Modeling and Simulation of Grid-Connected Photovoltaic Array System Using MATLAB/SIMULINK

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ABSTRACT

Renewable energy sources development is increasing rapidly to decrease CO2 emissions and use of fossil fuels. Solar power (PV) is example of intermittent renewable production. PV becomes more interesting source of renewable energy for distributed power generation because of their relatively small size, high power capability per unit of weight and longer life with little maintenance. This paper presents modeling and simulation of PV grid-connected microgrid system in MATLAB/Simulink environment to study the behavior of the system during steady state operation. The proposed microgrid system consists of solar PV array, power electronic converter, ultra capacitor (UC) and AC loads. UC system is used to support the PV panel during periods of reduction in solar irradiance whereas, Maximum Power Point Tracking (MPPT) is used to ensure that the output power of the system at maximum as possible. The proposed system is validated by means of simulation results. It is observable that the distributed generation operates stably and control works as expected.

Keywords: Photovoltaic (PV) – MPPT algorithm – Energy Storage System –Converters–Inverter.

1. Introduction

The increasing of the world energy demand due to the modern industrial society and population growth, is motivating a lot of investments in alternative energy solutions, in order to improve energy efficiency and power quality issues. Solar energy is one of the most important renewable energy sources. Against to the conventional not renewable sources such as gasoline, coal, etc. solar energy is clean, inexhaustible and free [1]. The use of photovoltaic energy is considered to be a primary resource, because there are several countries located in tropical and temperate regions, where the direct solar density may reach up to 1000W/m. A typical grid-connected photovoltaic system (GCPV) system consists of PV array, maximum power point tracker (MPPT) unit, inverter and utility grid can be represented in the block diagram as depicted in figure 1.

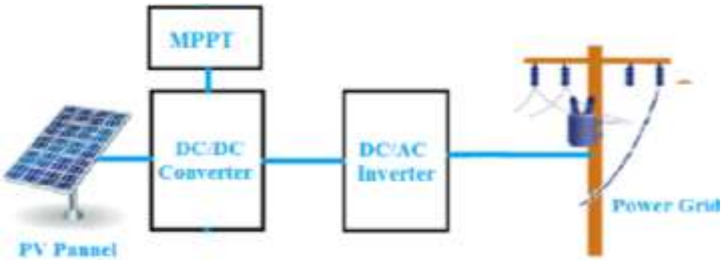

Figure 1: A typical GCPV system block diagram.

At present, photovoltaic (PV) generation is assuming increased as a importance renewable energy sources application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts.

The cell conversion ranges vary from 12% of efficiency up to a maximum of 29% for very expensive units [2]. In spite of those facts, there has been a trend in price decreasing for modern power electronics systems and photovoltaic cells, indicating good promises for new installations.

The PV generators exhibit non-linear I-V characteristics. On the other hand, the optimum operating point changes with the solar irradiation, and cell temperature [3]. Ultra-capacitor (UC), also known as super-capacitor, is a popular energy storage device for many applications because of its power density and ability to store and release power within short time periods is used [4]. Two different cases are simulated steady and transient states, and all simulation results have verified the validity of models and effectiveness of control methods.

2. Modeling of PV Array

PV cell is the most basic generation part in PV system. Single-diode mathematic model is applicable to simulate silicon PV cells. This model consists of a photocurrent source Iph, a nonlinear diode, series resistance Rs which represents the internal losses and shunt resistance Rsh, in parallel with diode to take into account leakage current to the ground as shown in figure 2.

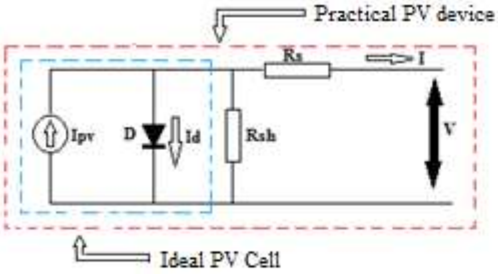

Figure 2: Model of a solar photovoltaic panel.

The mathematic relationship for the current and voltage in the single-diode equivalent circuit can be described as:

$$I = I_{ph} - I_s\left(e^{\frac{q(V+IR_S)}{AKT}} - 1\right) - \frac{(V+IR_S)}{R_{sh}} \qquad (1)$$

Where, Iph is photocurrent; Is is diode saturation current; q is electron charge (1.602 × 10-19 C; k is Boltzmann’s constant (1.381 × 10-23); T is cell temperature; A is PN junction ideality factor.

The Photocurrent is represented as a function of solar radiation and cell temperature and described as:

$$I_{ph} = \left(\frac{S}{S_{ref}}\right) X \left[I_{ph,ref} + C_T \left(T - T_{ref}\right)\right] \qquad (2)$$

Where, S is the real solar radiation (W/m^2), S_{ref}, T_{ref} are respectively the solar radiation and cell absolute temperature respectively, $I_{ph,ref}$ is the photocurrent in standard test conditions, C_T is the temperature coefficient (A/K).

The diode saturation current Is varies with the cell temperature as:

$$I_s = I_{s,\ ref} \left(\frac{T}{T_{ref}}\right)^3 e^{\left[\left(\frac{1}{T_{ref}}-\frac{1}{T}\right)\frac{qE_g}{AK}\right]} \qquad (3)$$

Where, Is, ref the diode saturation current in standard test conditions, Eg is the band-gap of the cell semi-conductor (eV) depending on the cell material. PV cells usually considered to have the same characteristics and arranged together in series and parallel to form arrays. The equivalent circuit of PV array is shown in figure 3.

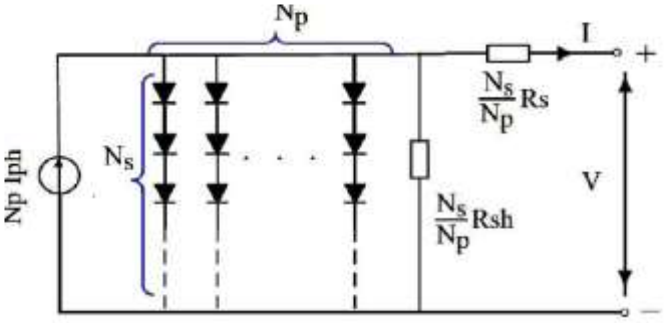

Figure 3: Equivalent circuit of PV array

$$I = N_P I_{ph} - N_P I_s\left(e^{(q(V/N_S+IR_S/N_P)/AKT)} - 1\right) - \left((N_P V/N_S + IR_S)/R_P\right) \qquad (4)$$

Where, Ns and Np are respectively cell numbers of the series and parallel cells. The above model has been implemented using Matlab/Simulink as depicted in the figure 4. Table 1 shows the electrical data of the used module.

Table 1: Electrical Performance of Sunpower 220 Solar Panel module Under Standard Test Conditions(STC)

Parameter	***Value***
Maximum power rating Pmax	220W
Rated voltage Vmpp	41.0V
Rated current Impp	5.37A
Open circuit voltage Voc	48.6V

Short circuit current Isc	5.75A
Voltage Temperature Coefficient Kv	-132.5mV/°C
Current Temperature Coefficient Ki	3.5mA/°C
Peak Power Per Unit Area	177W/m^2

STC: Irradiance 1000W/m^2 ,AM 1.5 spectrum, module temperature 25 °C.

3. Model Validation

A general block diagram of the PV model using MATLAB/Simulink is shown in figure 4 in which used to investigate PV module characteristic with that provided by manufacturer's datasheet. The block in figure 4 contains the sub models connected to build the final model. temperature Variable (T), and solar irradiation level variable (G) are the inputs to the PV model.

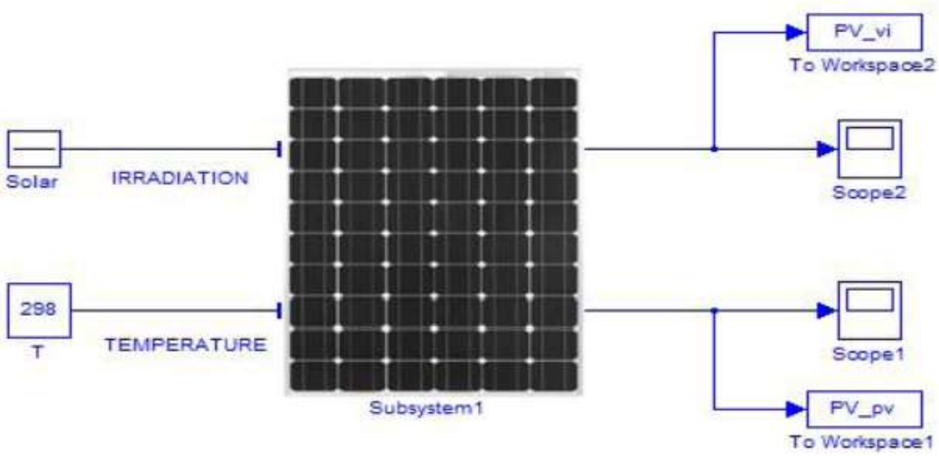

Figure 4: block diagram of the PV model

With different irradiations and temperatures, I-V and P-V Characteristics of PV array are simulated and the results as in figures 5, 6, 7 and 8 respectively.

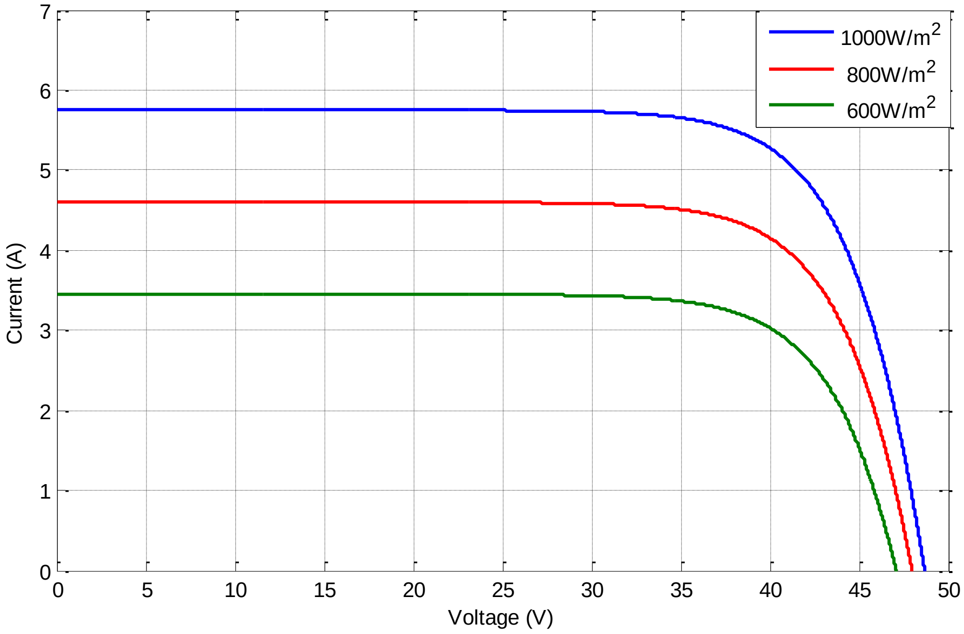

Figure 5: I-V Characteristic curves of the PV array with different solar Irradiations and constant temperature solar 25°C

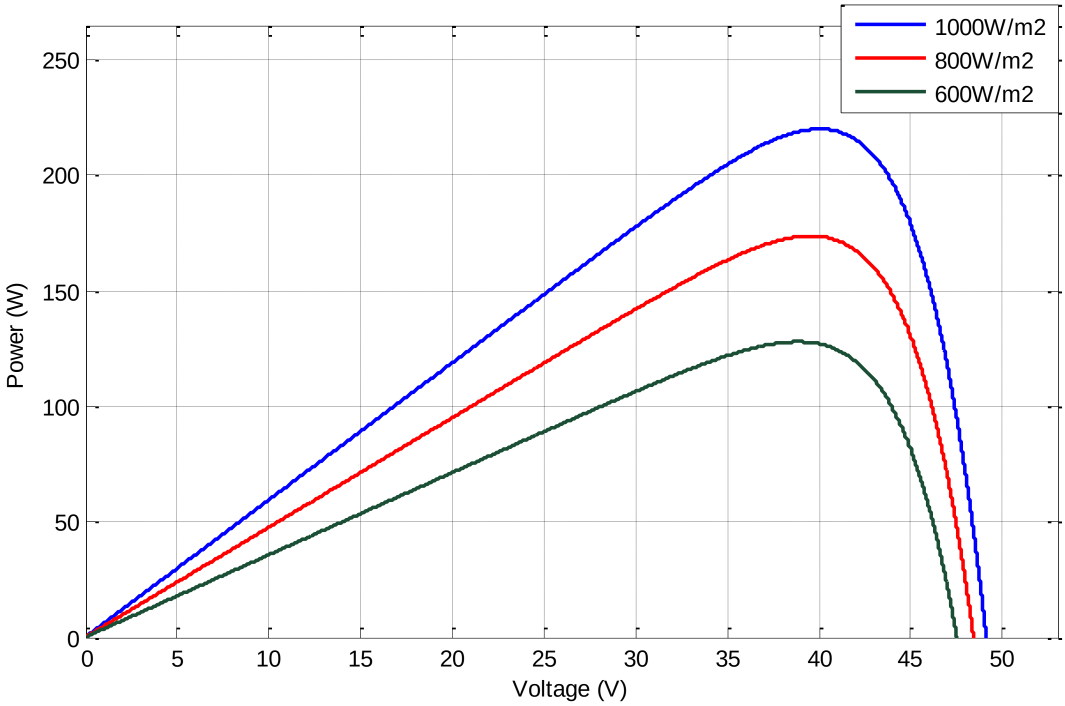

Figure 6: P-V Characteristic curves of the PV array with different solar Irradiations and constant temperature solar 25°C

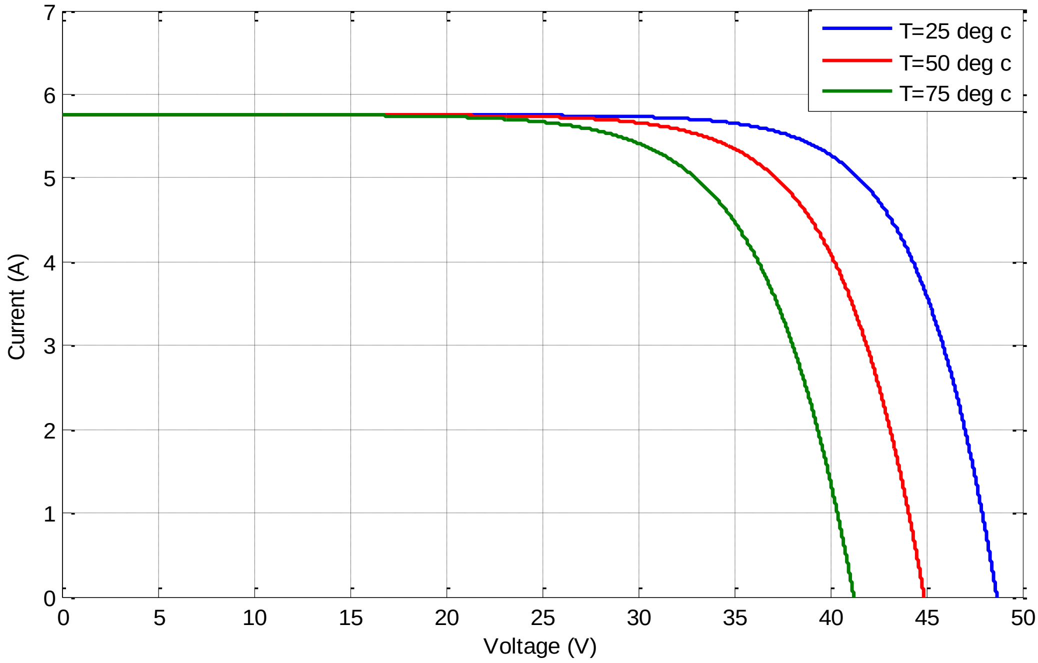

Figure 7: I-V Characteristic curves of the PV array with different cell temperatures and irradiation solar constant 1000 W/m^2

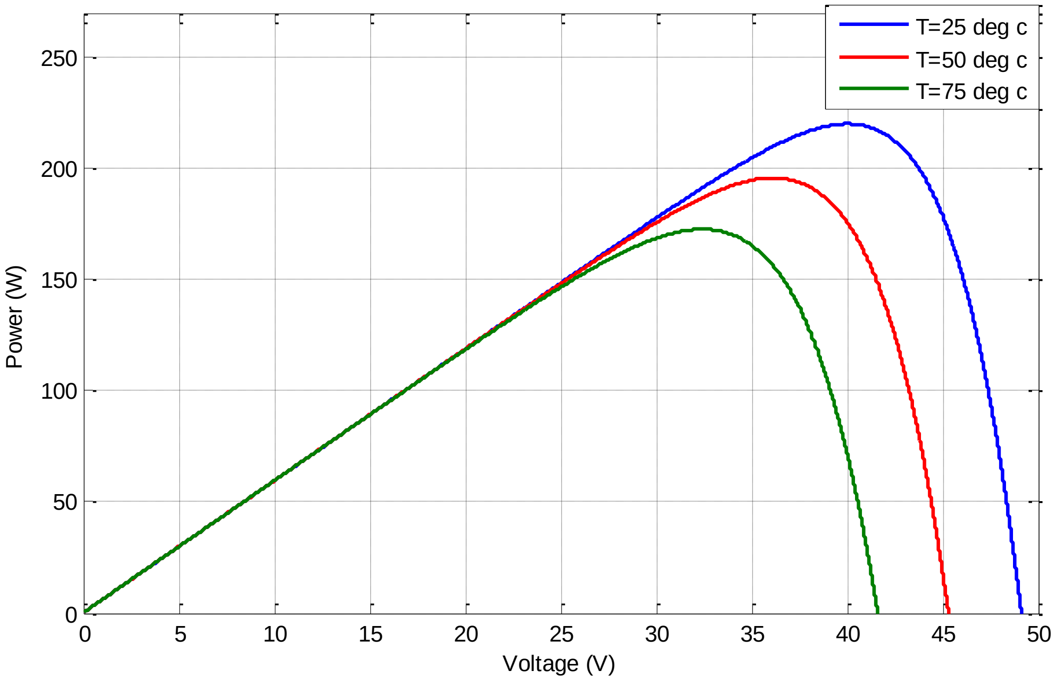

Figure 8: P-V Characteristic curves of the PV array with different cell temperatures and irradiation constant 1000 W/m^2

From the previous results it is evident that the PV array has nonlinear voltage-current characteristics, and there is only one unique operating point for a PV generation system with a maximum output power under a particular environmental condition.

4. Grid-Connected PV Generation System

Grid connected PV generator systems always a connection to the electrical network via a suitable inverter because a PV module delivers DC power. The grid inverter is different from a typical inverter that used in stand-alone PV system. The main specification of the grid inverter is that current drawn from the inverter is delivered to the utility grid at unity power factor [5]. The overall configuration of the grid-connected PV generation system is shown in figure 9. PV array is connected to the DC bus via a DC/DC boost converter. The ultra-capacitor energy storage system is composed of the ultra-capacitor, a bi-directional DC/DC converter and control system. The configuration should enable the ultra-capacitor operating in bi-directional mode. The primary objective is to maintain the common dc-link voltage constant [6]. The DC microgrid side then linked to AC grid by means of DC/AC inverter. The inverter has its independent control objective (boost inverter control PV generator to generate the maximum power and grid inverter control the active and reactive at AC bus to be constant). The power output obtained from a PV panel does not remain constant during the day. As the irradiance or temperature changes, so does the output power [7]. In order to improve the efficiency of the PV generation system in all the irradiation conditions, MPPT based in P&O algorithm is used to transfer maximum power to the load [8,9]. Three phase inverter is used to obtain a three-phase voltage output from DC source. In grid connected PV system, the output current of the voltage source inverter will be injected to the grid. The output of the inverter should be in phase and have an identical frequency to the voltage of the grid.

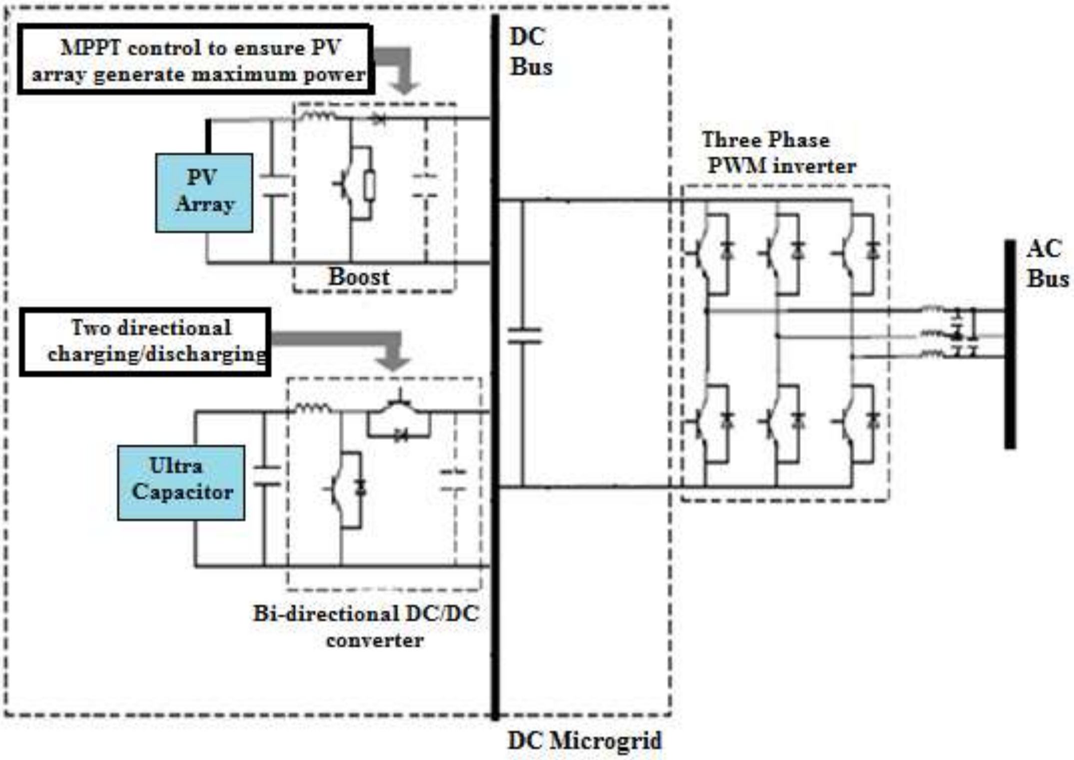

Figure 9: Grid-connected PV generation system Configuration

5. PV generation system

The whole PV system which used in this paper is comprised of 390 SunPower solar modules connected in series-parallel combination (15 series and 26 parallel) and totalling power of about 86Kw DC power, it should be interconnected into the grid using power electronics to convert DC to AC power.

6. Simulation Results and Discussion

The overall model of PV grid-connected system is implemented in MATLAB/Simulink and simulated at standard test condition (STC) with solar irradiance of 1000 W/m^2 and an operating temperature of 298K which called steady state operation case. At steady state, the distributed generation unit is operating at it's nominal point, and supply power to the loads, the ultra-capacitor energy storage system is inactive, i.e. neither charging nor discharging. phase look loop (PLL) technique is employed for the synchronization between PV system and grid (distribution network). The inverter topology should guarantee that the output current is a high quality sinewave and in phase with grid voltage. The resulted voltage and current at point of common coupling (PCC) should be in phase with each other and this can be seen in figure 10.

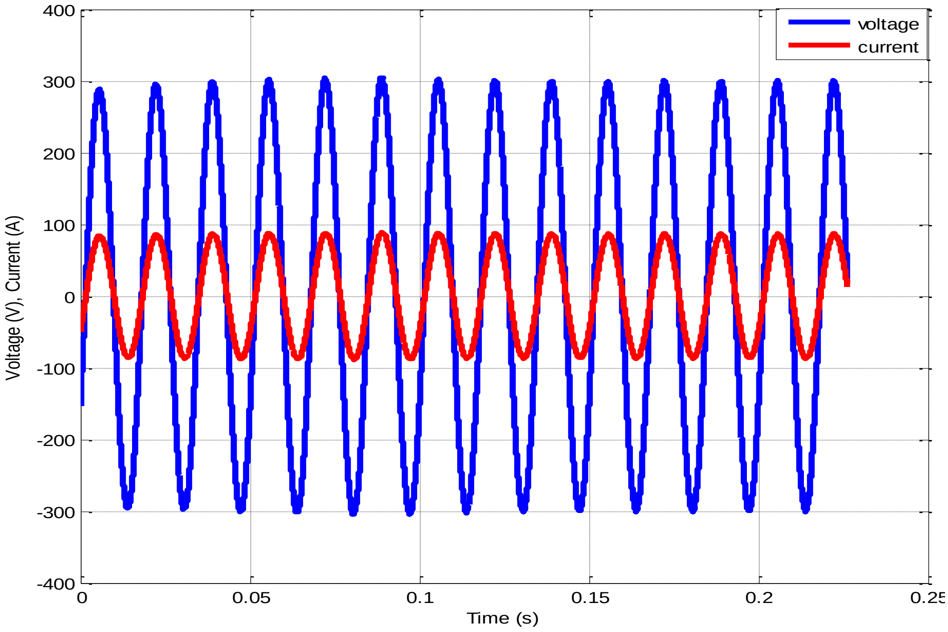

Figure 10: Voltage and Current at PCC during normal operation

Figure 11 shows voltage simulation result at DC Link when the system operates at standard test condition (T = 25C^{O}, G = 1000 W/m^{2}). The system composed of 15 module in series 41V each, so it generates 615V then boosted by means of boost converter to constant value of 700V.

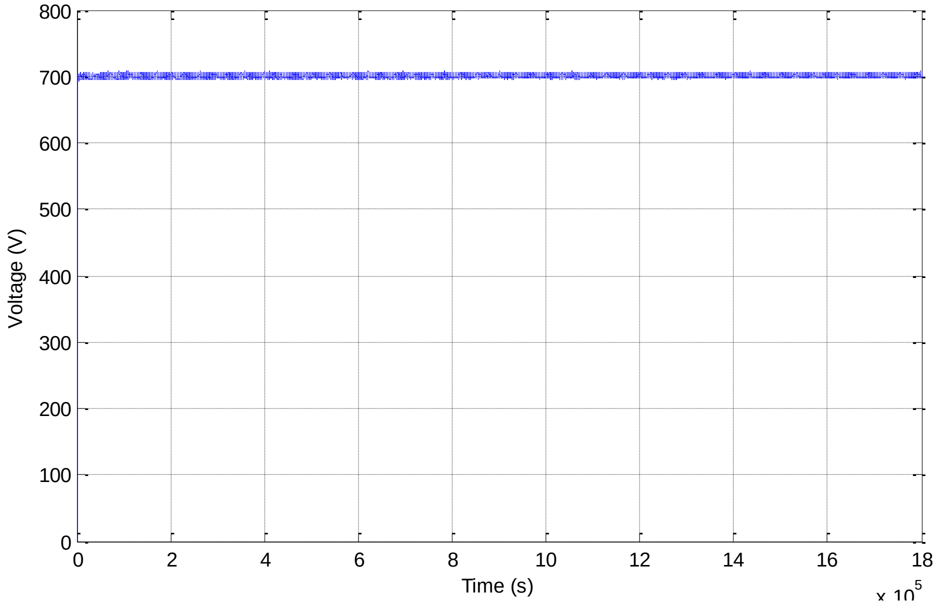

Figure 11: DC link voltage after boost-converter (V steady state = 700volts)

From the above figure it is observed that the input DC voltage to the inverter remains constant after the system gains its operational point at the maximum power point. Since the system operates at mentioned standard test conditions and energy storage device system is used for energy charging and discharging process, the PV system output power maintain constant at designed value (86KW) when weather condition changes during a day. Figure 12 shows the simulation result of DC power produced by the system.

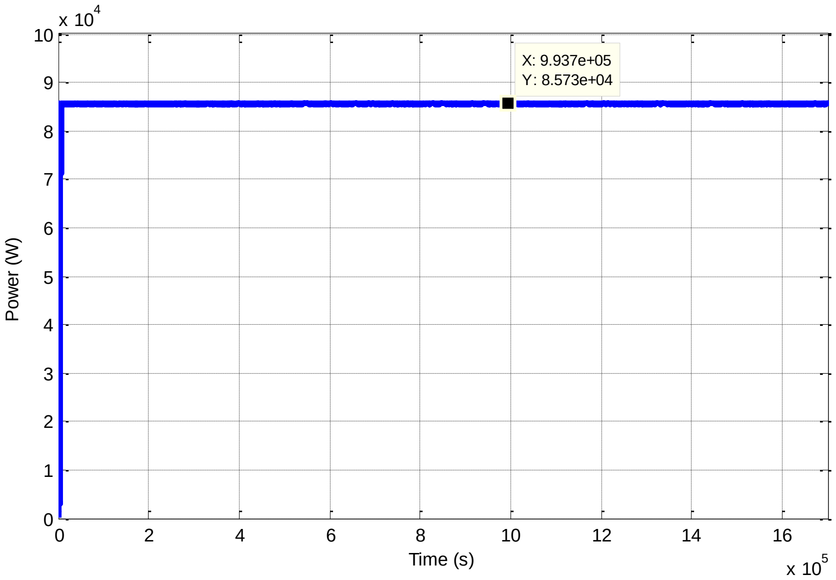

Figure 12: PV system power generation

From the above figure it is noted that the system reaches the rated power after short period of the time. Figure 13 shows the AC active and reactive power injected to the grid side at point of common coupling. From the figure it is noted that the AC power reaches it is nominal value after short period of time and then maintain stable at constant value in case of steady state operation.

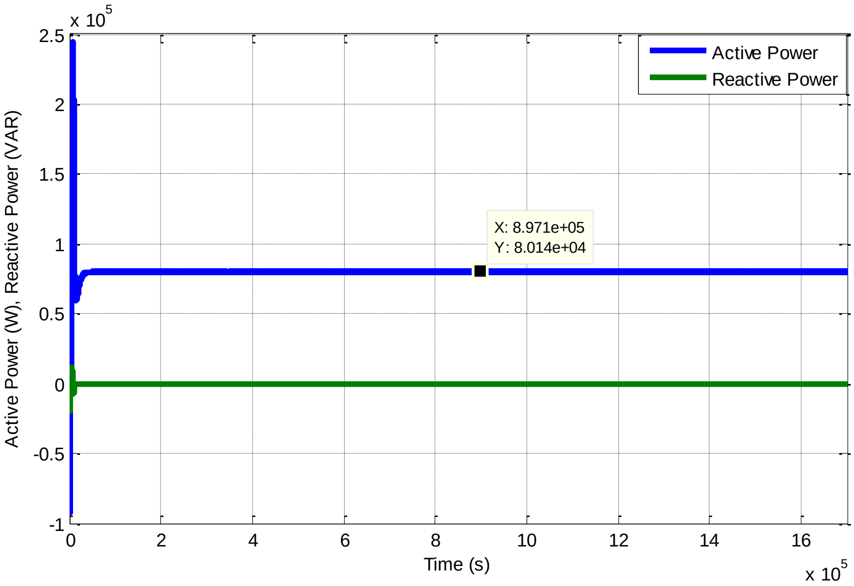

Figure 13: Injected AC power generated by PV system to the utility side

7. Conclusion

Solar source provide a realistic form of power generation. In the paper, a grid-connected PV system is presented to supply continuous power to the loads. The dynamic behaviour of the system, including device and grid level control strategies are examined for short-term transient simulations. Changing solar radiation causes a change in PV output. However, the PV system tracks the maximum power point for each case using (MPPT) control technique. When PV production is insufficient to meet load demand, the super capacitor is discharged to compensate the difference. Thus the super storage energy system helps to ensure sufficient DC voltage during the transients . The simulation results show an improvement in the whole system stability.

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