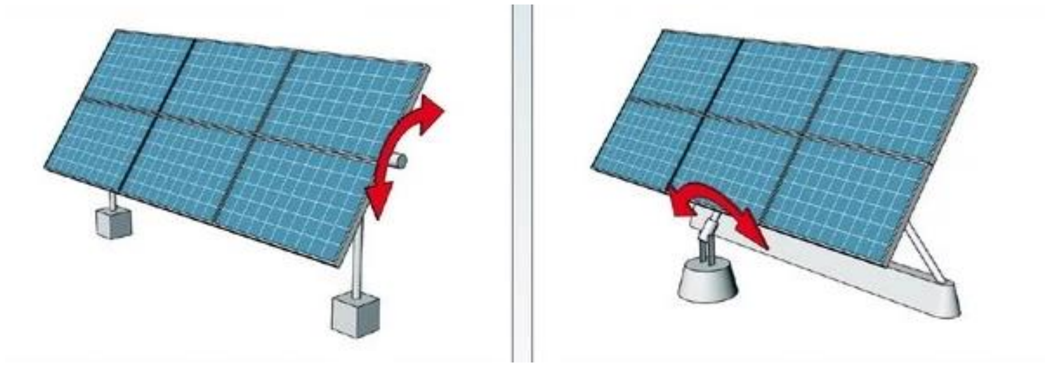


Figure 12 Single-axis solar tracking system.

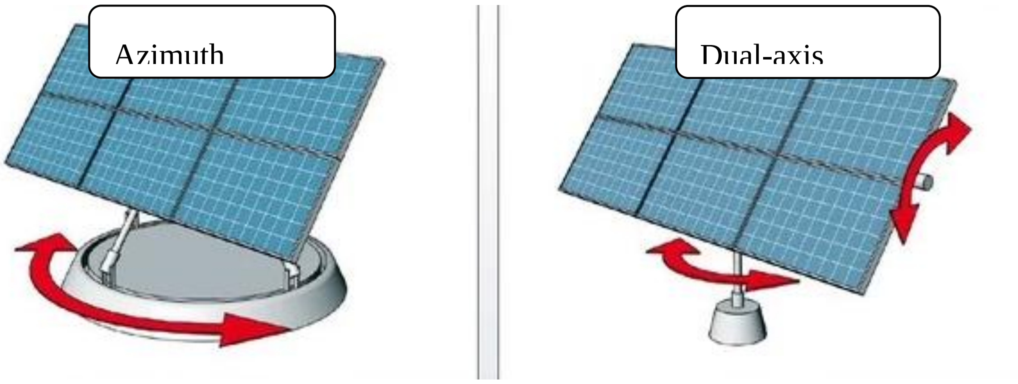


Figure 13 Dual-axis solar tracking system.

Figure 12 shows single-axis solar trackers, it rotates in one axis and the rotation axis can be horizontal or vertical this rotating improves the amount of total power produced by solar cells. In dual-axis solar trackers, maximum energy collection can be achieved, because of its moves in two different directions vertically and horizontally so it can track the sun's anywhere these types can added power output (approx. 45%) (alibaba.com," solar pv ground screw, photovoltaic mounting system, photovoltaic mounting system accessories, roof solar pv mounting bracket, ground pv, 2015., 2020).

III. CHARGING ELECTRIC VEHICLES FROM SOLAR ENERGY

A. EV charging

EV charging can be carried out today by Ac/Dc chargers (Yilmaz & Krein, 2012). In both techniques, the power coming out of the grid is transferred from Ac to Dc to charge the battery of the vehicle. For HEV and PHEV, the battery for electric vehicles is normally a few kWh and for PEV tens of kWh. A few examples are Hybrid Electric Vehicle (HEV): The Toyota Prius is the most widely recognized example of this types with 1.3kWh battery; A Plug-in Hybrid Electric Vehicle (PHEV): Mitsubishi Outlander are the top-selling versions with 12.0 kWh battery and A Plug-in Electric Vehicle (PEV): Toyota Rav4 with 75 kWh battery (García-Garre, Gabaldón, Álvarez-Bel, Ruiz-Abellón, & Guillamón, 2018).

The Dc charge power Pch is provided to the battery with the voltage Vev in terms of the charge current Iev.

$$Pch = Vev \times Iev$$

The energy supplied to the Ech battery for a period tch

$$\mathrm{Ech} = \int_{0}^{\mathrm{tch}} Pch \, dt$$

1. Ac Chargers for an EV

Ac charging of electric vehicle is conducted using a single or three phase Ac connection using an onboard Ac/Dc converter of EV's (Sae, 2010). There are three primary methods of commonly used Ac charging techniques (Van Den Bossche,, 2014) as shown in Figure 14 and Table 3:

1) Module 1, 1ϕ charger used in the USA (SAE J1772-2009).

2) Module 2 Mennekes, 1ϕ and 3ϕ charger used in Europe (VDE-AR-E 2623-2-2).

3) Module 3, 1ϕ and 3ϕ charger from the EV plug alliance.

4) Single phase Ac and Dc tesla dual charger in the United States.

Figure 14 Plug for Ac charging- From left show module 1 used in US, in the middle module 1 used in European and in the right Tesla plug.

According to limits on EV area and size, Ac charging is limited to charging speeds in module 2 up to 40kW. In the USA, the module 1 plug offers three power pins for single-phase charging (line, neutral and earth). module 2 plugs used extensively in Europe allows 3ϕ charging using five pins (3 line, neutral and earth).

2. Dc charging of EV

Dc charging is used for high power charging above 50 kW for electric vehicle. Dc charging comes under IEC 61851-1 as a module 4 charging (Stapleton & Susan , 12-Nov-2012). When a special Ac/Dc offboard converter provides immediately to the EV battery Dc power (Van Den Bossche, 2014). As we can see in Table 3 there are actually three types of internationally used Dc charging techniques as shown in Figure 15:

1) CCS/COMBO (Combined Charging System, Combo 1&2).

2) Module 4 CHAdeMO used by Nissan, Mitsubishi, and Kia.

3) Single phase Ac and Dc tesla dual charger in the United States and module 2 plug used for Dc charging in Europe.

Figure 15 Plug for Dc charging- From left show CCS/Combo charger used in US, European in the right and in the bottom CHAdeMO plug.

The three products require three control pins, primarily to transfer power, these products use 2 Dc power pins (Dc+, Dc-) and 1 for earth (E). However, the contact and control mechanism used changes. For example, Tesla uses a total of 2 pins for control and communication while CCS uses (PLC) and 2 communication pins. It should be remembered that the same physical pin for communications and control uses both type 1 and 2 Ac and type 4 Dc charging via CCS.

Tesla's charging mechanism is special in that it includes the same two power pins for both Ac and Dc single phases and two pins for communication. The Tesla framework is developed to charge the EV using a Tesla charger or a module 1 or module 2 adapter. A big advantage of Dc charge is that when charging an EV at home at a charge-point module 2 it will take all the night; the process can be completed in less than an hour by a Dc charge. Nice for those who are on the highway sometimes and need a fast recharge every once in a time. Although it is necessary to note that the EV battery can only charge up to 80%, however, the 20% should be charged using module 2 to save the battery.

Table 3 Ac and Dc Charging plugs module.

Plug	Number of pins (Communication)	Charging level	Voltage, current, Power
Type 1 SAE J1772 USA/Japan	3 power pins – L1, N, E 2 control pins – CP, PP (PWM over CP)	Ac Level 1	1Φ 120V, ≤16A, 1.9 kW
		Ac Level 2	1Φ 240V, ≤ 80A, 19.2kW
Type 2 Mennekes Europe	4 power pins – L1, L2, L3, N, E 2 control pins – CP, PP (PWM over CP)	Ac Level 1	1Φ 230V, ≤ 32A, 7.4kW
		Ac Level 2	3Φ 400V, ≤63A,43kW
Type 4 CHAdeMO	3 power – Dc+, Dc-, E 7 control pins (CAN comm.)	Dc Level 3	200,500v ≤ 400A, 200kW
SAE CCS/ Combo	3 power pins –Dc+, Dc-, E 2 control pins – CP, PP (PLC over CP, PE)	Dc Level 3	200 -1000V ≤ 200A, 200kW
Tesla US	3 power pins – Dc+, Dc-, E (or) L1, N, E 2 control pins – CP, PP	Dc Level 2	Model S, 400V, ≤ 300A, 120kW

B. System Architecture

According to (Messenger & Abtahi, 2017) the propose that to run efficiently on any PV models, the whole architecture of the device should take into consideration the following limitations: Place of the facility, including predictions of the climate, solar radiation and wildlife performance, Usable space for the whole systems implementation and requisites for electrical load and electric codes at a given site. Solar power EV charging stations have to follow above-mentioned design restrictions. and for such charging stations there are three main categories of system architectures (Bhatti, Salam, Aziz, Yee, & Ashique, 2016):

- Grid-Connected Photovoltaic system (GCPV) with Energy Storage Device ESD.
- Grid-Connected Photovoltaic system (GCPV) without ESD.

- Off-grid PV system with (ESD).

1. Off-grid PV System with (ESD)

In this system's design, power from photovoltaic system and, energy storage device (batteries) is used together for meeting load power needs, and any unused power is going back to ESD. As we can see that in this system's design energy storage device (ESD) is work as storage unit. This system is ideally suited to distant areas (village areas), So this work is not taken into consideration for architecture. This design is seen in figure 16 (Rajeev & Sundar, 2013, October).

a. Advantage

- This can be put in rural communities without grid reliance.
- It is simple to install, remove and convert into a portable module.

b. Disadvantage

- Total price for Solar panels and for ESD to meet the need for EV load would have to be very significant.
- If ESD is continually run, maintenance would become an issue.
- This style of design can only be used successfully if an outside control mechanism is included.
- It is not really a safe method; it is impossible to use ESD to charge EV if solar power is unavailable.

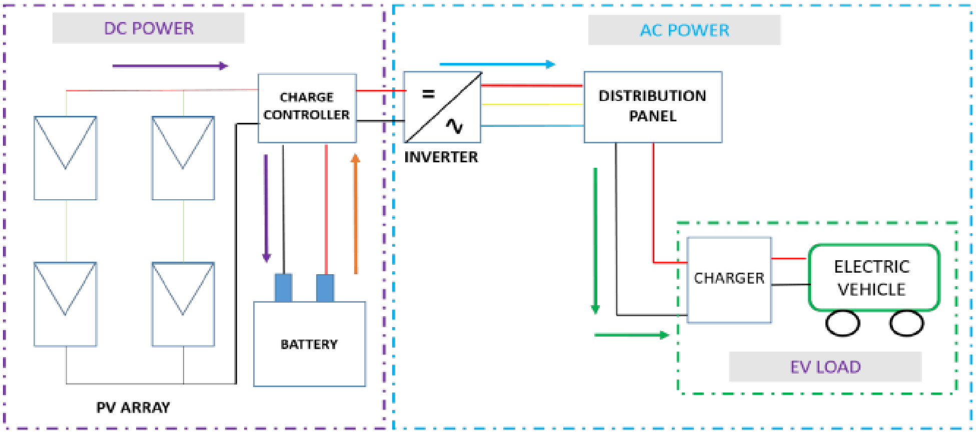


Figure 16 Off-grid PV system design for Electric Vehicle Charging Station (EVCS).

2. GCPV System with ESD

This system's basic framework is shown in figure 17. The key change from the previous architecture is that the grid feature and a bimodal inverter are added. ESD works as a backup when grid failure occurs. This provides an effective solution for a less grid-connected network with optimal the size of PV and energy storage to meet load needs effectively. Unlike the inverter in the previous section, this inverter is able to change charging styles i.e., utilizing solar power to charge a battery through charging controller when the battery power is low, if the battery is fully charged, it supplies power to electric vehicle load, although solar power is fed into the grid under no load condition. this kind of system is more preferable for metropolitan areas than distant site.

a. Advantage

- More stable than in the previous part, as this mechanism will continue to fulfill loads even though the grid failure occurs. It can even be built to have less grid dependency.
- For this type of technology, 100 percent use of the Time of use (TOU) pricing may be made with an external controller to control the power supplied into the grid from the part of the DC.

b. Disadvantage

- The storage device raises the estimated price.
- In this system design, the protection and maintenance specifications are far more than previous design.
- An additional external controller and battery monitoring device must be added in certain situations to ensure stable operation of the system.

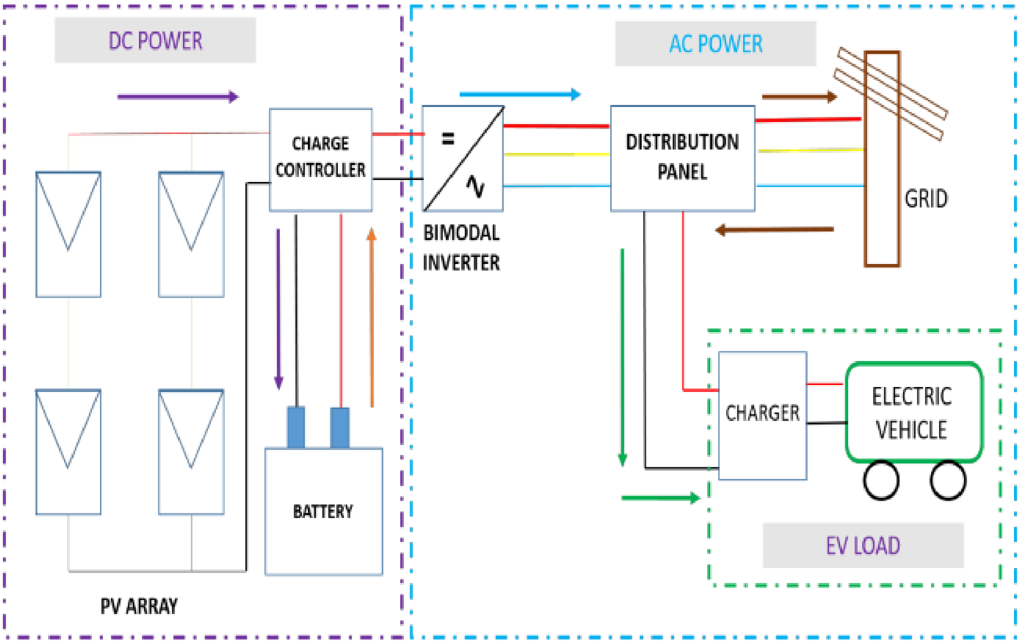


Figure 17 GCPV system design with ESD for Electric Vehicle Charging Station (EVCS).

3. GCPV System without ESD

This system's basic framework is shown in figure 18. The supply of PV power is used solely to satisfy the load needed and the extra energy rather than charging the EV load is injected into the grid. With this kind of design grid operates as a storage unit. At the University of Wilfrid Laurier identical module have been installed.

a. Advantage

- Reliable method i.e., the grid will support the Electric vehicles if solar radiation is less (or) unavailable.
- The extra construction costs are minimized in the absence of storage system.

b. Disadvantage

- Acceptance from the respective distribution organizations is necessary for large-scale installation.
- This module cannot be installed in areas where grid interconnectivity is not allowed.

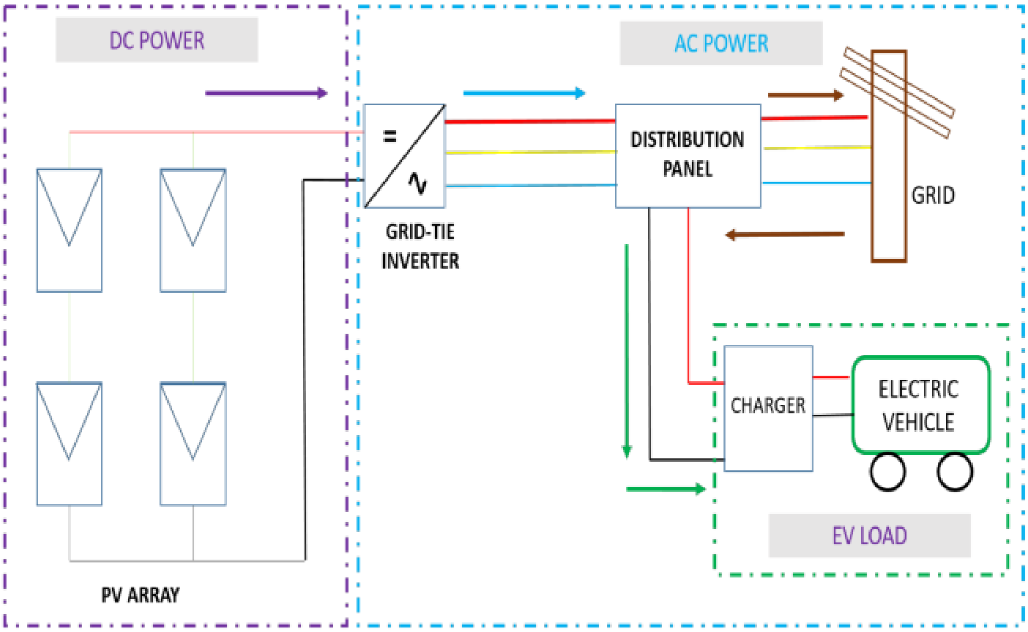


Figure 18 GCPV system design without ESD for Electric Vehicle Charging Station (EVCS).

C. Component Selected

The main components being used in specified design are photovoltaic systems, electric vehicle charging station (EVCS), controller, inverter, connectors, cables, and mounting system. The photovoltaic systems and electric vehicle charging station (EVCS) used were previously explained in chapter 2, and chapter 3, respectively.

1. Controller

Microcontrollers or solar battery regulators are electronic devices used for electrical current or voltage flow control across electric batteries. Its fundamental functions included avoiding full discharge or over battery charging and that a primary battery life security mechanism. A standalone unit or an integrated circuit connected to the battery system can refer to the term charge controller or the regulator. In general, there are several microcontrollers of solar battery such as PWM controller, MPPT controller, MPU controllers.

Maximum Power Point Tracking (MPPT) Controller: this microcontroller is installed to let high voltage Photovoltaic panels for charging batteries with lower voltage. In other way the controller covers the batteries from photovoltaic solar cell thus allow the batteries to work optimally in harsh climates, also this controller extracts the most energy capacity from photovoltaic systems. Even if it is isolated (separated) from the cells, it still can work effectively. The major issue is, in low light scale for instance at morning or sunsets, the controller could transmit little or no power to storage battery.

Pulse Width Modulated (PWM) Controller: Essentially, higher voltage spikes are used in the transfer charged current from photovoltaic panels to storage batteries. These are some of the difficulties with the using PWM controller is that many components of 12V require 8V or more at the battery until they run correctly. Then when a battery storage is discharged under that level the PWM controller would have trouble transmitting power Regardless of how much are generated by solar panels.

Memory Protection Unit (MPU) Controller: This will be the first generation of photovoltaic charge controllers perform functions in one direction. Certain advantages of using on and off controller is that operating is really easy, effective with low heat, and it also manages to conserve life of the battery while it avoids above and under charging batteries.

2. Inverter

Mainly focused on the power produced by solar panels, three simple inverters or converters are usable that convert DC supplied from solar panels to AC that can be used to charge vehicle at house or at station those converters are, string inverters, micro inverters, and power optimizers.

String Inverters: It requires installing the solar cells in parallel with strings that transmit the power they utilize into a single inverter. The panels generate the same overall energy at higher voltages. It decreases cable cost and reduces inner energy losses that result in improved performance.

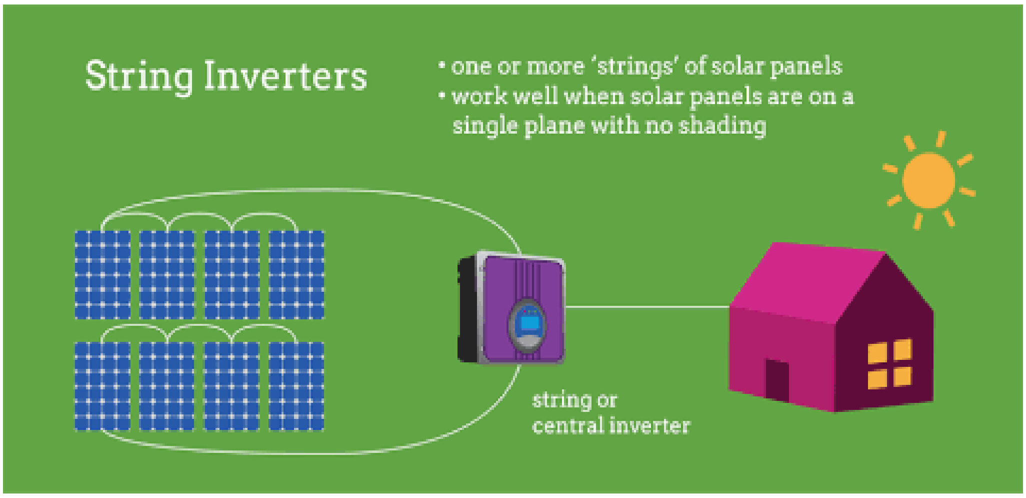


Figure 19 String inverter.

Micro Inverters: Dissimilar to the previous type, it used to convert the DC that supplied by solar cells to AC, and we provide each panel with one microinverter. Any breakdown from one of the panels due to shadows, debris or snow lines does not impact the other panels' activities because every micro inverter uses the highest power. While individual micro-inverters are typically less effective than string inverters, the total efficiency of these systems is improved due to each inverter work independently.

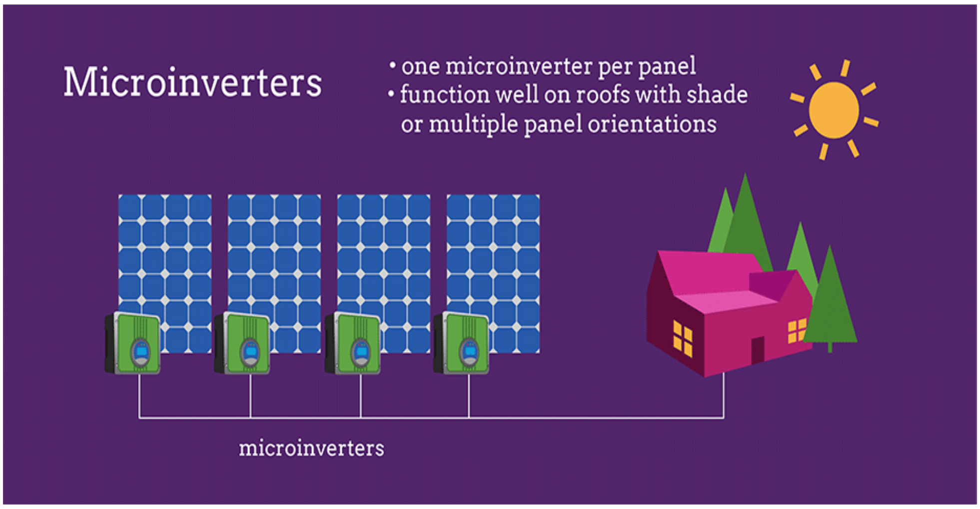


Figure 20 Micro inverter.

Power Optimizers: Like micro inverters, both technologies are attempting to separate individual panels to maximize the effectiveness of the whole system. Power optimizers have been used to manage the overall output of the panel arrays to regulate and change the load connected continuously to keep the system running at its peak. This is classified as MPPT using an intelligent system.

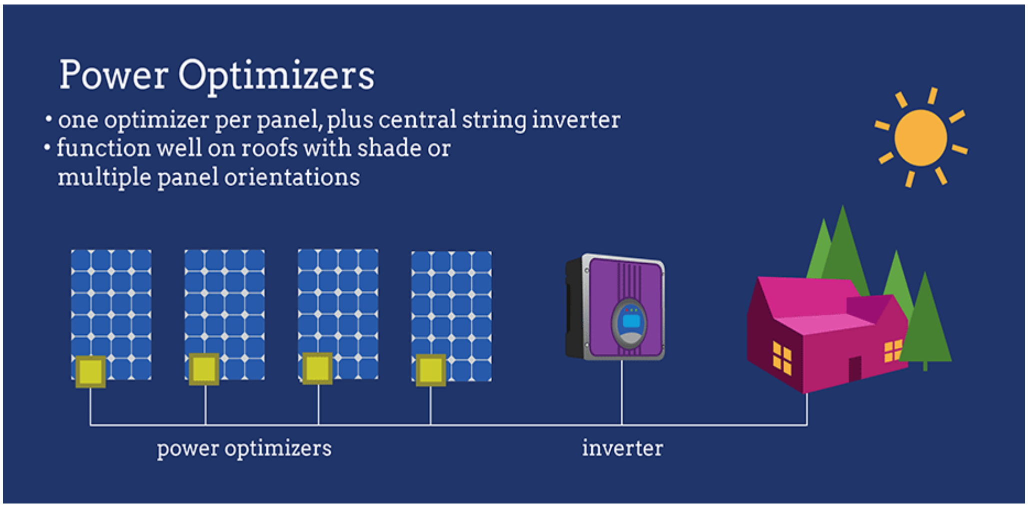


Figure 21 Micro inverter.

3. Storage Batteries

Solar store batteries are considered as key elements of standalone renewable energy sources in order to store the energy source continuously. Various battery styles are designed to meet these particular demands. Solar storage batteries divided in to three group lead acid storage batteries, lithium-ion storage batteries and flow batteries. Furthermore, we can choice the batteries based on some parameters such as storage capacity, power transfer rate, discharge period, battery performance, the price of storage battery, impact on the environment (Ibrahim, et al., 2012), and eventually the storage battery self-discharge level.

Lithium-Ion Battery: Nowadays the most popular storage battery found in new technology generally in mobile phones. Its different types consist of manganese storage models, nickel, cobalt. In comparison to battery storage forms of lead acid, essentially, lower maintenance is needed, poor self-discharge, greater energy and thus provide higher current outputs. Even after shown above advantages, they are more costly, and need much voltage/current balanced protection.

Flow Battery: Flow battery for solar energy storage is consisted of basically redox vanadium and hybrid models. It is also considered a new type of storing for solar energy and cost supposedly in the coming years to be lower than lithium acid. Flow batteries provide an ideal power source.

Lead Acid Storage Battery: Usually called as valve regulated battery, it contains of, Gel, flooded lead acid models and Absorbed Glass Mat (AGM). The flooded lead-acid has a large replacement/maintenance and remove risk factor since the evaporated electrolytes are continually refilled. Where AGM and Gel are recombinant because the needed little or no maintenance and filling, because the electrolytes are minimally evaporated to ensure their environmental protection. It has low cost as compared with lithium-Ion batteries, also it has high life cycle, large capacity, and high performance. This type of storage battery will be the best choice for solar energy standby.

Figure 22 Lead Acid Storage Battery.

4. Cables, Connectors, Mounting System

Connecting the modules without cables is incomplete, connectors, disconnecting the power of AC and DC side safely, and mounting racks for solar cells placing. The energy transmission from solar cells to EV charger is impossible without these axilla elements.

IV. RESULTS AND DISCUSSION

In this section, we describe the simulation results and the discussion of our proposed method, high accessibility PV power for EV users is available since photovoltaic cells can be attached to the rooftop and as solar parking lots near the location of EVs, as shown in Figure 23 drawn in SKETCH UP. There is a huge amount of unusable PV capacity on top of buildings or parking lots, and this should be taken advantage of in the future. Therefore, charging electric vehicles from the Photovoltaic panels will keep EVs economical and decrease the net costs of the charging infrastructure. This is the vision and motivation for this thesis.

Figure 23 Photovoltaic panels powered EVs charging stations where it installed at rooftop and parking lots.

A. PVsyst Model:

The process suggested is done with MATLAB to design a 50kw of charging station powered by PV for EVs, however before we use MATLAB, we are going to use PVsyst to study, size, and data analysis of complete PV systems. With our focus area, King Hussein Business Park (KHBP)-Jordan is located at latitude/longitude: 31.973N/ 35.992E and also having an average annual temperature of 18.2 degrees centigrade.

Based on data that we have entered on PVsyst programs such as latitude, longitude altitude (1000m above sea level), country, and region we can know the solar paths at King Hussein Business Park as shown in figure 24 where the x-axis represents azimuth (0°) and the y-axis represent sun height. According to the figure below we can figure out, we will produce more energy in summer (1: June) more than in winter (7: December).

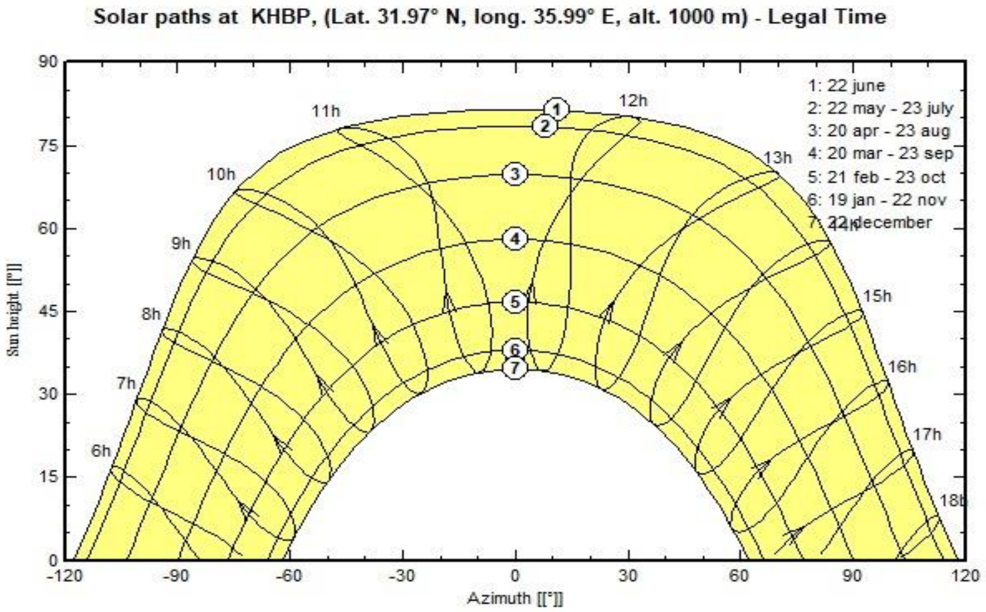
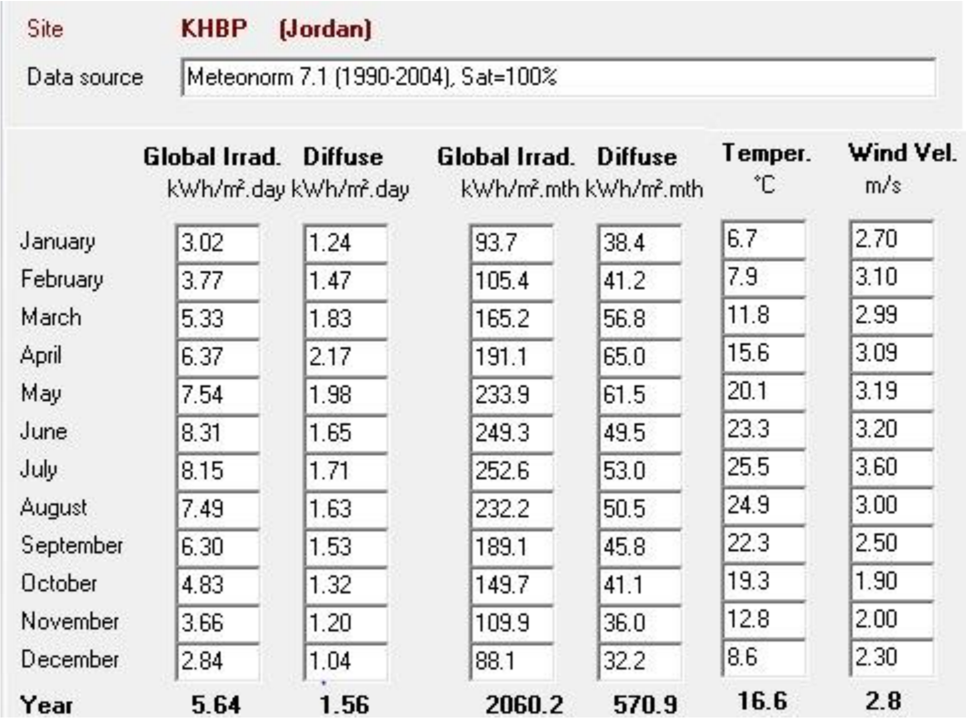


Figure 24 Solar paths at KHBP.

Figure 25 shows the solar annual average irradiance and temperature value in the daytime for each month of the year. According to the figure below, we can figure out that the values of global irradiance, diffusion of the sunlight, wind velocity, and temperature increase in summer and decrease in winter. If we take a look at the figure below, we can figure out that (May, June, July, and August) have the highest value comparing to any other months in each column. The total global irradiance for all the year is 2060.2 Kwh/m²year and the average are 171.7 Kwh/m². mth, also the average temperature is 16.6 °C.



Site **KHBP (Jordan)**

Data source Meteonorm 7.1 (1990-2004), Sat=100%

	Global Irrad. kWh/m^2.day	Diffuse kWh/m^2.day	Global Irrad. kWh/m^2.mth	Diffuse kWh/m^2.mth	Temper. °C	Wind Vel. m/s
January	3.02	1.24	93.7	38.4	6.7	2.70
February	3.77	1.47	105.4	41.2	7.9	3.10
March	5.33	1.83	165.2	56.8	11.8	2.99
April	6.37	2.17	191.1	65.0	15.6	3.09
May	7.54	1.98	233.9	61.5	20.1	3.19
June	8.31	1.65	249.3	49.5	23.3	3.20
July	8.15	1.71	252.6	53.0	25.5	3.60
August	7.49	1.63	232.2	50.5	24.9	3.00
September	6.30	1.53	189.1	45.8	22.3	2.50
October	4.83	1.32	149.7	41.1	19.3	1.90
November	3.66	1.20	109.9	36.0	12.8	2.00
December	2.84	1.04	88.1	32.2	8.6	2.30
Year	**5.64**	**1.56**	**2060.2**	**570.9**	**16.6**	**2.8**

Figure 25 Solar annual average irradiance and temperature value in daytime for each months of the year.

Figure 26 shows the solar planes orientation and planes tilt angles yearly irradiation, where the field type is Fixed Tilted Plane also tilt angle is 30°and the azimuth is 0°for the planes. According to the figure below, we can figure out that the transportation factor equals to 1.12. Azimuth plane is known as the angle between south and plane for the northern hemisphere and the angle between north and plane for the southern hemisphere. The transposition factor is described as the ratio between the fallen irradiation on the surface, to the horizontal irradiation i.e., what we obtain or lose when we are tilting the surface. Also, there is something called loss by respect to optimum (Loss/opt.) it means that we have losses because we do not choose the best value of tilt angle and azimuth so according to the value that we have it means we have chosen the optimum value of tilt angle and azimuth.

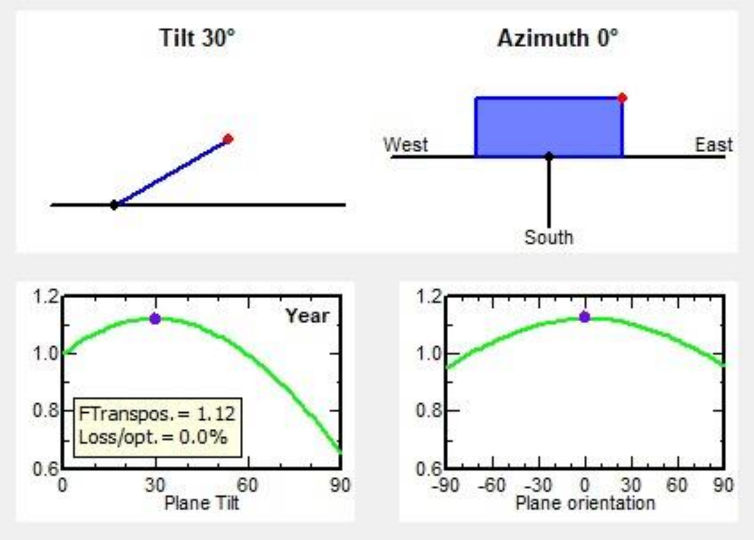
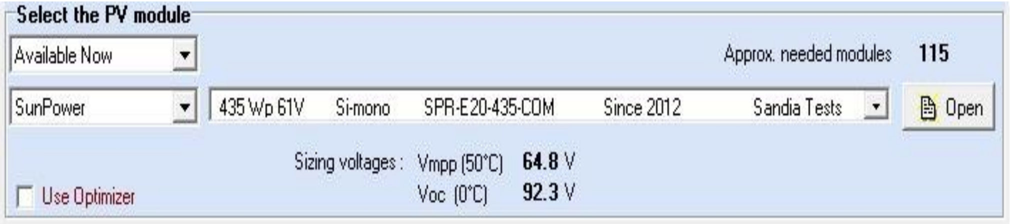


Figure 26 Solar planes orientation and planes tilt angles yearly.

Figure 27 shows the grid systems definition and variant. After doing more than 20 iterations on PVsyst we can say that we find the optimal choice for our design firstly we will enter planned power 50kWp, secondly, we will select PV module (SunPower) and the power of each panel is (435 Wp). According to the figure below we can figure out that the maximum voltage (Voc) for each panel is 92.3V and the minimum voltage value is the same as the maximum power point voltage for each panel is 64.8V. The parameters used for this type of cell, short circuit current I_{SC} =6.43A, maximum power point current I_{mpp}=5.97A, maximum power point voltage V_{mpp}= 64.8V, and open circuit voltage Voc = 92.3V. If we take a look at the figure below, we can figure out that the approximate needed number of modules is 115.



Select the PV module

Available Now

Approx. needed modules 115

SunPower

435 Wp 61V Si-mono SPR-E20-435-COM Since 2012 Sandia Tests

Sizing voltages : Vmpp (50°C) 64.8 V

Voc (0°C) 92.3 V

☐ Use Optimizer

Figure 27 Selection of PV module.

Thirdly we are going to select the inverter as shown in figure 28. We are going to select ABB inverter type and the power of our inverter based on the power of our design so, our design is 50 Kw then we need only one inverter with power

50Kw, or we can use tow inverters with power 25Kw for each one. The parameters used for this type of inverter, minimum voltage required to work the inverter = 300V, the maximum voltage that can the inverter hold out =950V, power of the inverter =50 KW and maximum efficiency =98.54%.

Select the inverter

Available Now

ABB

50 kW 300 - 950 V TL 50/60 Hz TRIO-50.0-TL-OUTD-US-480 Since 2016

☑ 50 Hz

☑ 60 Hz

Nb. of inverters 1 ☑

Operating Voltage: 300-950 V

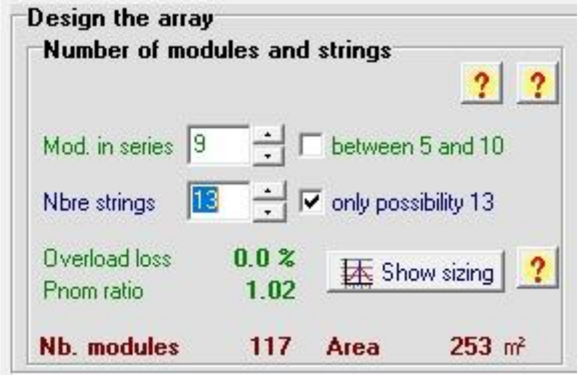
Input maximum voltage: 1000 V

Global Inverter's power 50.0 kWac

"String" inverter with 16 inputs

Figure 28 Selection of inverter.

Finally, we will design the array based on the number of modules and strings as shown in figure 29. According to the figure below we can figure out that the number of models in series for our design will be 9 and the number of strings will be 13 based on these results the number of modules for our design will be 117 (13*9) will cover 253m^2. According to the figure below we can figure out, there is no overload on the inverter because we get 0.0% and this is good for our system and the nominal power ratio is too small 50.9KW/50KW 1.02 (the ratio between maximum PV power and nominal AC power).



Design the array

Number of modules and strings

Mod. in series 9 ☐ between 5 and 10

Nbre strings 13 ☑ only possibility 13

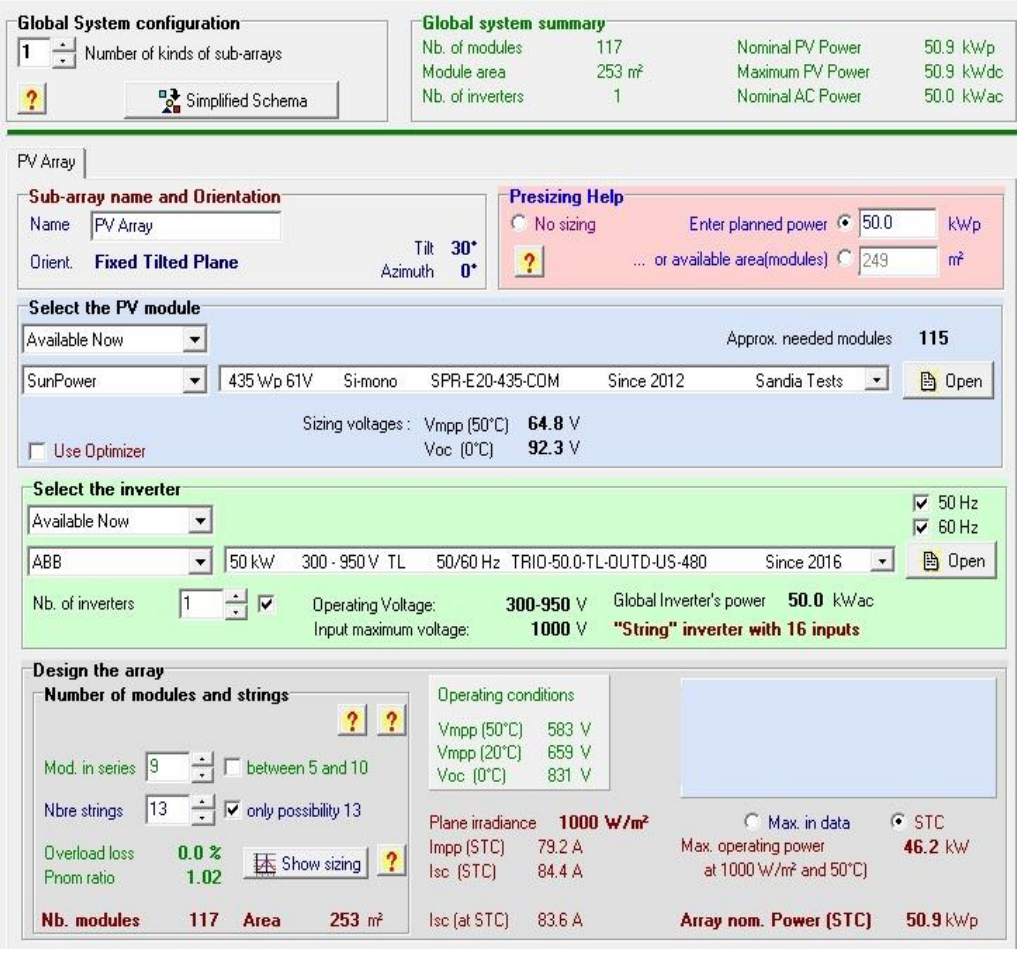
Overload loss 0.0 %

Pnom ratio 1.02

Nb. modules 117 Area 253 m²

Figure 29 Number of modules and strings.

Figure 30 shows the global system's configuration of the previous design based on a 50KW solar PV system. According to the figure below we can figure out that the number of models is 117, module area 25m^2, the number of inverters is 1, the power generated by PV system design in PVsyst is 50.9KW (DC), nominal AC power for our design 50KW (AC).


Global System configuration
1 Number of kinds of sub-arrays

Global system summary
Nb. of modules 117
Module area 253 m²
Nb. of inverters 1
Nominal PV Power 50.9 kWp
Maximum PV Power 50.9 kWdc
Nominal AC Power 50.0 kWac

Sub-array name and Orientation
Name: PV Array
Orient.: Fixed Tilted Plane
Tilt 30°
Azimuth 0°

Presizing Help
○ No sizing
Enter planned power ● 50.0 kWp
... or available area(modules) ○ 249 m²

Select the PV module
Available Now
SunPower
435 Wp 61V Si-mono SPR-E20-435-COM Since 2012 Sandia Tests
Approx. needed modules 115
Sizing voltages : Vmpp (50°C) 64.8 V
Voc (0°C) 92.3 V
☐ Use Optimizer

Select the inverter
Available Now
ABB
50 kW 300 - 950 V TL 50/60 Hz TRIO-50.0-TL-OUTD-US-480 Since 2016
☑ 50 Hz
☑ 60 Hz
Nb. of inverters 1 ☑
Operating Voltage: 300-950 V
Input maximum voltage: 1000 V
Global Inverter's power 50.0 kWac
"String" inverter with 16 inputs

Design the array
Number of modules and strings
Mod. in series 9 ☐ between 5 and 10
Nbre strings 13 ☑ only possibility 13
Overload loss 0.0 %
Pnom ratio 1.02

Nb. modules 117 Area 253 m²

Operating conditions
Vmpp (50°C) 583 V
Vmpp (20°C) 659 V
Voc (0°C) 831 V

Plane irradiance 1000 W/m²
○ Max. in data ● STC
Impp (STC) 79.2 A
Isc (STC) 84.4 A
Max. operating power at 1000 W/m² and 50°C) 46.2 kW
Isc (at STC) 83.6 A
Array nom. Power (STC) 50.9 kWp

Figure 30 Global systems configuration.

Now we are going to learn something about PV losses in our design these losses happened from dust, the voltage drops in cables, inverter losses, array losses, and the high temperature it represents the total losses we lose annually in the system. Figure 31 shows the loss diagram for the design in one year. According to the figure below, we can figure out that we have array losses and inverter losses, and its value is -6.0% and -1.8% respectively. From the figure below the array nominal energy is 114.9MWh and the losses percentage is -7.8% after we remove the losses from the nominal energy, we will get 106.1MWh this will represent the energy injected into the grid. Incidence Angle Modifier (IAM factor on global) this represents transmission deficit due to the incidence angle.

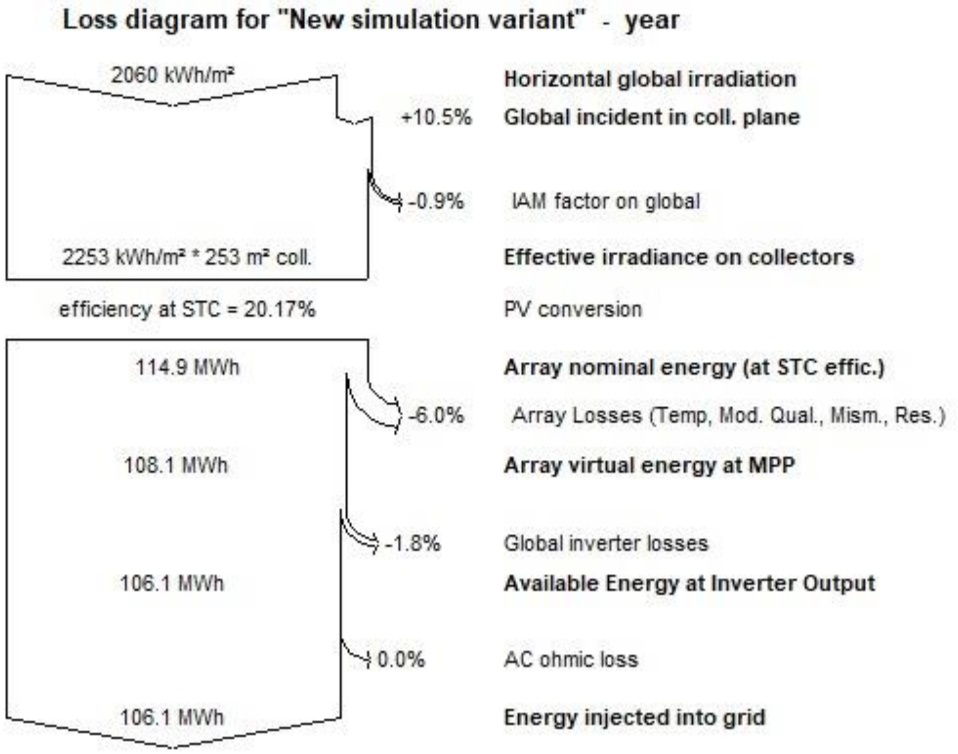


Figure 31 Losses diagram over the whole year.

Figure 32 shows the probability distribution based on the annual injected energy into the grid. According to the figure below we can figure out that we have energy grid simulation, P50, P75, and P90 where energy grid simulation equal 106.1 MWh it shows the energy injected into the grid, P50 show the generation probability like 50% it means when the design run the probability distribution, as 50 times of generation this means P50 show 50% probability P50 correspond with annual energy injected of 106.1MWh, P75 correspond with annual energy injected of 104.3MWh P75 means that there is a 75% chance that the annual energy injected to the grid level of 104.3MWh will be exceeded and 25% chance that annual energy injected to the grid will be less than 104.3MWh and P90 correspond with annual energy injected of 102.6MWh P90 means that there is a 90% chance that the annual energy injected to the grid level of 102.6MWh will be exceeded and 10% chance that annual energy injected to the grid will be less than 102.6MWh. P-value can be considered as how we are sure the generation over the period will exceed a given value.

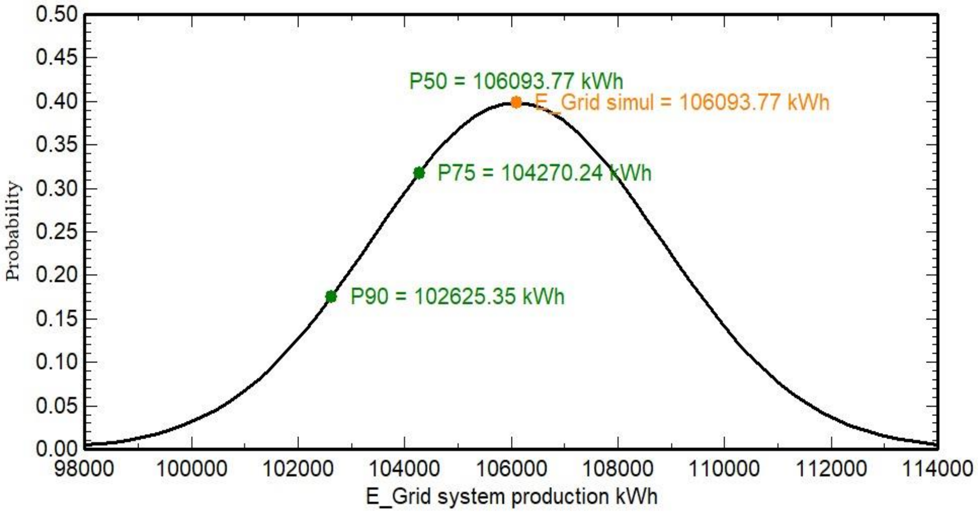
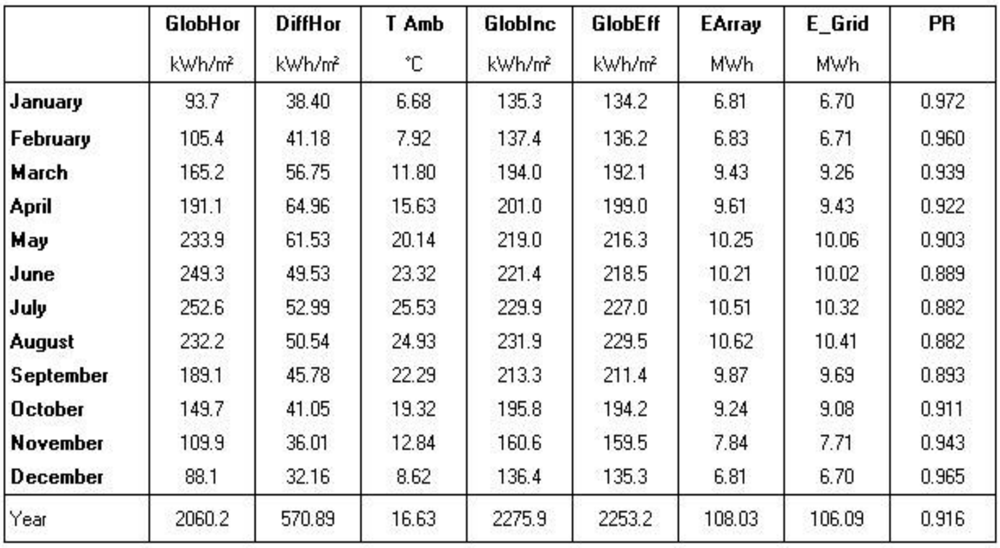


Figure 32 Probability distribution based on the annual injected energy into grid.

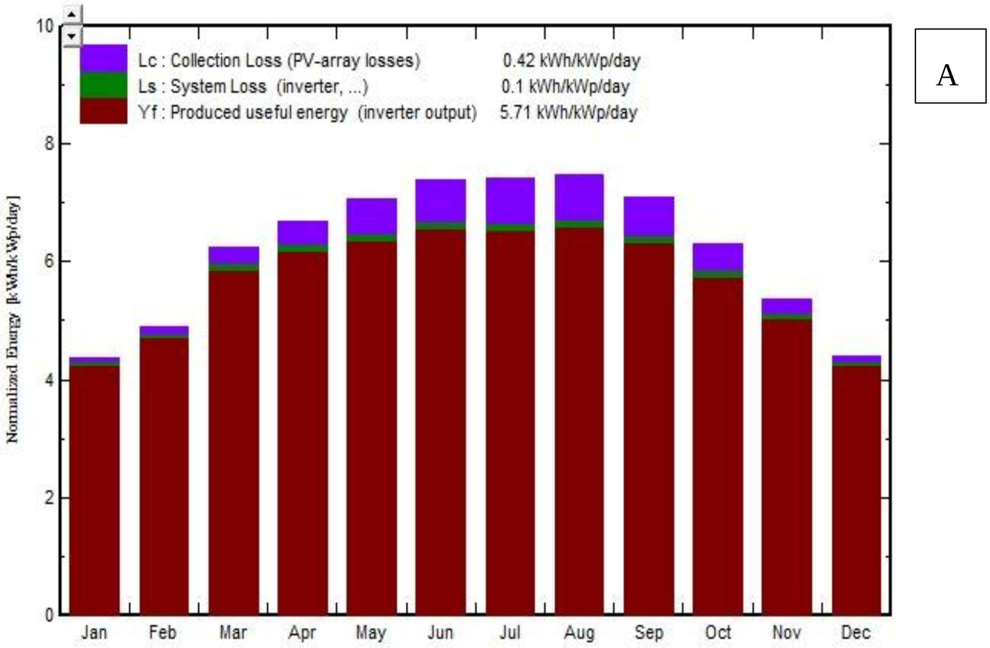
Figure 33 shows the annual energy production of the system design. According to the figure below we can figure out that we have horizontal global irradiation (Glob_Hor), horizontal diffuse irradiation (Diff_Hor), ambient temperature (T_Amb), global incidence (Glob_Inc), effective global (Glob_Eff), effective energy at the output of array (E_Array), energy injected to the grid (E_Grid) and performance ratio (PR). GlobHor represent the irradiation fallen on the system without tilt angle however, GlobInc represents the irradiation fallen on the system with tilt angle as we can see that GlobInc has a higher value compared to Glob_Hor value. Glob_Eff represents the real irradiance that we will have, and we will depend on this value as we can see that Glob_Eff has a lower value compared to Glob_Inc value. E Array represent how much array produce in each month as we can see that summer has the highest production energy (May, June, July, and August) and their value (10.25, 10.21, 10.51 and 10.62) MWh respectively and the total annual energy production was 108.03 MWh. E_Grid represents the injected energy into the grid as we can see that E_Grid has a lower value compared to E_Array value based on the losses in the system. PR is the most important component in solar power stations because it shows the efficiency of our system. According to the figure below, we can figure out that we have a PR equal to 91.6%.



	GlobHor kWh/m²	DiffHor kWh/m²	T Amb °C	GlobInc kWh/m²	GlobEff kWh/m²	EArray MWh	E_Grid MWh	PR
January	93.7	38.40	6.68	135.3	134.2	6.81	6.70	0.972
February	105.4	41.18	7.92	137.4	136.2	6.83	6.71	0.960
March	165.2	56.75	11.80	194.0	192.1	9.43	9.26	0.939
April	191.1	64.96	15.63	201.0	199.0	9.61	9.43	0.922
May	233.9	61.53	20.14	219.0	216.3	10.25	10.06	0.903
June	249.3	49.53	23.32	221.4	218.5	10.21	10.02	0.889
July	252.6	52.99	25.53	229.9	227.0	10.51	10.32	0.882
August	232.2	50.54	24.93	231.9	229.5	10.62	10.41	0.882
September	189.1	45.78	22.29	213.3	211.4	9.87	9.69	0.893
October	149.7	41.05	19.32	195.8	194.2	9.24	9.08	0.911
November	109.9	36.01	12.84	160.6	159.5	7.84	7.71	0.943
December	88.1	32.16	8.62	136.4	135.3	6.81	6.70	0.965
Year	2060.2	570.89	16.63	2275.9	2253.2	108.03	106.09	0.916

Figure 33 Annual energy production.

Figure 34 A&B show the annual produced useful energy (inverter output) and performance ratio (PR). According to figure A below we can figure out that the red color represents annual production energy in summer the production will increase based on high temperature, the green and blue colors represent losses (PV array and inverter) also the losses increase in summer based on high temperature. According to figure B below, we can figure out that PR decrease in summer because we have a high temperature.



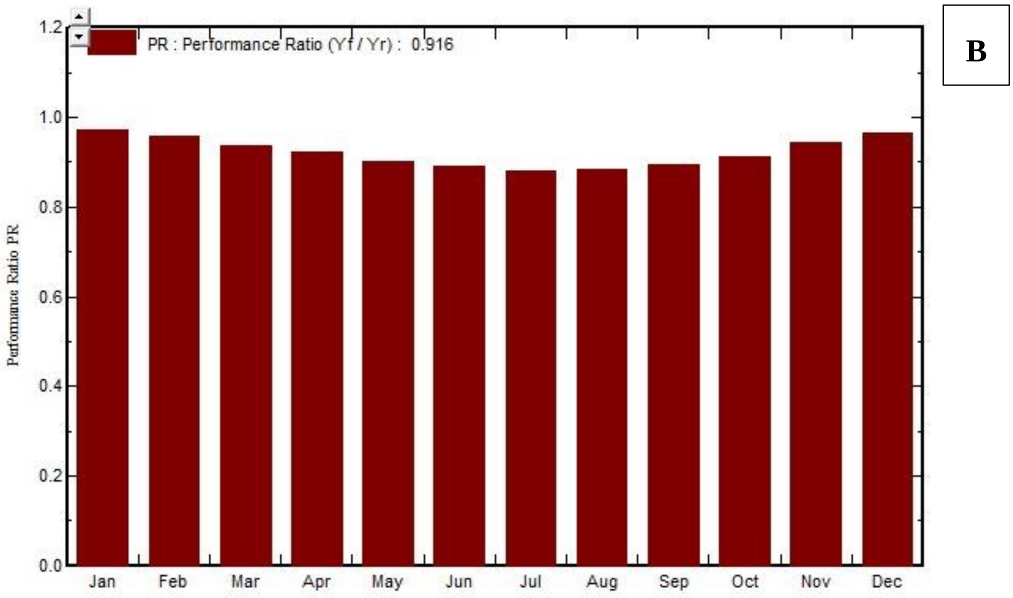


Figure 34 Annual produced useful energy (inverter output) and performance ratio (PR).

B. Component Selected

The main components being used in specified design are photovoltaic systems, electric vehicle charging station (EVCS), controller, inverter, connectors, cables, and mounting system.

1. Solar PV Array:

For 50kW system using PV syst V6.88, SunPower SPR-E20-435-COM is selected which has PV array consists of a variety of separate PV modules or panels which are connected in 9 series and with 13 parallel string to transmit the current and voltage that any system's needs. The larger the array surface area, the more solar energy would be produced in overall. The solar array is selected for the worst condition which happen in December in Amman Jordan with about 2.8 kW/m^2 at 8.6 ^{o}C.

2. Maximum Power Point Tracking (MPPT) Controller:

This microcontroller is installed to let high voltage Photovoltaic panels for charging batteries with lower voltage. In other way the controller covers the batteries from photovoltaic solar cell thus allow the batteries to work optimally in harsh climates, also this controller extracts the most energy capacity from photovoltaic systems. Even if it is isolated (separated) from the cells, it still can work effectively. The major issue is, in low light scale for instance at morning or sunsets, the controller could transmit little or no power to storage battery.

3. Inverter:

We are going to select ABB inverter type and the power of our inverter based on the power of our design so, our design is 50 Kw then we need only one inverter with power 50Kw, or we can use tow inverters with power 25Kw for each one. The parameters used for this type of inverter, minimum voltage required to work the inverter = 300V, the maximum voltage that can the inverter hold out =950V, power of the inverter =50 KW and maximum efficiency =98.54%.

4. Lithium-Ion Battery:

We have selected Lithium-Ion Battery of LG chem model namely EM048290P5B1 290Ah. There are at least 255 modules required to be connected 51 parallel strings with each has 5 batteries in it. It gives a total of more than two days of autonomy.

C. Simulink Model:

Simulink is a graphical extension to MATLAB for modeling and simulation of systems. In Simulink, systems are drawn on screen as block diagrams. Many elements of block diagrams are available, such as transfer functions, summing junctions, etc., as well as virtual input and output devices such as function generators and oscilloscopes. Simulink is integrated with MATLAB and data can be easily transferred between the programs. We use the Simulink to simulate the PV charging station for EVs. In this simulation, there are nine phases of Simulink Model as shown in the following diagram. The MPPT algorithm is used for charge controller with boost control charging.

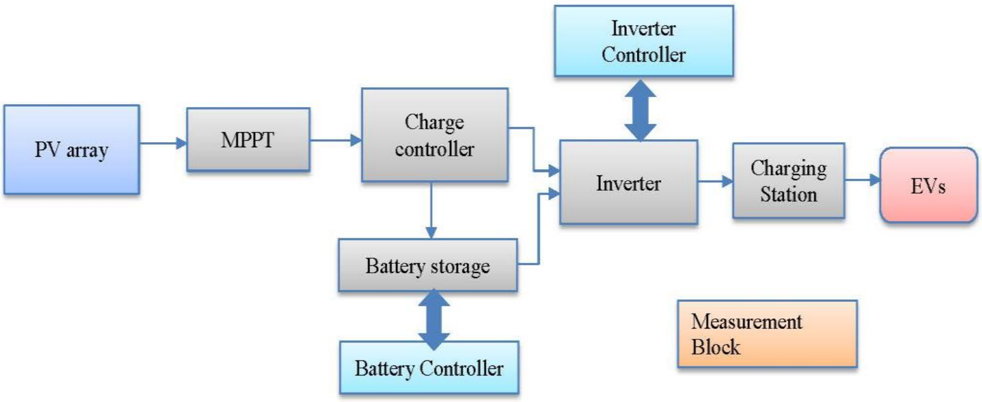


Figure 35 Layout of the Charging Station in Simulink.

1. PV Array

Discrete system with time step of 1e-6 second is used with the constant input of irradiation value and temperature to the solar array SunPower SPR-E20-435-COM. The specifications of solar array are already discussed above. There are 13 string of PV panels with each has 9 panels connected in series making an area of about 252.963594 square meter to generate about 50 kW of nominal power.

2. Controller Block

The flow of current from the PV system is controlled by controller block also known as buck converter circuit as shown in figure 36. The buck converter operates as a regulator to step down the input voltage from the PV array while maintaining its power delivery to charge the battery. This is achieved by stepping down the input voltage and increasing the output current delivered to the battery. The buck converter circuit consists of an IGBT (switch), a high-power inductor, diode, and an input and output capacitor. The output voltage of the buck converter can be determined by the ratio between Vout (V-bus) the output voltage and Vin the input voltage of buck converter.

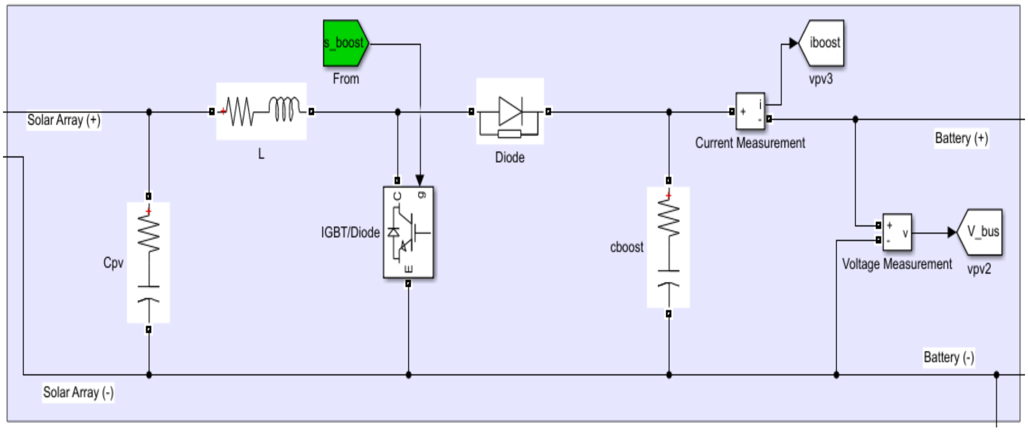


Figure 36 Buck Converter or Controller Block

3. MPPT Block

The MPPT is commonly used in many small and medium commercial solar PV charge controller and grid connected inverter due to its tracking effectiveness and simplicity of implementation. The MPPT algorithm track the maximum power of the PV array and output its duty cycle relevant to the tracked maximum power to the battery charge controller.

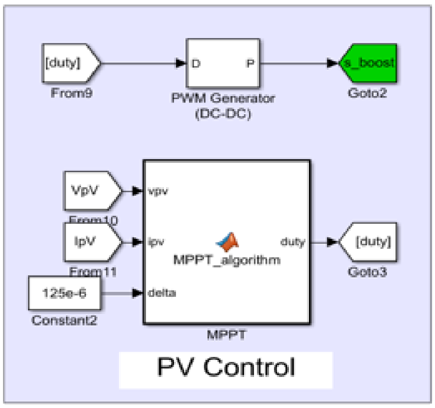


Figure 37 MPPT Simulink Block.

Perturb & observe technique is used because of its ease in implementation. The advantage is the circuitry used for the method is simple and requires only two sensors. The algorithm is generated by perturbing a small increment in voltage of PV and observing resultant change in power. If ΔP is positive, then perturbation will lead towards maximum power point and if ΔP is negative, then operating point has moved away from maximum point. Hence the perturbation should be reversed to return back to the maximum point.

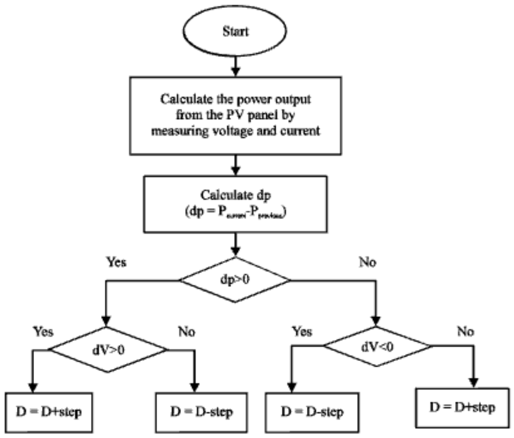


Figure 38 Flowchart of the Perturb and Observe method.

4. Battery Block

The battery charge controller was developed to charge a Lithium-Ion battery using the 2-diode charging method. The method of charging includes two bidirectional converters each for charging and discharging respectively operated by a signal coming from the battery. According to the figure below we apply switching signals for both of the bidirectional converters for positive side switch (S-P) and for negative side switch (S-N). When the produced photovoltaic power lower than the required power for the charging station (load), then the battery must feed the charging station (load). For another case if the produced photovoltaic power higher than that the charging station need then the battery must charge to keep constant voltage.

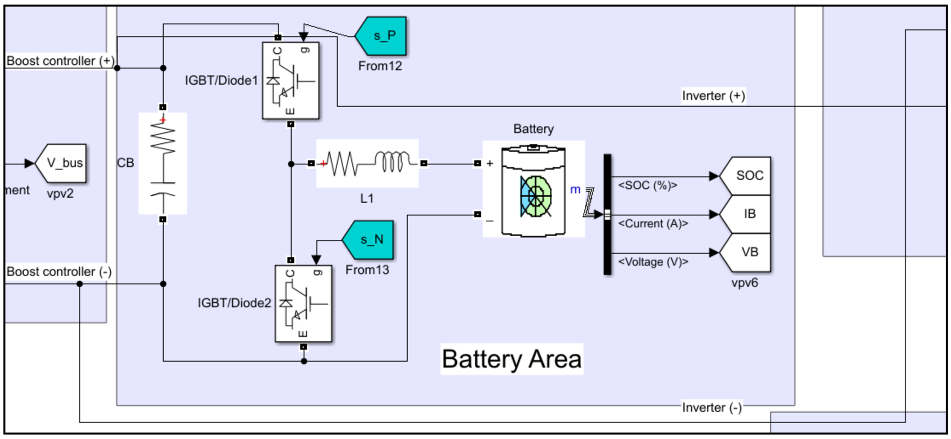


Figure 39 Battery block

5. Battery Controller Block

Battery Controller Block provide the signal to bidirectional converters connecting to the battery block to run alternately in case of charging and discharging depend upon the system voltage and battery current using two PI controller and a PWM generator with specified values is used to obtain the desired results. According to figure 40 we use PWM generator to control battery side also to produce signals for positive and negative side of bidirectional converters. We use logical operator (Not) because we know that the positive side is a complement for negative side. Also, we will generate duty signal for PWM generator we can generate it by using PI controller.

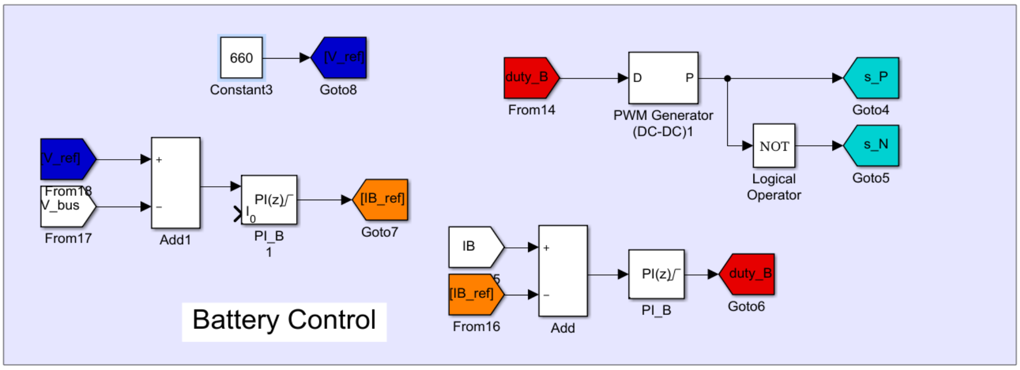


Figure 40 Battery controller block

6. Inverter Block

In inverter block single stage universal module with single filter is used with controlling signal coming from the controller block. 50kW inverter is selected for this purpose.

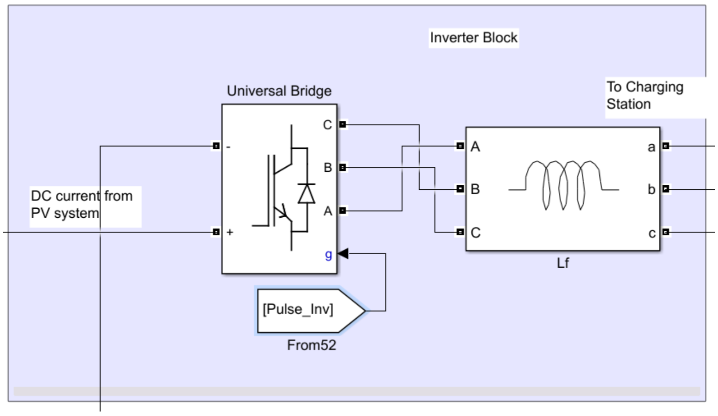


Figure 41 Inverter Block

7. Inverter Controller Block

The purpose of this block is providing the pulsating signal to the universal bridge which converts the DC current to AC current. It takes the Voltage and current from the AC signal and using PI Controller and system voltage allow the conversion of DC to AC maintaining the maximum active power using modulation and duty signal.

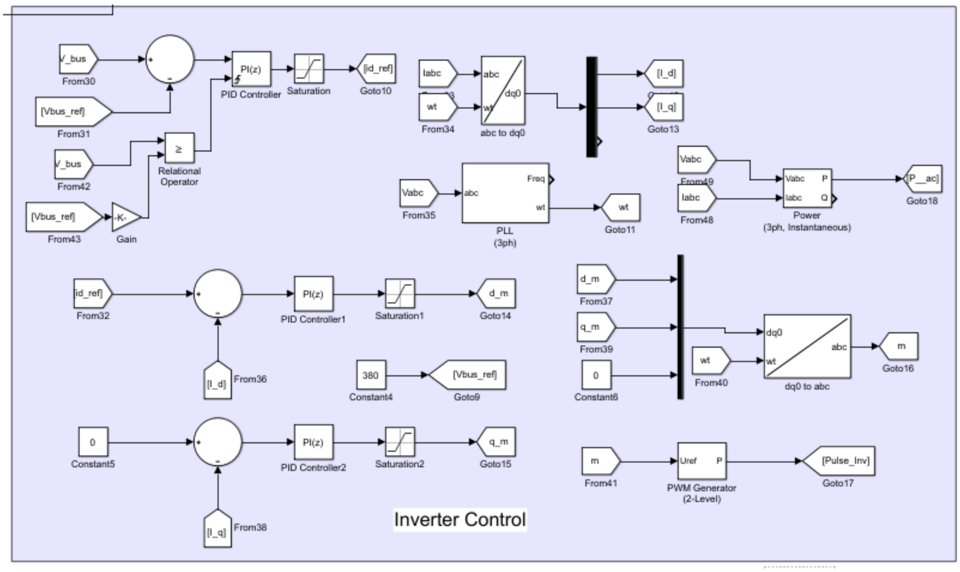


Figure 42 Inverter control

8. Charging Area

Charging station block has the distribution panel for two charging port each of 25 kW power with the available power in the lines.

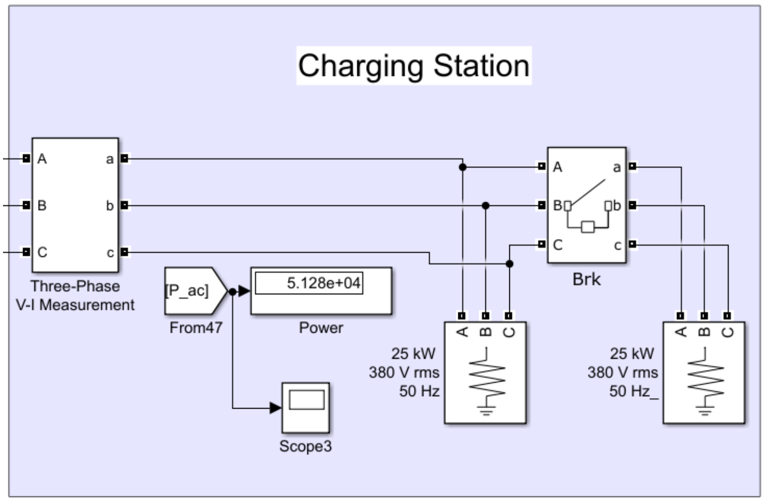


Figure 43 Charging Area

9. Measurement Block

The purpose of this block is to measure the parameters being produced at PV array, inverter, buck converter, battery and at the load.

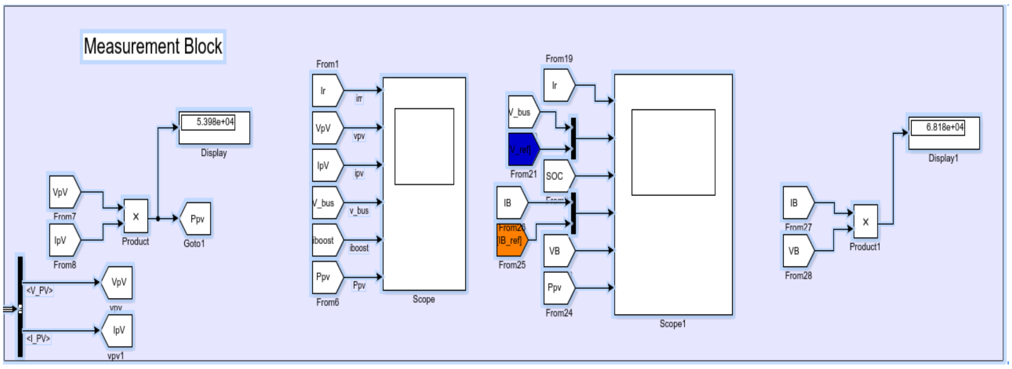


Figure 44 Measurement block

Figure 45 is extracted from the PV-Array of the specified model in Simulink as shown bottom, these figures show the characteristic of the panel at different voltage and the maximum power point is around 660 V and our peak point PV power is around 5.1 KW that is why the system is selected for the 660 V to achieve the maximum out at maximum efficiency. While the red color shows the result of single panel at 25 ºC while the tow figures represent the system current and power vs voltage at 1000 W/m2.

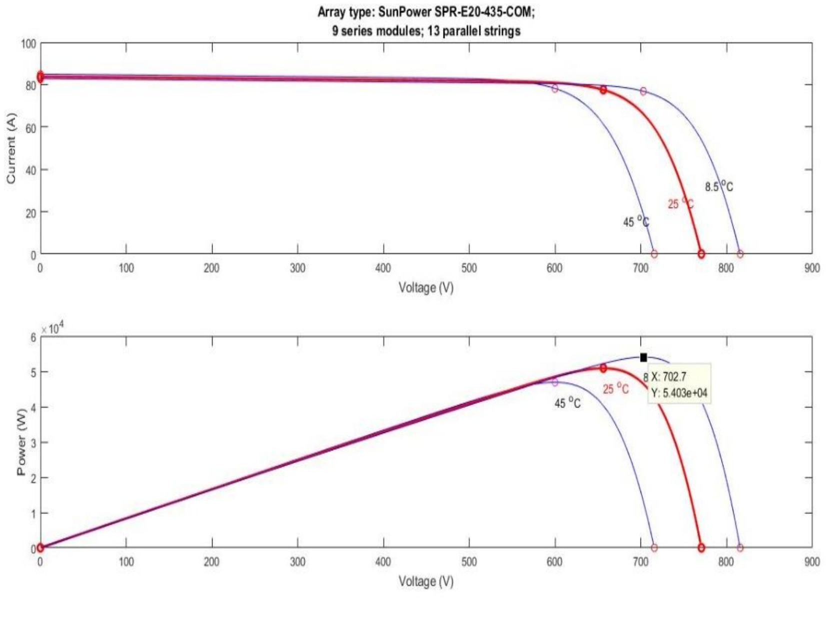


Figure 45 Top: I-V curve at 1000 W/m2, Bottom: P-V curve at 1000 W/m2.

The system is simulated at 1e-5 second of the discrete interval at the worst condition available in Jordan using a global atlas. And the power is around 52kW is achieving at the PV array terminals as shown in figure 46. The power is initially zero at t=0 sec and increases with time as expected it increase till 52kW and flatten out.

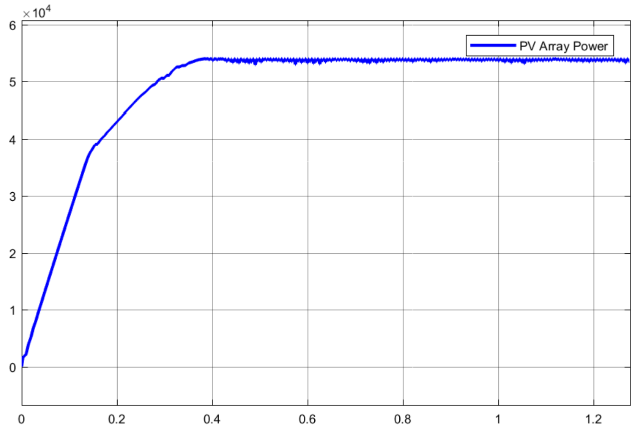


Figure 46 PV array power

In figure 47, the output voltage, panel voltage, output current, panel current, and power of photovoltaic is plotted at an irradiance value of 1000 W/m2. Where “irr” represents irradiance value, v_bus represents output voltage, Vpv is the voltage at the panel, iboost is current in buck converter terminal (output current), Ipv is the current at the terminal of the panel while Ppv here means the power of the photovoltaic panel. According to Simulink, we try different irradiance (0, 250, 500, 750, 1000) W/m2 based on these values the figures below change so, if we increase the irradiance from 0 to 1000 W/m2 the Vpv, Ipv, Vout, Iout, and Ppv will change as shown in figures below. We can figure out that V-bus (Vout) and IPV are changing depending on irradiance also Vpv stays constant and Ppv (= Vpv*Ipv) is changed based on Vpv and IPV. The output current (iboost) changed because the output voltage (V-bus) is changed.

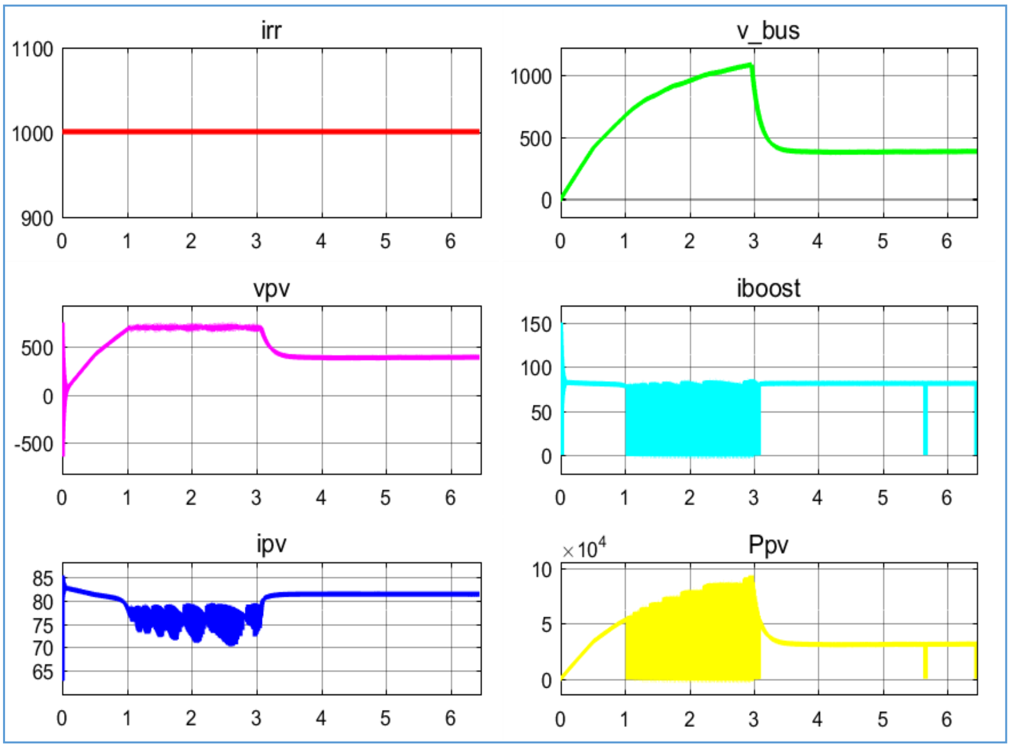


Figure 47 System voltage, panel voltage, current of system and buck converter is plotted at irradiance value of 1000 W/m2.

In figure 48, the voltage, current at the battery terminal along with reference current and voltage is plotted. In the beginning, we check the results at 0 W/m2 irradiance we can figure out that the battery current is around 2000A and the state of charge (SOT) is decreasing so the battery is discharging, and photovoltaic power is zero and the reference voltage is 660 V so we are going to increase the irradiance to 500 W/m2 we can figure out that the battery current is around -4000A and state of charge (SOT) is still decreasing so the battery is discharging, and the reference voltage is 660 V so we are going to increase the irradiance to 1000 W/m2 we can figure out that the battery starts charging in t=3 sec because the state of charge (SOT) is increasing and battery current is negative it means the battery is charging and PV power is higher than the consumed power in charging station (load). According to figure 47, we can say that if we decrease the irradiance the output voltage will be the same 660 V, battery current will increase, the battery voltage will decrease, and the power of PV will decrease. Battery discharging when the battery current is positive, and the state of charge is decreasing.

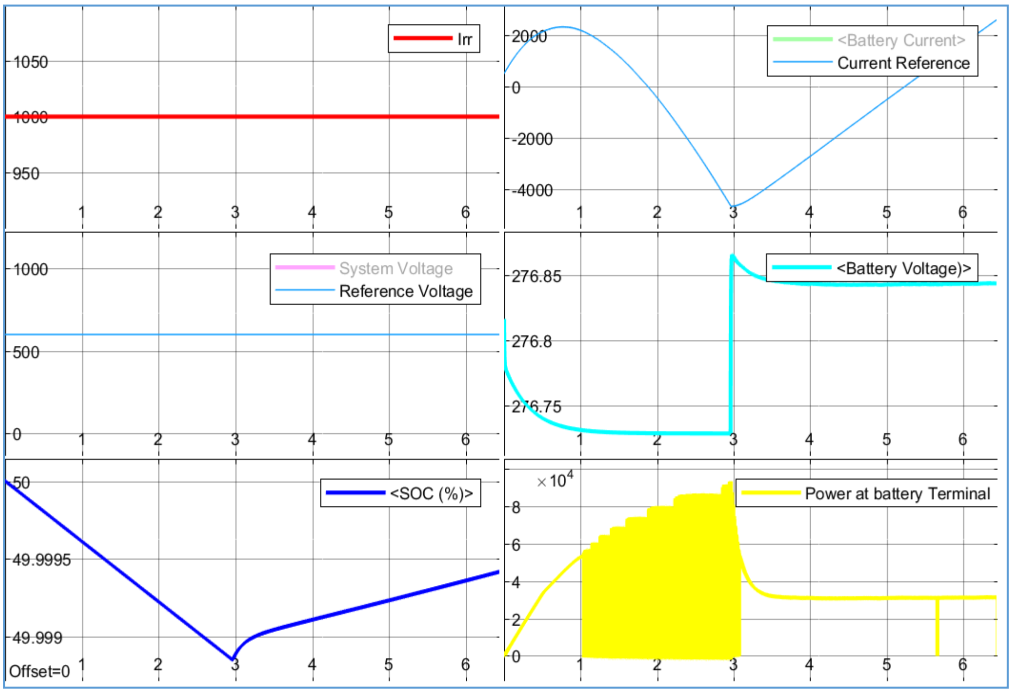


Figure 48 Results at battery terminal at 1000 W/m2 irradiance value.

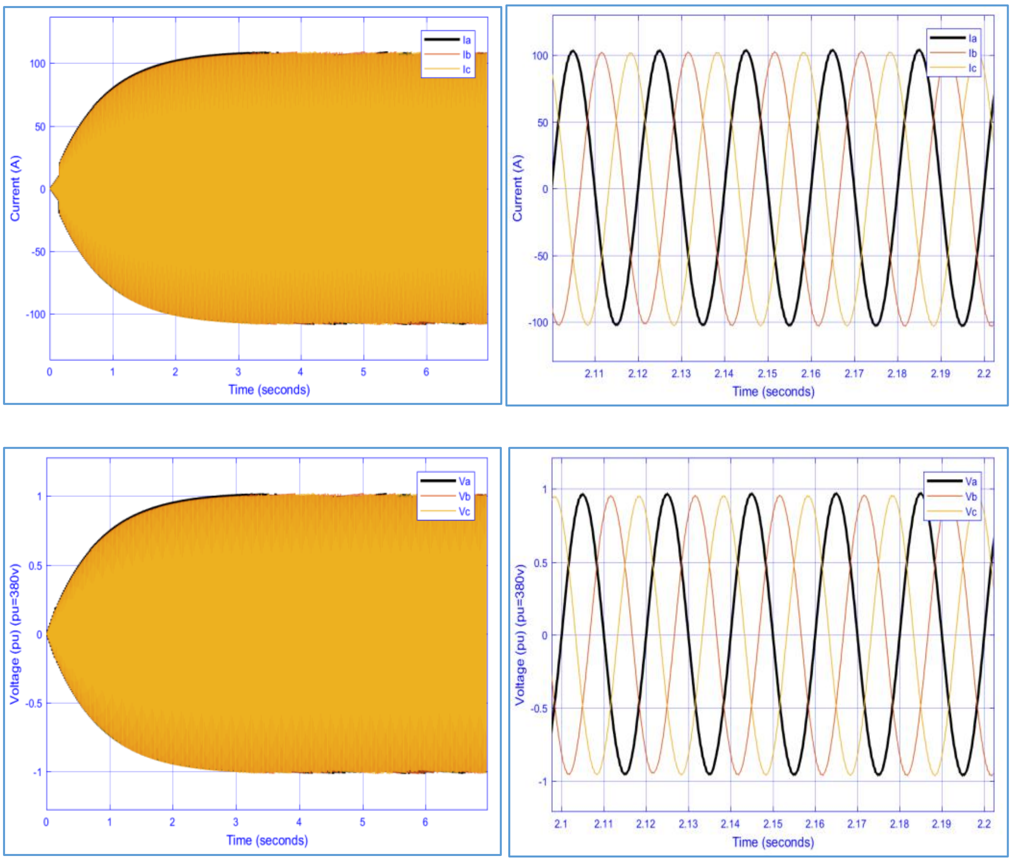


Figure 49 Results at Inverter terminal at 1000 W/m2 irradiance value.

In figure 49, the result of the inverter of current and voltage is shown and is calculated at 1000 W/ m2, the result shows the smooth transition of DC to AC due to the presence of appropriate filters and controlling signal. According to the figure below we can see that at the beginning the current and voltage is zero because the bus capacitor is empty so it has no voltage, so it has no voltage and when the system is starting to work the capacitor voltage will charge from the grid so the grid current will increase then the voltage and current will be stable.

In figure 50, the power production at the charging station available for EVs is shown. The initial ripples are too due to the start of PV-panels and PI- controller which stop the discharging of battery. The other minor ripples are due to lack of filters and currently reevaluating the models to remove the unnecessary ripples.

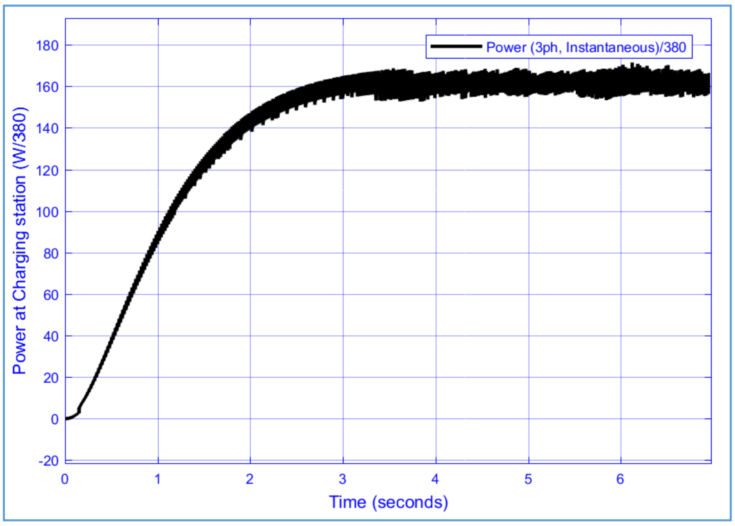


Figure 50 Power at Charging Station at 1000 W/m2 irradiance value

Figure 51 shows the daily input-output diagram of the previous design based on a 50KW solar PV system. According to the figure below we can figure out that the input-output diagram often in the form of a linear relationship for grid connected system where each object in the diagram reflects one day's production. On the x-axis, you have the energy injected to the grid [kWh/m2/day] On the y-axis, you have the system's production [kWh/day].

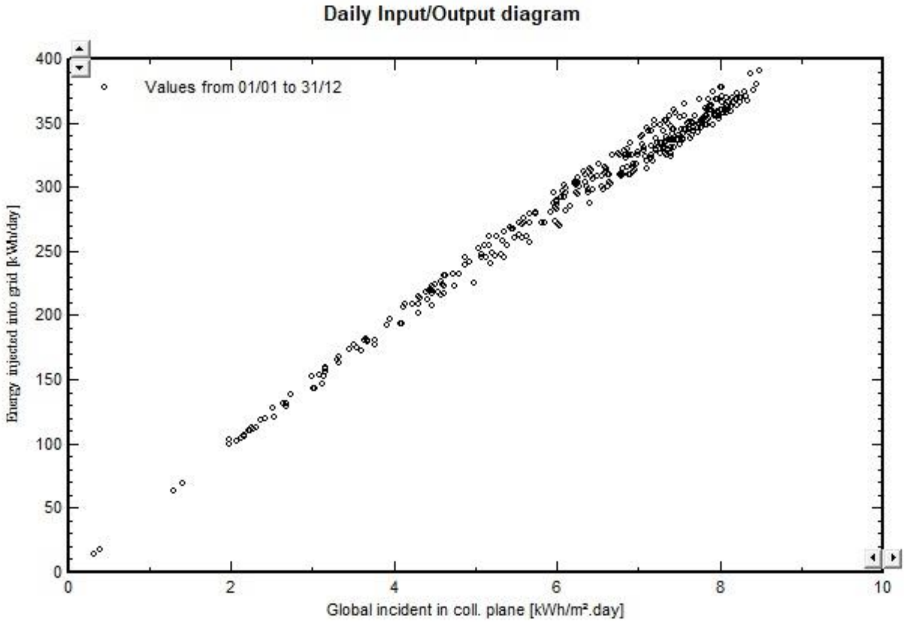


Figure 51 Daily input-output diagram

Figures 52 show the daily system output energy injected into grid as we can see that the solar resource it is not necessarily higher in everyday in summer as compared to winter, it depends on the climate (clouds), daily weather features (thunderstorms...) and tilt angle. Also, temperature is normally higher in summer than in winter, hence the efficiency decreases.

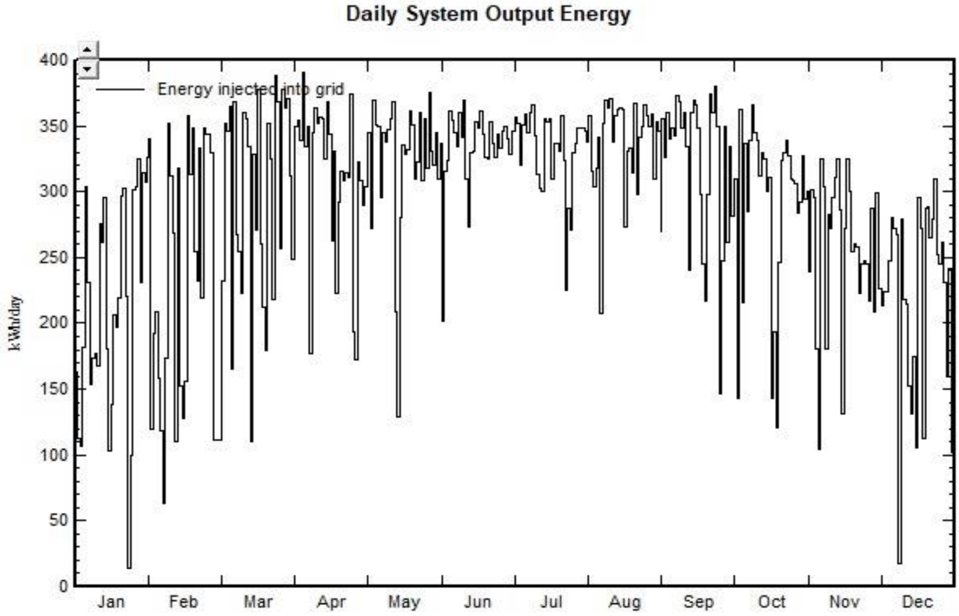


Figure 52 Daily system output energy injected into grid.

V. CONCLUSION

In this paper, the selection of effective modules to have the requisite energy output to charge electric vehicles requires the efficient use of renewable energy. With a surface area of 253m2, SunPower SPR-E20-435-COM PV modules at 30 tilt angles and zero azimuth, the total global irradiance for all the year is 2060.2 Kwh/m^2year and the average are 171.7 Kwh/m^2. mth, also the average temperature is 16.6 °C, 106.1MWh this represents the energy injected into the grid.

The EV charging station using MPPT based controller is designed and simulated in MATLAB Simulink module at 1e-5 sec of discrete-time. The system is initially designed in PVsyst Software, and the equipment selected from PVsyst is then selected in Simulink with their respective parameters and results in form of Voltage, power, current, and State of charge, etc. have been extracted in for of graph for all the major equipment. The result found is satisfactory with a slight error in the filtering process.

Since solar power generation and charging takes place every day, the most electric car charging has to be carried out during working time by using solar cells to charge electric vehicles, which would greatly affect the reduction in carbon emissions during the day, which is the biggest human interest. Through this work, we hope that it will serve as the foundation for other research work in this field.

VI. REFERENCES

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