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Design of a 50 kW Solar PV Powered Charging Station for EV's

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Abstract: ***The need for a clean environment promotes the increase in the number of electric vehicles (EVs) has led to an increase in power demand, which results in the design and development of the charging stations for electric vehicles. Charging stations are the main source of energy for EVs and their locations are critical to the accessibility of EVs in a city. Thus, the demand for plug-in electric vehicles (PEVs) charging for public vehicle charging systems is increasing. This paper reports the design of a 50-kW solar photovoltaic (SPV) charging station for plug-in hybrid electric vehicles. The purpose of the proposed system is to create a powerful, intelligent charging station that is powered by solar energy for charging PHEVs at workplaces. The design is targeted to King Hussein Business Park (KHBP), Jordan. The selection and recommendation of PV modules, inverter rating, and battery bank is chosen on the results generated by an online tool PV Syst. The proposed design is targeted to a surface area of 253 m2. The EV charging station using MPPT based controller is designed and simulated in MATLAB Simulink. 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 satisfy the charging demand of EV users, most importantly, reduce the energy cost.***

Keywords: electric vehicles (EVs), charging stations, plug-in electric vehicles (PEVs), solar photovoltaic (SPV), MPPT, MATLAB.

1. Introduction

There is an 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 19thcentury than gasoline cars. There are now many other sales designs in the world and their existence is estimated to rise dramatically in the next thirty years. Developments in energy storage, the design flexibility of vehicles, electric grid mechanization moreover the value of EVs for Customers, companies, and government organizations would improveand encourage long-term moves to improved transportation alternatives[1].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[2].

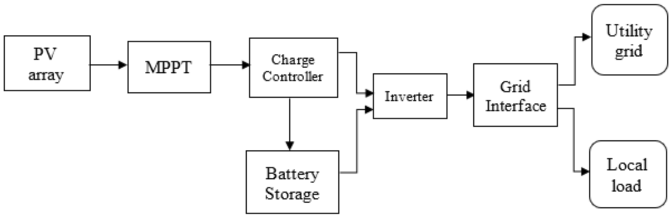


Figure 1: Functional diagram of solar powered charging station connected to grid.

On the other hand, if EVs are charged from a grid that 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 the future. The best renewable energy sources for 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:

- 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. 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.
- The power demand and energy on the grid is decreased due to electric charging because the charge energy is provided locally "green" by solar panels [3].
- 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 [4], [5].
- PV devices typically use a battery to store solar energy to handle the fluctuations in solar activity both daily and seasonal [6], [7].

These days, with worldwide concern for greenhouse gases and environmental pollution, EVs are being produced at 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. Besides, 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 solve the environmental problems, to charge electric vehicles from renewable energy.

2. EV Charging Methodology

a) Charging an EV from Grid

Although charging EVs 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 a 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[8]. Salman Habib, Muhammad Kamran, and Umar Rashid were carried out the amount of entry and discharge or charge techniques of vehicles that 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 [9]:

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

EV charging from the grid also has no positive effect on 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 emissions used to charge these EVs. This is because the emission decrease advantages of charging stations decrease with the increased grid CO2 level.

b) 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 say 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.

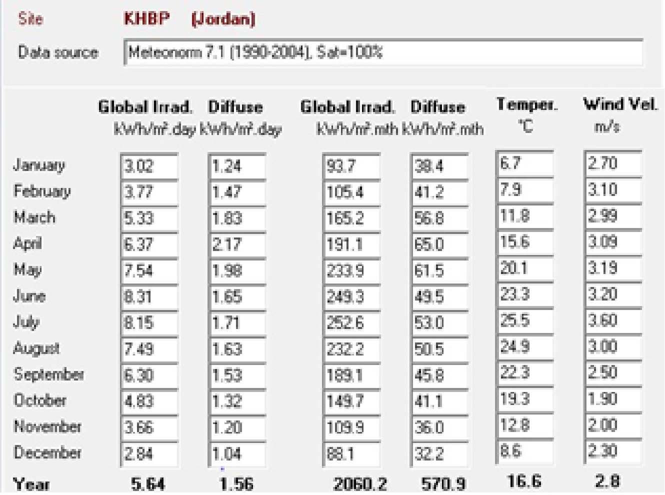
Also, through multiple types of research the variable nature of renewable energy sources (RES) over grids of power systems have been developed to reduce through Intelligent coordination and storage capabilities of PHEVs [10].The places of the Solar Powered Charging Stations (SPCS) will mainly focus on the terms of operation of the EVs:

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

3. System Modelling

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 2 where the x-axis represents azimuth (0°) and the y-axis represent sun height. Accordingto the figure below we can figure out, we will produce more energy in summer (1: June) more than in winter (7: December).

Figure 2 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 is 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/m².day	Diffuse kWh/m².day	Global Irrad. kWh/m².mth	Diffuse kWh/m².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 2: Solar annual average irradiance and temperature value in the daytime for each month of the year at KHBP.

The main components being used in the specified design are photovoltaic systems, electric vehicle charging stations (EVCS), controller, inverter,connectors, cables, and mounting system is shown in Figure 3.1.

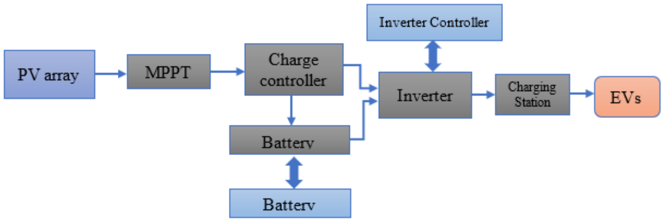


Figure 3.1: MATLAB implementation of the blocks.

a) Solar PV Array

For a 50kW system using PV Syst V6.88, SunPower SPR-E20-435-COM is selected which has a 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 overall. The solar array is selected for the worst condition which happens in December in Amman Jordan with about 2.8 kW/m^2 at 8.6 ºC.

b) 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 two 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%.

c) Maximum Power Point Tracking (MPPT) Controller

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.

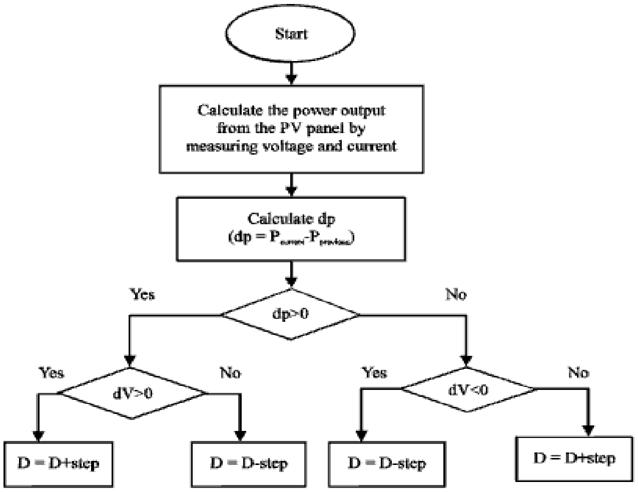


Figure 3.2: Flowchart of the Perturb and Observe method.

d) 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 string with each has 5 batteries in it. It gives a total of more than two days of autonomy.

e) MATLAB/SIMULINK Implementation

Simulink is a graphical extension to MATLAB for modeling and simulation of systems. In Simulink, systems are drawn on the 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.

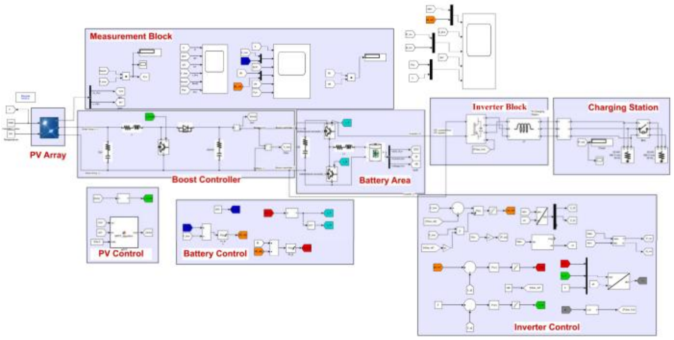


Figure 4.1: Matlab implementation of 50 Kw charging station for EV's

In this simulation, there are nine phases of the Simulink Model as shown in the following diagram. The MPPT algorithm is used for a charge controller with boost control charging. The discrete system with a time step of a 1e-6 second is used with the constant input of irradiation value and temperature to the solar array. The specifications of the 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 253 square meters to generate about 50 kW of nominal power. The flow of current from the PV system is controlled by the controller block also known as buck converter circuit as shown in Figure 4.2.

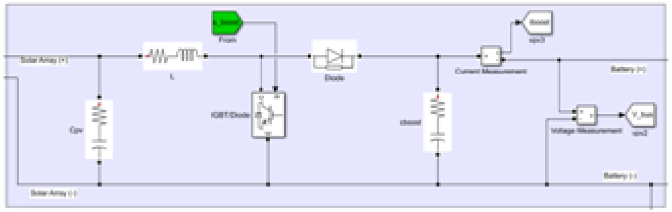


Figure 4.2: Buck converter controller block.

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, a 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 V in the input voltage of the buck converter.

The MPPT is commonly used in many small and medium commercial solar PV charge controllers and grid-connected inverters 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 shown in Figure. 4.3.

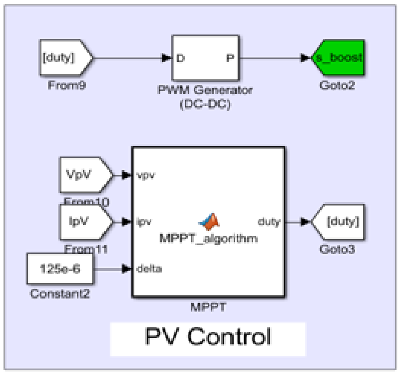


Figure 4.3: MPPT PV control

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.

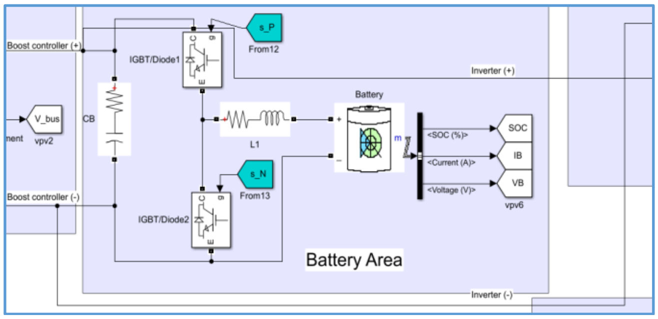


Figure 4.4: Battery block

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 4.5 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.

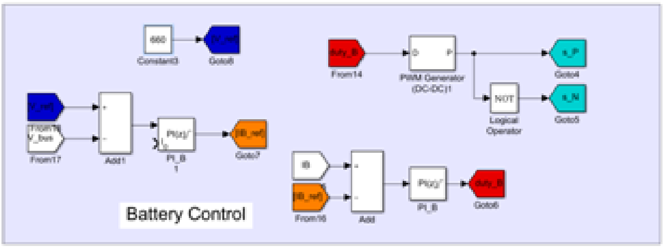


Figure 4.5: Battery controller block

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.

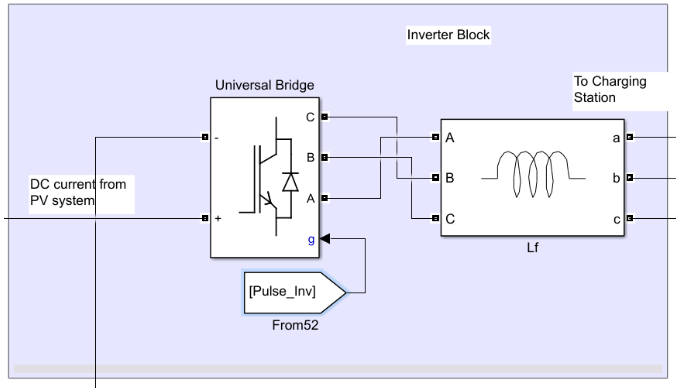


Figure 4.6: Inverter block.

The purpose of inverter controller blockis 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.

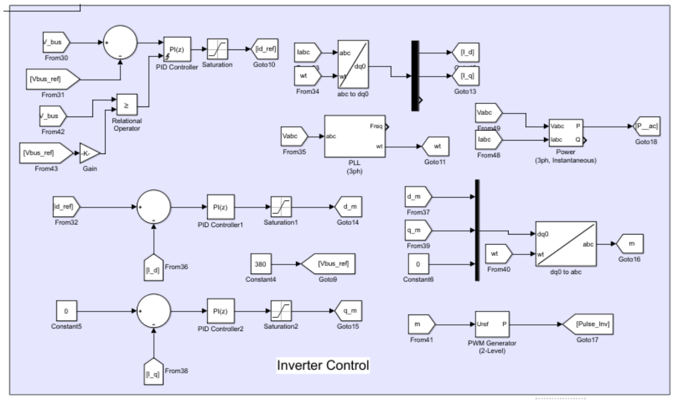


Figure 4.7: Inverter controller block

4. Results

In this section, the simulation results are presented and analyzed of the proposed design of 50KW PVby using PVSYST and MATLAB software. 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 5.1 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 paper.

Figure 5.1: Photovoltaic panels powered EVs charging stations where it installed at rooftop and parking lots.

The solar path or horizon indicates that how much useful sun is shown in Figure 5.2.

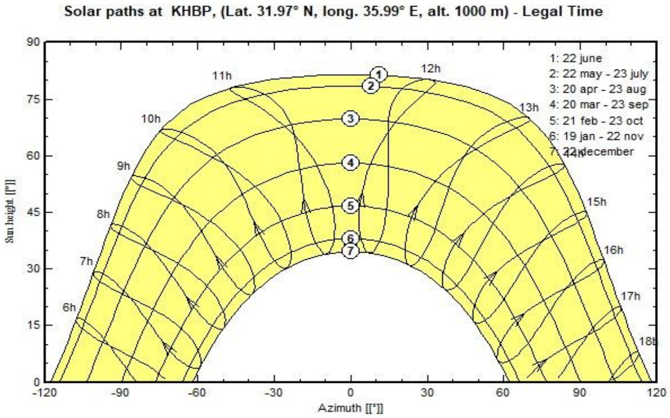


Figure 5.2: Path of the sun over a year in KHBP.

Also, we analyzed 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 5.3 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.

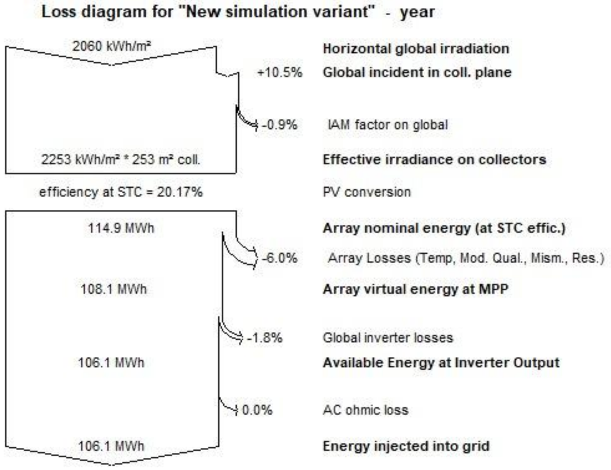


Figure 5.3: Losses diagram over the whole year.

Table 1 shows the annual energy production of the system design. According to the table 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 table below, we can figure out that we have a PR equal to 91.6%.

Table 1: Annual energy production

	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

The global horizontal irradiance kWh/m2 increases from January to July and then decreases from August to December. The highest value of global horizontal irradiance recorded as 252.6 kWh/m2 during July and lowest value of 88.1 kWh/m2 in December. The ambient temperature 0C is highest in July with a value of 25.53 0C and in January it is lowest at 6.68 0C.

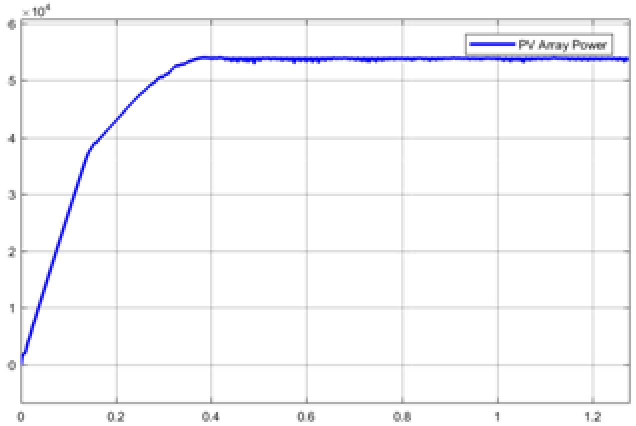


Figure 5.4 & 5 show the annual produced useful energy (inverter output) and performance ratio (PR). According to figure d below we can figure out that the red color represents annual production energy in summer the production will increase based on high temperature, the green and blue colors represent losses (PV array and inverter) also the losses increase in summer based on high temperature. According to figure e below, we can figure out that PR decrease in summer because we have a high temperature.

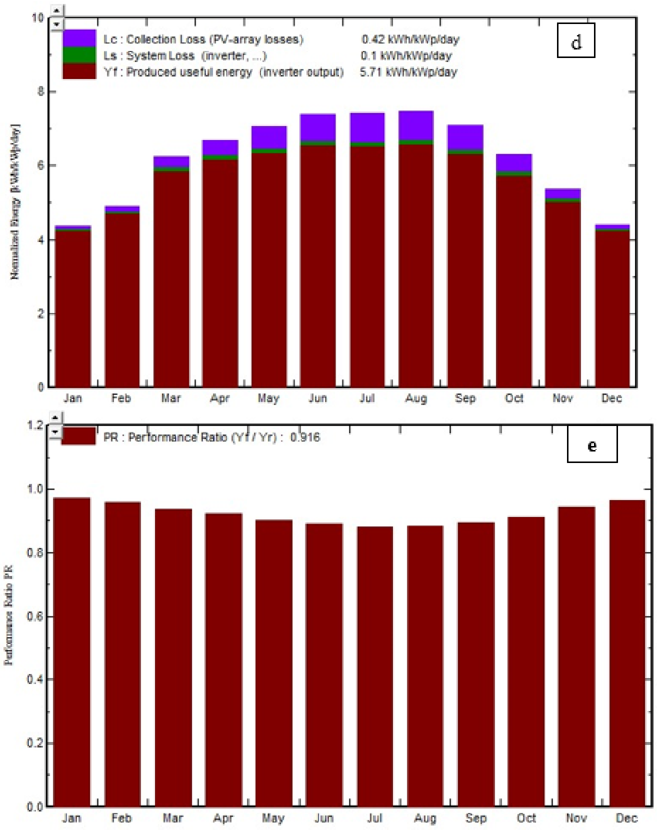


Figure 5.4 & 5: Annual produced useful energy (inverter output) and performance ratio (PR).

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 5.6. The power is initially zero at t=0 sec and increases with time as expected it increase till 52kW and flatten out.

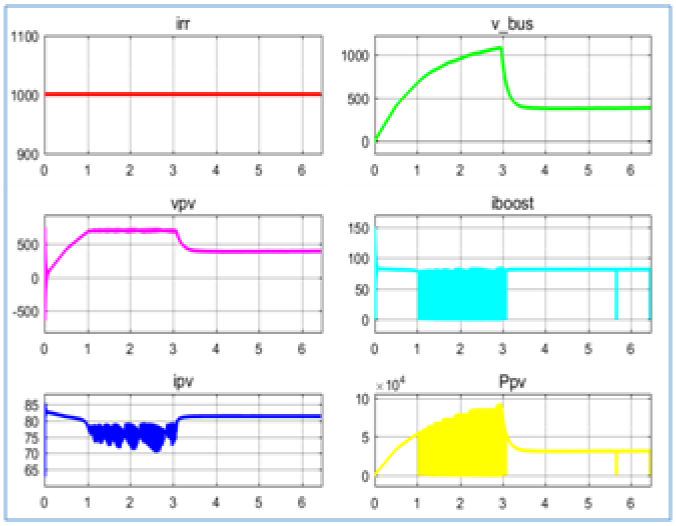


Figure 5.6: PV array power.

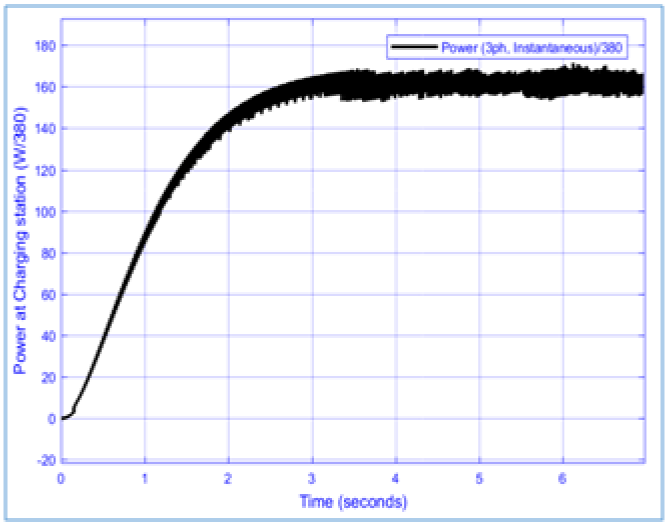


Figure 5.7 Power at charging station at 1000 W/m2 irradiance value.

In figure 5.7, 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 the battery. The other minor ripples are due to a lack of filters and currently reevaluating the models to remove the unnecessary ripples.

In figure 5.8, 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.

In figure 5.9, 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 below, 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 5.8 System voltage, panel voltage, current of system and buck converter is plotted at irradiance value of 1000 W/m2.

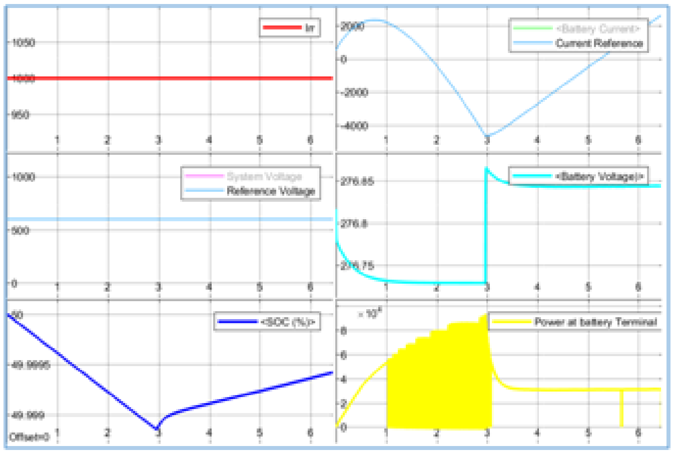


Figure 5.9: Results at battery terminal at 1000 W/m2 irradiance value

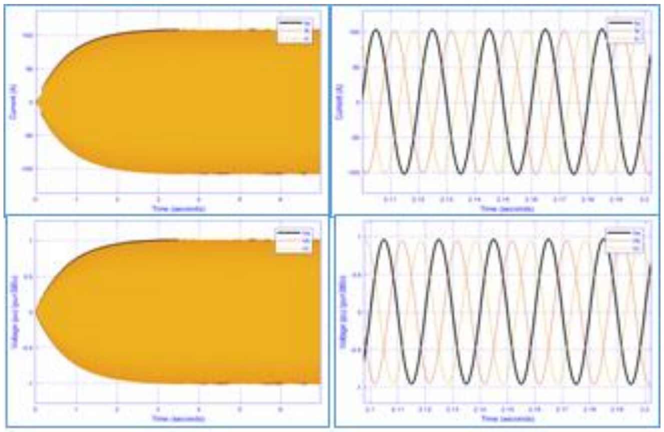


Figure 5.10: Results at Inverter terminal at 1000 W/m2 irradiance value

In figure 5.10, 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.

5. 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/m²year and the average are 171.7 Kwh/m². 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.

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