

Modeling and Simulation of Grid Connected PV Generation System Using Matlab/Simulink

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ABSTRACT

This paper describes the Grid connected solar photovoltaic system using DC-DC boost converter and the DC/AC inverter (VSC) to supplies electric power to the utility grid. The model contains a representation of the main components of the system that are two solar arrays of 100 kW, boost converter and the grid side inverter. The paper starts with a system description, in this part we have given a definition and a short overview of every component used in this system and they are taken separately. The PV cell model is easy, accurate, and takes external temperature and solar radiation into consideration. It also proposes a maximum power point tracking (MPPT) algorithm. The algorithm incorporated in a DC/DC converter is used to track the maximum power of PV cell. Finally, the DC/AC inverter (VSC) of three-level is used to regulate the output voltage of DC/DC converter and connects the PV array to the grid. Simulation results show how a solar radiation's change can affect the power output of any PV system, also they show the control performance and dynamic behavior of the grid connected photovoltaic system.

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1. INTRODUCTION

Because energy resources and their utilization will be a prominent issue of this century, the problems of natural resource depletion, environmental impacts, and the rising demand for new energy resources have been discussed fervently in recent years [1]. Grid-connected photovoltaic (PV) power systems have been sustaining an exponential growth rate during the past decade. This steep growth is driven by a growing concern about climate change, rebates and tax incentives, and reduction in PV system cost. The main disadvantage of solar energy based electrical power supply is that power generation is not constant throughout the day, as it always changes with atmospheric conditions [2]. Further, the efficiency of solar energy conversion to electrical energy is very low, only in the range of 9-17%. Therefore, maximum power point tracking (MPPT) is an essential part of a grid-tied solar PV system to ensure that maximum available power is always extracted out of the PV panel at all conditions and steered to the AC grid, considered as an infinite sink of power ideally [3]. This feature has an essential role in dynamic response and efficiency of the photovoltaic system, in literature, different MPPT algorithms are introduced and among them the "Perturb and Observe (P&O)" and "Incremental Conductance" are mostly used [4],[5], on the other hand, some MPPTs are more rapid and accurate and thus more impressive, which need special design and familiarity with specific subjects such as fuzzy logic [6], or neural network [7] methods.

Grid connected PV systems feed electricity directly to the electrical network, operating parallel to the conventional electric source. The simplest grid-connected PV system contains a PV array and an inverter

unit used for residential purpose to generate clean electricity near the point of use [8]. One of the main technical barriers that can ultimately limit further PV penetration is the fast variations in the PV system's output power induced by cloud transients. Such events are known to cause voltage fluctuations which may lead to excessive operations of voltage regulation equipment and light flickering [9].

Solar irradiance variability, which can be easily recorded using a pyranometer and a data logger, is used in numerous studies to assess the AC power injected into the grid by PV systems. But in reality, the two variables are not perfectly proportional with one another, nor synchronized in time due to delays within the inverter circuit elements and controls.

As a consequence, computer models that accurately simulate the dynamic behavior of PV systems under moving clouds would thus be of high value. In this paper, a dynamic MATLAB/Simulink model of a three phase grid-connected PV system that can be used to predict the deviations in AC power output under variable solar irradiance is presented. The commonly used perturb-and-observe technique for Maximum Power Point Tracking (MPPT) is used in the present model. Figure 1 shows a typical utility interactive PV system, it is found that the deviation between solar radiation and output power variability that may be caused by the MPPT and buffer capacitor is minimal and can often be neglected. As a result, the variations in solar irradiance can be considered as a good indication of power fluctuations.

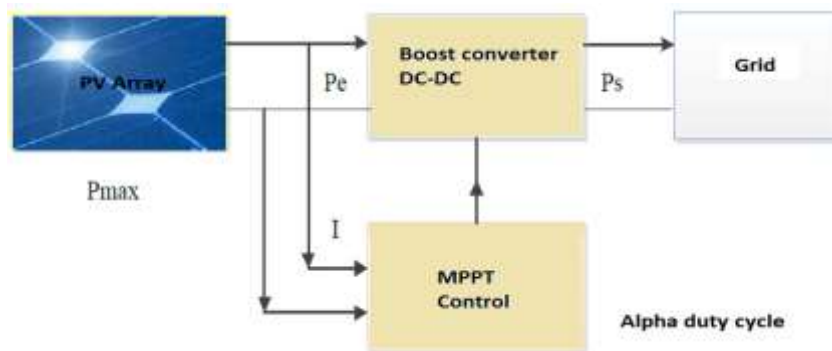


Figure 1. Utility interactive pv system

2. SYSTEM DESCRIPTION

Figure 2 shows two PV arrays of 100kW connected to a 25kV grid via two DC-DC boost converters and a three-phase three-level Voltage Source Converter (VSC). Maximum Power Point Tracking (MPPT) is implemented in the boost converter by means of a Simulink model using the 'Perturb & Observe' technique.

The proposed model contains the following components:

- Two PV arrays delivering a maximum of 200 kW at 1000 W/m² sun irradiance.
- Two DC-DC boost converters (orange block) that are used to increase the voltage output of PV1 and PV2 to 500 V DC.
- Three-level three-phase VSC inverter (blue blocks) that is used to convert the DC voltage delivered by the arrays of (500 V) to an AC voltage of 260 V and also to keep a unity power factor.
- Capacitor Banks of 20 kVar used to filter the harmonics produced by the VSC.
- A three-phase coupling transformer of 200 kVA. And 260/25kV.
- Utility grid.

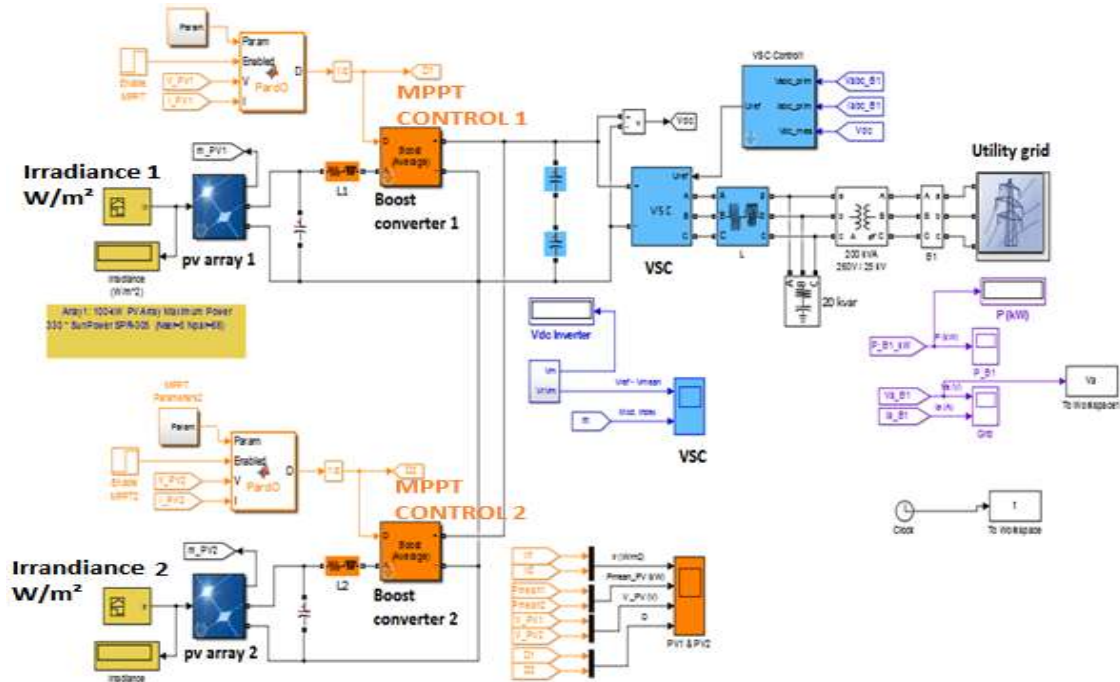


Figure 2. Whole PV grid-connected system

2.1. The photovoltaic generator

The PV system represented in this paper consists of two photovoltaic arrays work in parallel that are PV1 array and PV2 array. The 100-kW PV1 array « SunPower (SPR-305) », consists of 66 strings of 5 series-connected 305.2W modules connected in parallel (66*5*305.2 W= 100.7 kW).

Manufacturer specifications for the module « SPR-305 » are listed in Table 1. The PV array block has one input that allow you varying sun irradiance (input 1 in W/m²). The irradiance profile is defined by a Signal Builder block which is connected to the PV array inputs. The characteristics I-V and P-V of one module SunPowerSPR-305-WHT type are represented in Figure 3.

Table 1. Specifications of « SunPower (SPR-305) » PV-array

Model name	SunPower SPR-305-WHT
No. of cells	96 in series
Open circuit voltage (Voc)	64.2 V
Short circuit current (Isc)	5.96 A
Maximum Power Voltage(Vmp)	54.7 V
Maximum Power Current (Imp)	5.58 A

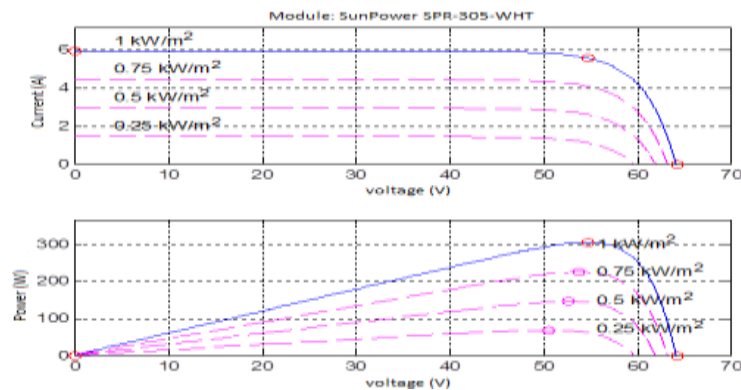


Figure 3. The characteristics I-V and P-V of one module SunPower SPR-305-WHT type

The characteristics of PV1 array are shown below:

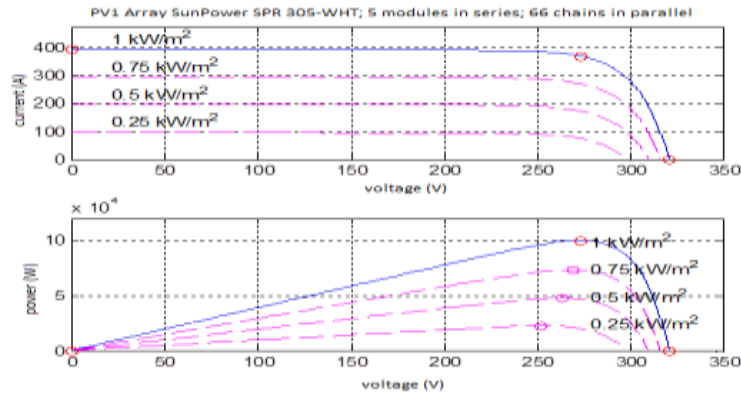


Figure 4. The Characteristics I-V and P-V of the PV1 array

However the PV2 array of 100 kW, uses 488 panels « Kyocera KD205GX-LP », consists of 61 strings of 8 series-connected 205 W modules connected in parallel ($61 \times 8 \times 205 \text{ W} = 100.04 \text{ kW}$). Manufacturer specifications for the module « Kyocera KD205GX-LP » are listed in the Table 2:

Table 2. Specifications of « Kyocera KD205GX-LP » PV-array

Model name	Kyocera KD205GX-LP
No. of cells	54 in series
Open circuit voltage (Voc)	33.2 V
Short circuit current (Isc)	8.359 A
Maximum Power Voltage (Vmp)	26.6 V
Maximum Power Current (Imp)	7.7 A

The characteristics I-V and P-V of one module Kyocera KD205GX-LP type are represented in Figure 5.

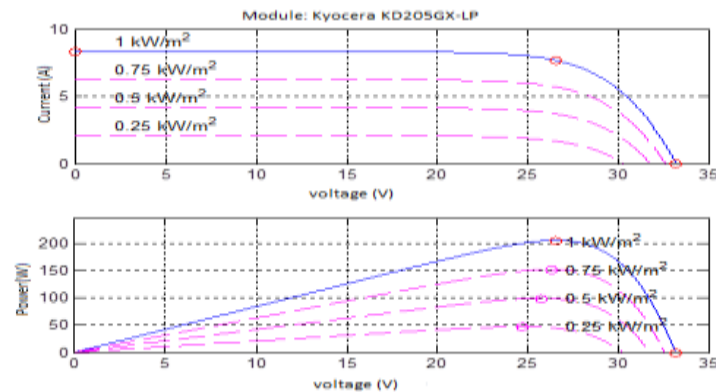


Figure 5. The characteristics I-V and P-V of one module Kyocera KD205GX-LP type

The characteristics of PV2 array are shown below:

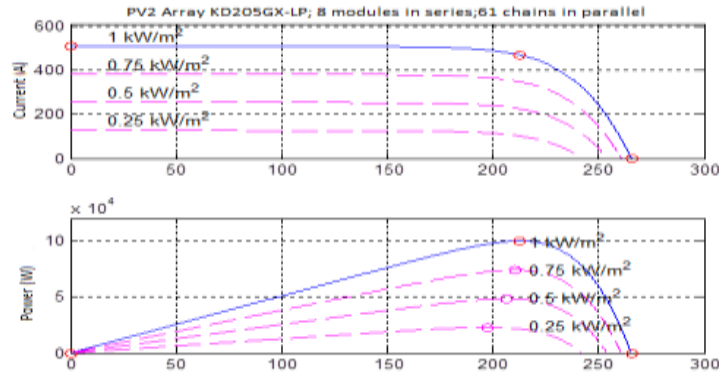


Figure 6. The Characteristics I-V and P-V of the PV2 array

2.2. Boost converter

It is implemented in this proposed system by using a diode and a MOSFET. In the boost converter the average output current is less than the average inductor current, and a much higher rms current would flow through the filter capacitor due to this reason a large value of the inductor and filter capacitor is required than those of buck converter [10]. When the MOSFET switch is ON, the current through the inductor increases and the inductor starts to store energy. When the MOSFET switch is closed, the energy stored in the inductor starts dissipating. The current from the voltage source and the inductor flows through the fly back Diode D to the load. Thus the average voltage across the load is greater than the input voltage and is determined with help of the duty cycle of the gate pulse to the MOSFET switch [12].

Figure 7 shows the schematic diagram for the boost converter used in this research work to step up the PV output voltage to a higher level suitable for the DC/AC inverter operation that connected to the utility grid [11].

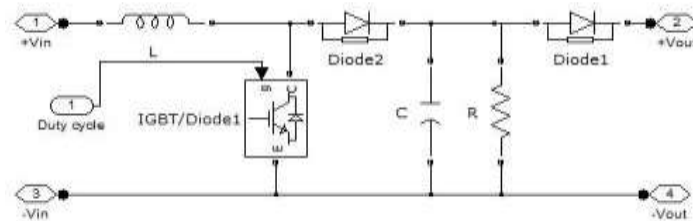


Figure 7. Boost converter

$$V_0 = \frac{V_s}{1-D} \tag{1}$$

$$D = \frac{T_{on}}{T_{sw}} \tag{2}$$

$$T_{sw} = T_{on} + T_{off} \tag{3}$$

Where:

- a. V_s Is source voltage
- b. V_0 Is the output voltage of the converter
- c. D Is the duty cycle

- d. $F_{sw} = \frac{1}{T_{sw}}$ Is switching frequency of the converter
- e. T_{on} Is on time period of the semiconductor switch
- f. T_{off} Is off time period of the semiconductor switch

In our model, we have two boost converters used to increase the DC voltage delivered by the two PV1 and PV2 arrays to 500V. The two boost converters use the MPPT controller that automatically varies the duty cycle to generate the voltage required to extract the maximum power.

2.3. Maximumpower utilization of photovoltaic (PV) power sources

At any given time, to extract the maximum power generated by a solar cell, the solar System has to be equipped with a maximum power point tracker (MPPT). It helps to operate the PV system at the maximum output power point for a given set of conditions, thereby maximizing the array efficiency. The MPPT does this by constantly controlling the PV voltage or current independently regardless of the load connected. The MPPT technology is commonly implemented in the DC-DC converters, but due to technological advancements in recent times, now it can also be implemented in the DC-AC inverters. Although, several MPPT methods are available, the most commonly practiced is Perturb and Observe so it will be used in our present study [13]-[14].

2.3.1. Perturb-and-observe (P&O) method

The perturb-and-observe (P&O) algorithm is the most commonly used in practice for MPP tracking. It is based on the fact that as the voltage is perturbed and the rate of change of power $\frac{dp}{dt}$ is observed. Based on the sign (positive or negative) of the derivative $\frac{dp}{dt}$, the voltage value is increased or decreased to reach MPP, thereby yielding a zero, $\frac{dp}{dt}$ derivative. As the nature of this algorithm is absolutely based on perturbation, one can notice some oscillations even after the MPP is reached [13],[15].

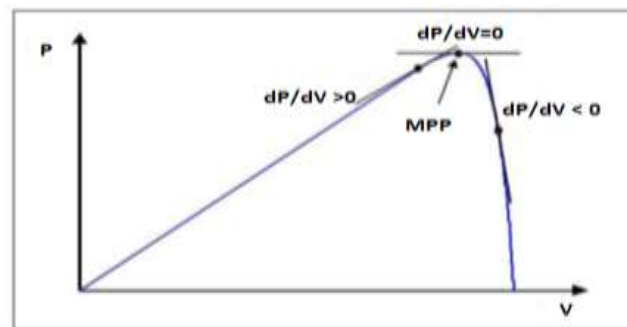


Figure 8. Power vs voltage curve showing MPP

2.4. VSC Inverter

PV modules generate direct current (DC) and voltage. However, to feed the electricity to the grid, alternating current (AC) current and (AC) voltage are needed. Inverters are the equipment used to convert DC to AC. In addition, they can be in charge of keeping the operating point of the PV array at the MPP. This is usually done with computational MPP tracking algorithms. There are different inverter configurations depending on how the PV modules are connected to the inverter.

The VSC converts the 500 V DC link voltages to 260 V AC and keeps power factor at unity. The VSC control system consists of two control loops:

- a. An external control loop which regulates DC link voltage to +/- 250 V.
- b. An internal control loop which regulates grid currents (active and reactive) current components.
- c. The control system uses a sample time of 100 microseconds for voltage and current controllers.

Boost and VSC converters with pulse generators use a fast sample time of 1 microsecond in order to get an appropriate resolution of PWM waveforms [16].

3. SIMULATION RESULTS AND DISCUSSION

Simulation starts with standard test conditions (25 °C, 1000 W/m²). From t=0 sec to t=0.05 sec, the pulses for boost converters and VSC inverter are blocked. The voltage of PV1 array correspond to the open circuit voltage (5 panels in Series * Voc = 5 * 64.2 = 321 V), and for PV2 array (8 panels in Series * Voc = 8 * 33.2 = 265.6 V) (see Figure 9). At this time the VSC inverter of three-level functions as an uncontrolled rectifier (diode) and the DC capacitors are charged over 500 V (Figure 11).

At t = 0.05 s, boost converter and VSC inverter are unlocked. The DC voltage is set at Vd = 500V (see Figure 11). The duty cycles of the two boost converter equal to 0.5 and 0.6 respectively (see Figure 10) irradiance is set at 1000 W/m² as shown in Figure 12. The nominal speed is reached at t = 0.25s, the voltage generated by the array PV1 is $V_{PV1} = (1-D_1) * V_d = (1-0.5) * 500 = 250$ V, while the voltage generated by the array PV2 is $V_{PV2} = (1-D_2) * V_d = (1-0.6) * 500 = 200$ V.

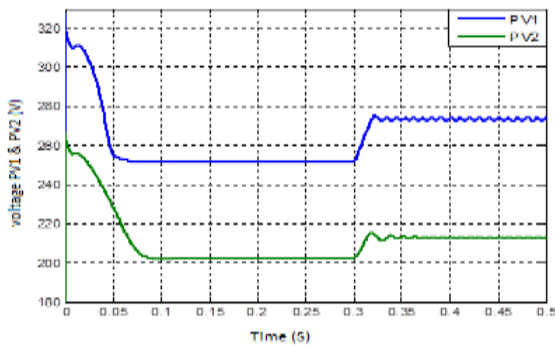


Figure 9. Voltage generated by PV1 and PV2 arrays

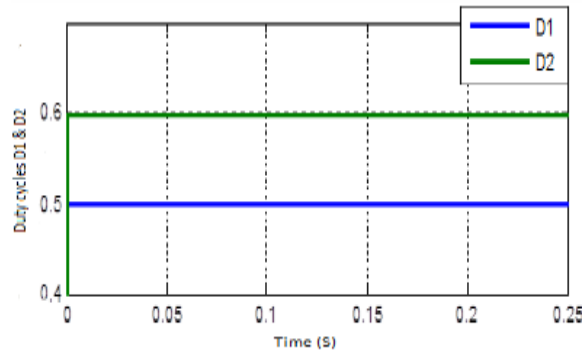


Figure 10. Duty cycles of PV1 and PV2 arrays

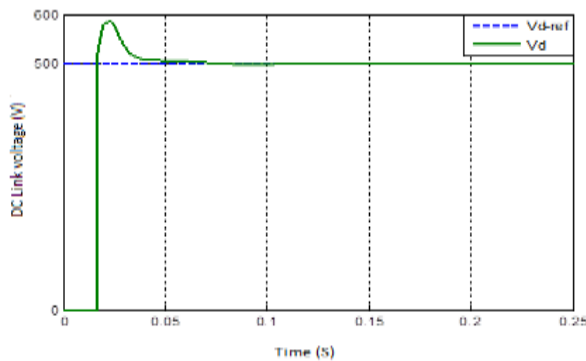


Figure 11. DC link voltage Vd

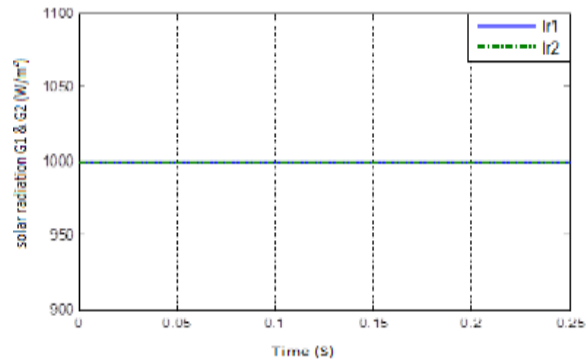


Figure 12. Irradiance of the PV1 and PV2 arrays

The power generated by arrays PV1 and PV2 are on the order of 97 kilowatts and 98 kilowatts respectively, while the maximum powers with irradiance of 1000W/ m² are estimated at 100.7 kilowatts to 100.04 kilowatts (see Figure 13). It is important to note that the voltage and current of phase A at 25 kV busbar are in phase (power factor equals to 1) as shown in Figure 14.

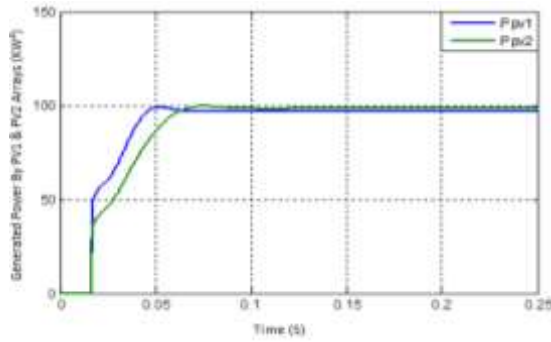


Figure 13. The powers generated by the PV1 and PV2 arrays

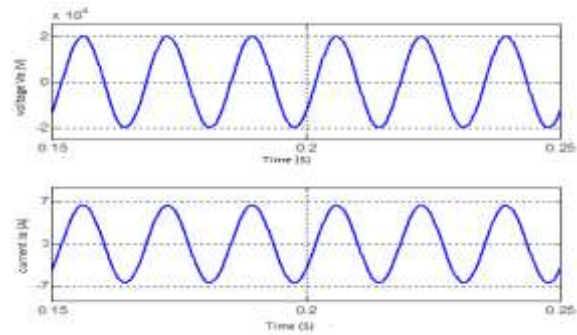


Figure 14. Current and voltage injected into the grid

At $t = 0.4$ s both MPPT controls are enabled. MPPT1 controller starts controlling the voltage generated by PV1 by acting on the duty cycle of the first boost converter in order to extract the maximum power. The maximum power of the first PV array (100.7 kilowatts) is obtained when the duty cycle D_1 equals to 0.453. At $t = 0.6$ s, the voltage of the array PV1=274 V as expected from the specifications of the PV array ($N_{\text{serie}} \cdot V_{\text{mp}} = 5 \cdot 54.7 = 273.5$ V).

From $t = 0.7$ s to $t = 1.2$ s, the irradiance I_{r1} decreases linearly from 1000 W/m^2 to 250 W/m^2 . From time $t=1.1$, the irradiance I_{r2} also decreases linearly from 1000 W/m^2 to 250 W/m^2 (Figure 16). Both MPPT controllers continue tracking the maximum power delivered by each PV array. At $t = 1.2$ s when the irradiance I_{r1} reaches the value of 250 W/m^2 , the duty cycle D_1 is around 0.485. The corresponding voltage and power are 255 V and 22.6 kilowatts respectively. For the second PV array, the irradiance I_{r2} reaches the value of 250 W/m^2 at $t = 1.65$ s, where the duty cycle $D_2=0.6$.

Note that tracking the maximum power point by the MMPT controller is ensured even when the irradiance changes rapidly. From $t = 1.5$ s to $t = 3$ s various changes of the irradiance I_{r1} and I_{r2} are applied to illustrate the good performance of the MPPT controller.

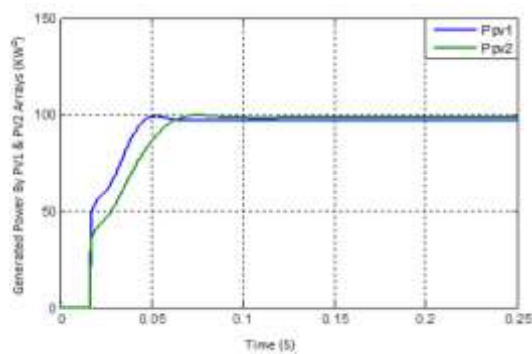


Figure 15. Power generated by the PV1 and PV2 arrays

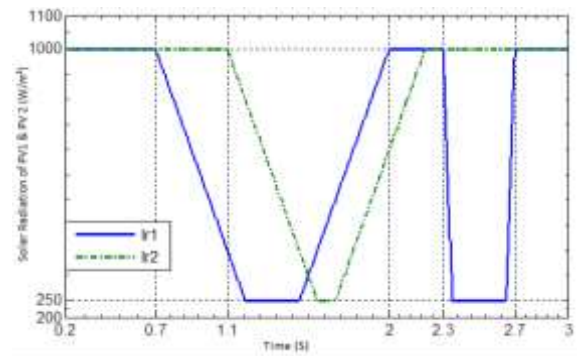


Figure 16. Irradiance of the two arrays

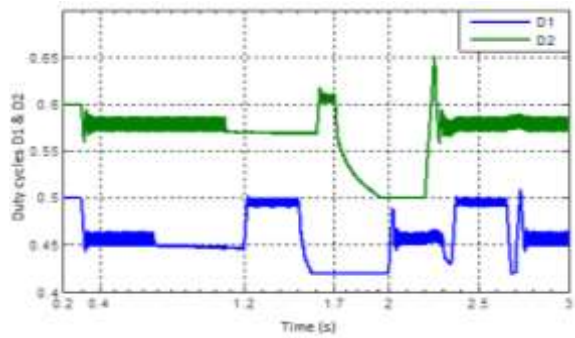


Figure 17. Duty cycles of the PV1 and PV2 arrays

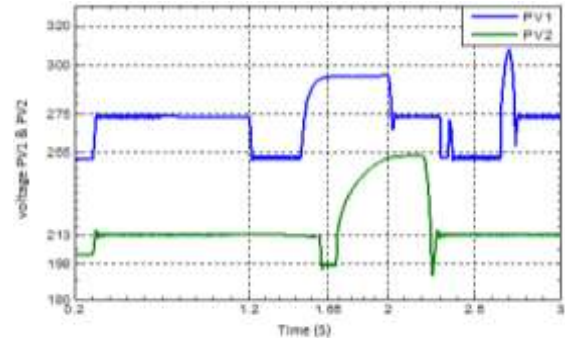


Figure 18. Voltage generated by the PV1 and PV2 arrays

Figure 19 shows the power injected into the grid. From $t = 0$ s to $t = 0.05$ s the power injected into the grid is growing because the pulses of boost converter and VSC inverter are blocked. At $t = 0.05$ s the pulses are enabled, the power injected into the grid is 195 kW.

From $t = 0.2$ s to $t = 0.75$ s the irradiance is 1000 W / m^2 , while the injected power reaches its maximum value. From $t = 0.75$ s to $t = 2.75$ s several variations in the irradiance lead to change the power injected into the grid to stabilize at 2.75 s and takes the value of 200 kilowatts.

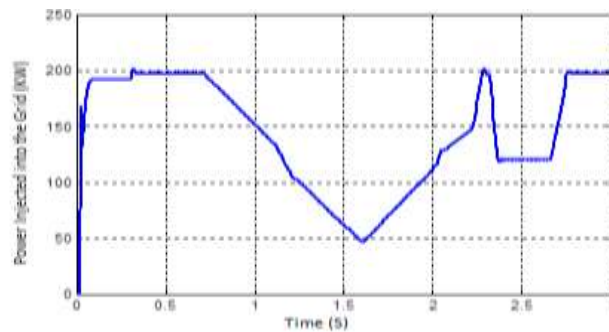


Figure 19. Power injected into the grid

4. CONCLUSION

This paper presents the modeling and simulation of grid connected PV system with Perturb and Observe MPPT Algorithm to inject the power extracted from a photovoltaic array and obtain unitary power factor in varying weather conditions. According to the results obtained from the simulation, we can say that it is essential to operate the system at the MPP (Maximum Power Point) of a PV array, in other words we should always extract the maximum power from the PV module by modulating the duty cycle of the boost converter in order to enhance the power injected into the grid, otherwise the PV array is not fully exploited which consequently is reflected by a higher losses in the energy transferred from the PV array to the utility grid. Also the Pulse width modulation (PWM) technique has been developed beside inverters. So that we can obtain a sinusoidal waveform at the output of the inverter and the total harmonic distortion (THD) of the output voltage can be reduced. The results confirm the adequate performance of whole designed control.

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