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RESEARCH ARTICLE

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MODELING OF PV ARRAY AND INTEGRATION WITH GRID

SOURAV DIWANIA[1], LOVELEEN KAUR[2]

[1]PG Student, Electrical Engineering Department

[2]Assistant Prof., Electrical Engineering Department

PEC University of Technology, Chandigarh, India

ABSTRACT

In this Paper a simplified model of photovoltaic array using MPPT technique is presented which is connected to voltage source inverter and then to utility grid to perform various power system studies. First the relation between solar radiation and PV output is presented. The changes in PV output voltage and output power is detected as irradiation level changes. Then the control scheme of VSC is presented which is used to connect the inverter to the utility grid. The use of power electronics technology like DC boost converter and voltage source inverter plays an important role in managing an effective grid integration of the PV system but power electronics switches injects harmonics into the supply system and pollute the main line with harmonics. so finally harmonic compensation using LC filters is also presented.

Key Words: photovoltaic, Boost converter, maximum power point tracking(MPPT), voltage source inverter, inverter control, harmonic compensation.

I. INTRODUCTION

In today's world use of renewable energy is increasing day by day especially the solar and wind energy as these sources are available easily and also pollution free but the technology required to detect these sources of energy is much more complex than other renewable energy sources. Most of the countries tries to increase the use of renewable energy for example- in Malaysia under National Renewable Energy and Action Plan, 2009 up to 73 % is targeted for RE in generation mix where most of it come from solar PV. Renewable accounted for nearly 65% of newly installed power capacity in Europe and nearly 20% of annual power production. Advancement in technology used in solar energy have brought around tremendous growth in the solar PV market as well, which is projected to surpass other renewable energy sources in the coming years. Now a day's most of hospitals, colleges and small scale industries employed solar PV at the rooftops in order to meet the increasing energy demands. Figure1 shows that photovoltaic installations goes on increasing worldwide due to the various advantages of solar energy discussed in this paper.

But problems occurs during integration of PV array to the supply system and the storage of solar energy. There are certain other drawbacks like changes in irradiation level and temperature level which will affects the performance of PV array. The interconnection will have a impact on system operation and stability especially on voltage control scheme, protection coordination and network stability. For assessing the impacts, it is important to carry a thorough power system studies and analysis with high PV penetration.

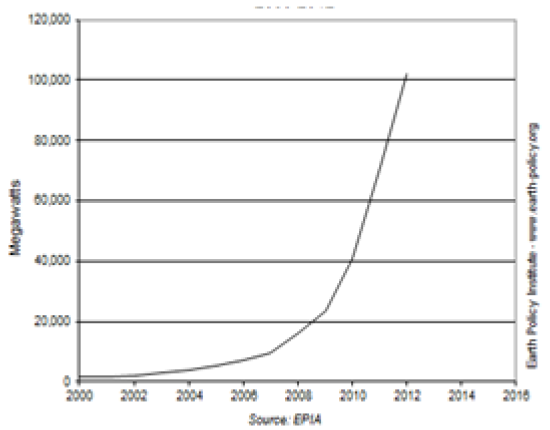

Fig.1. World cumlative solar photovoltaic installations

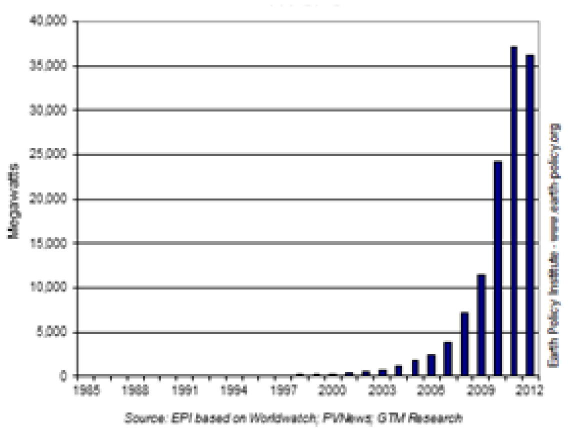

Fig.2. World annual solar photovoltaic production

II. PHOTOVOLTAIC STUDY AND ITS MODELING

A photovoltaic is the method of converting solar energy into direct current electricity using semiconducting material that exhibits photovoltaic effect. the photovoltaic effect refers to the photon of light exciting electrons into a higher state of energy allowing them to act as a charge carrier for an electric current. Classification of PV cells is on the basis of the type of materials used to manufacturing them. Photovoltaic cells are made of silicon and other semiconductor materials. The PV cell equivalent model is required to simulate its behavior. One of the models proposed is the double exponential model depicted in figure 3. Using the p-n junction physics a cell can be modeled as a DC current source in parallel with two diodes that represent currents escaping due to diffusion and charge recombination mechanisms. Two resistances, R_S and R_P, are included to model the contact resistances and the internal PV cell resistance respectively.

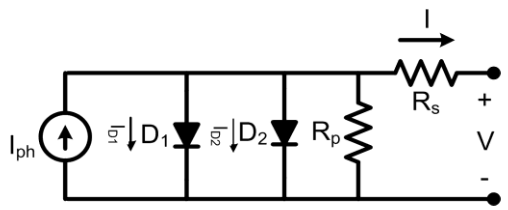

Fig.3. Double exponential PV cell model

The relationship between the PV cell output current and terminal voltage is governed by equation given as:

$$I = I_{ph} - I_{D1} - I_{D2} - \frac{V + IR_s}{R_p}$$

$$I_{D1} = I_{01}\left[e^{\left(\frac{q(V+IR_s)}{akT}\right)} - 1\right]$$

$$I_{D2} = I_{02}\left[e^{\left(\frac{q(V+IR_s)}{akT}\right)} - 1\right]$$

Where I_{ph} is the PV cell internal generated photocurrent, I_{D1} and I_{D2} are the currents passing through diodes D_1 and D_2, a is the diode ideality factor, k is the Boltzmann constant ($1.3806503 \times 10^{-23}$ J/K) T is the cell temperature in degrees Kelvin, q is the electron charge ($1.60217646 \times 10^{-1}$C), I_{01} and I_{02} are the reverse saturation currents of each diode respectively.

Assuming that the current passing in diode D_2 due to charge recombination is small enough to be neglected, a simplified PV cell model can be reached as shown in fig.4.

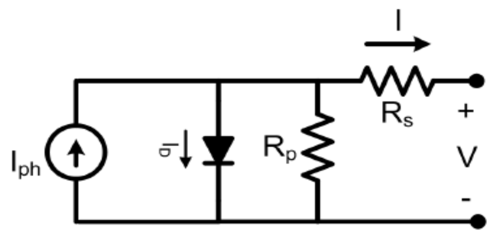

Fig.4. Simplified PV cell model

This model provides a good compromise between accuracy and model complexity. In this case, current I_{D2} can be omitted from above equations and the relation simplifies to:

$$I = I_{ph} - I_0\left[e\left(\frac{q(V+IR_s)}{akT}\right) - 1\right] - \frac{V+IR_s}{R_p}$$

It is clear that the relationship between the PV cell terminal voltage and output current is nonlinear because of the presence of the exponential term in the above equations. The presence of the p-n semiconductor junction is the reason behind this nonlinearity. Now the modeling of PV array is done by connecting solar cells in series in order to increase the voltage level and in parallel in order to increase the current level. Figure 5 shown below explains how cells are arranged to make PV module. and then modules are arranged to make PV panel. In this paper a 1MW PV panel is connected to utility grid using MPPT technique. The 1-MW PV array of the detailed model uses 330 Sun Power modules (SPR-305). The array consists of 66*10 strings of 5 series connected modules connected in parallel (10*66*5*305.2 W= 1000.7 kW = ~ 1MW). A PV of 1MW is made from the 330 Sun Power Modules(SPR-305) with 5 modules in series and 5 modules in parallel.

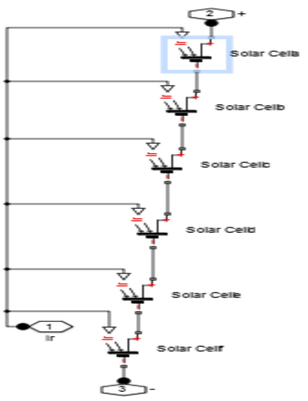

Fig.5. Solar cells connected to make PV module

In that way 96 solar cells are taken to make one PV module.

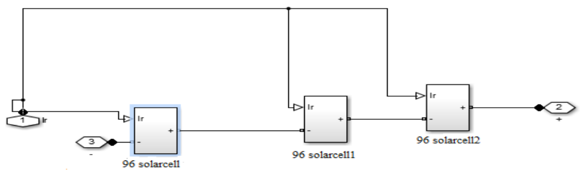

Fig.6. PV modules are arranged to make PV array

III. MPPT TECHNIQUE

Maximum power point technique is used to track the maximum power. MPPT techniques control DC converters in order to extract maximum output power from a PV array under a given weather condition. The DC converter is continuously controlled to operate the array at its maximum power point despite possible changes in the load impedance. Different schemes of MPPT algorithms such as Perturb and Observe, Incremental Conductance, Fractional Open Circuit Voltage, Fractional Short Circuit Current, Fuzzy Logic Control, Neural Network are to be studied and implemented. The MPPT algorithm thus proposed will identify the suitable duty ratio in which the DC/DC converter should be operated to obtain maximum power output. The efficiency of solar cells depends on many factors such as temperature, insulation, and spectral characteristics of sunlight; dust, shading, which result in poor performance. In addressing the poor efficiency of photovoltaic systems, various methods were proposed among which a concept is called “maximum point power tracking”(MPPT) is implored. The photovoltaic has an optimum operating point to extract the maximum power called the maximum power point (MPP), which varies depending on cell temperature, insulation level, the nature of load, the technology of the photovoltaic cells. The variation in solar irradiation and temperature causes the tracker to deviate from the maximum power point, thus the tracker needs to response within a short time to these variations to avoid energy loss. A variety of maximum power point tracking (MPPT) method is developed. In this paper incremental conductance method is used. In this algorithm exploits the fact that the slope of the power-voltage curve of a PV array is equal to zero at the maximum power point. The slope is positive in the area to the left of the maximum power point and negative in the area to the right. , the algorithm was modified in order to include an integral regulator. The integral regulator minimizes the error where the regulator output will be equal to duty cycle correction. Mathematically, this can be summarized as:

$dP/dV=0$ where $P= V*I$

d(V*I)/dV = I + V*dI/dV = 0

dI/dV = -I/V

The integral regulator minimizes the error (dI/dV + I/V)

The incremental conductance algorithm is illustrated in figure 7 given below where V_{ref} is the reference control signal for the DC converter. Similar to the perturb and observe algorithm, the performance of the incremental conductance MPPT is affected by the increment size of V_{ref} used here as a controlled variable. MPPT is a technique that inverters of grid connected PV solar systems employ to maximize power output. In the incremental conductance method the controller measures incremental changes in PV array current and voltage to predict the effect of a voltage change. This method require more computation in the controller but can track changing conditions more rapidly than the perturb and observe method like the P&O algorithm, it can produce oscillations in power output.

The flowchart of incremental conductance method is shown in figure.7.

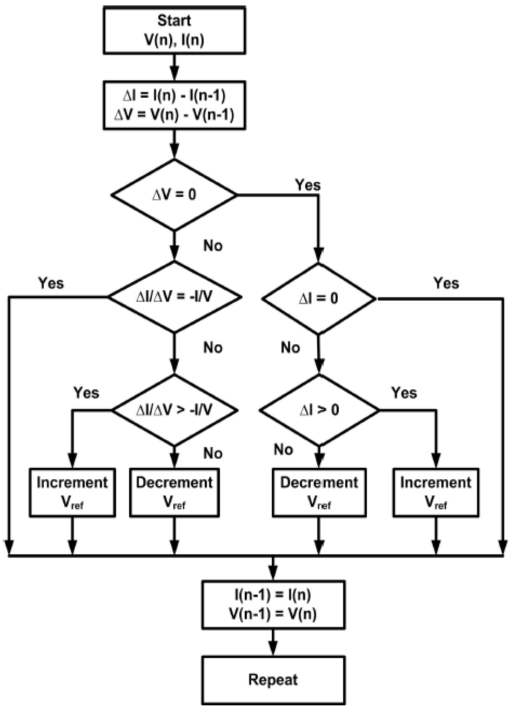

Fig.7. Flowchart of Incremental conductance method

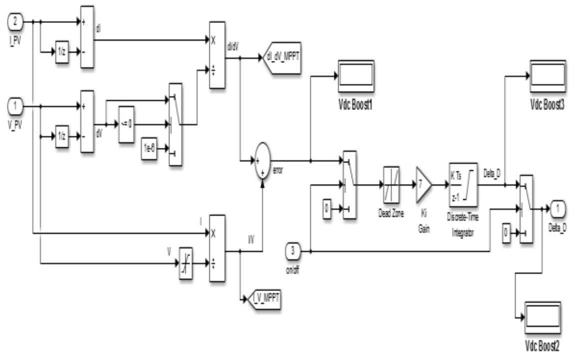

Fig.8. Simulink of Incremental conductance method

The simulink method of incremental conductance method is shown in figure 8.

IV. DC-DC CONVERTER

To implement the MPPT technique a DC-DC converter is required. There are two types of DC-DC converter mainly buck converter and boost converter. The buck converter is used to step down the DC voltage while the boost converter is used to step-up the DC voltage. The buck-boost converter is used to step-up and step down the DC voltage based on duty cycle. These converters are popular because of their high efficiency and compact size. The boost converter is chosen where the duty cycle of the boost dc-dc converter is controlled by PWM signal from controller implementing Incremental Conductance and integral regulator algorithm. Therefore, whatever the weather (irradiation and temperature) and the load conditions, the control system of the converter will ensure the operating point is optimized for maximum power transfer. The boost converter is a high efficiency step-up DC/DC switching converter. The converter uses a transistor switch, typically a IGBT, to pulse width modulate the voltage into an inductor. Rectangular pulses of voltage into an inductor result in a triangular current waveform. We'll derive the various equations for the current and voltage for a boost converter and show the tradeoffs between ripple current and inductance. the simulink model of boost converter is shown in figure9. MPPT technique should implemented on DC-DC converter circuit in order to operate the PV array at maximum power point. LC filter should be used at the output terminal of Boost converter in order to reduce the ripples in output current. The capacitor at output is required to maintain the constant voltage across the output terminal of DC-DC converter which is also the input voltage to the voltage source inverter.

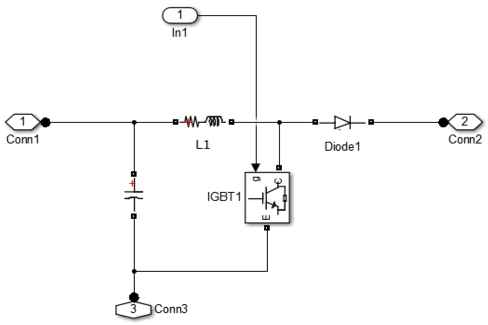

Fig.9. Simulink model of boost converter

V. VOLTAGE SOURCE INVERTER

The inverter is required to convert the DC voltage obtained from DC-DC converter to AC. In voltage source inverter(VSI) the output voltage does not depends on load parameters while the load current depends on load parameters. To maximize the system efficiency the inverter must be optimized in design and control.

For a photovoltaic power system a voltage source inverter is developed which requires only a minimum number of components. Most commercial inverters for photovoltaic applications include a transformer and several sections of power conversion. To reduce the degree of complexity it is proposed to omit the transformer and to use only one section of power conversion. Thereby system losses, size and costs decreases. By the mode of operation of a voltage source inverter, the solar array voltage is not free eligible. In VSI and choppers we use IGBT's and GTO in place of thyristor because they does not require separate commutation circuits.

But for very high power rating the only option is thyristor which requires forced commutation. The selection of inverter circuit is very important aspect of integration into the utility grid. Because direct integration of output inverter into grid is not possible. In order to reduce the harmonic content on AC side of inverter we must use several technique like PWM technique. The control scheme of VSI is shown in figure below. The final step is to integrate the PV panel, DC-DC converter, MPPT, voltage source inverter and utility grid. another widely used method of VSC control is vector control. In this thesis Vector Different control strategies of VSC are known. One way to control VSC-based converters is power-angle control, which is also called voltage-angle control. It is perhaps the most straight forward controller for grid-connected VSCs control is used.

Vector current control is the most popular control method used for VSC-based HVDCs. The basic principle of the vector current controlled VSC is to control instantaneous active and reactive grid currents independent of each other.

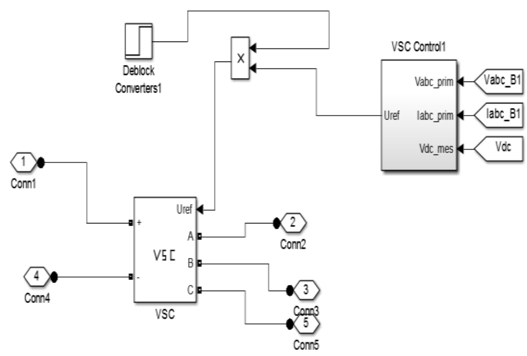

Fig.10. VSI control scheme

VI. RESULTS AND DISCUSSION

In this paper variations in the irradiation level are taken and then detects the changes in output current, voltage and power level. The figure below shows the variation in irradiation level. In this paper constant irradiations of 1000W/m^2, step irradiation level in which step change occurs and ramp irradiation level in which a ramp change occurs in order to see the variations in the output.

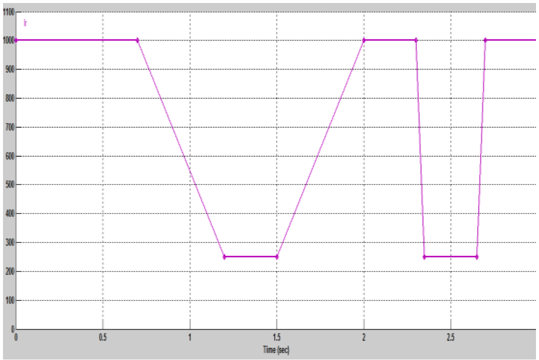

Fig.11. Changes in irradiance level

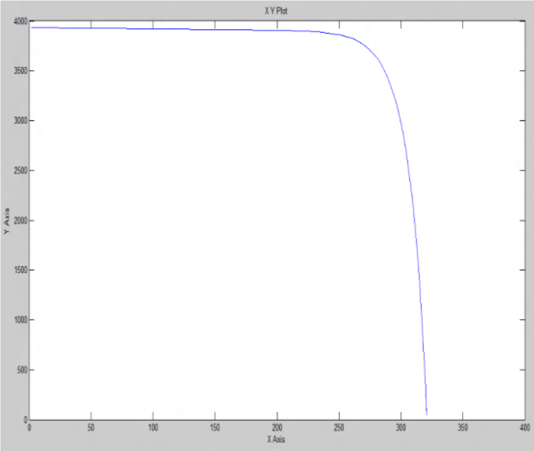

Fig.12. I-V Characteristics of PV Array

The I-V characteristics of PV panel at constant irradiance level and constant temperature is shown in figure12. In figure 12, the characteristics of current-voltage of the PV module 330 Sun Power Modules (SPR-305) is shown. We know that the equation of photovoltaic current contains the exponential term due to which the characteristics becomes non-linear. We get the non- linear characteristics from the simulation also. The characteristics are obtained at a standard temperature of 25^0C and a irradiance of $1000W/m^2$.

The figure 13 explains the power-voltage characteristics of PV panel at standard conditions.

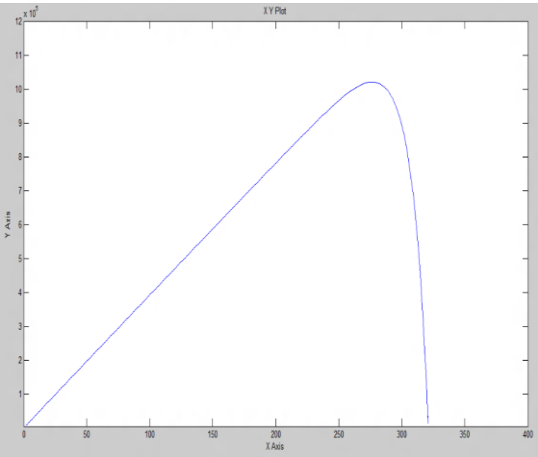

Fig.13. P-V Characteristics of PV array

As the temperature and irradiance level changes the characteristics of a photovoltaic modules also changes. the irradiance varies from 250, 500, 750 and 1000 and the temperature is constant. The result in figure 14 is the current-voltage curve which shows that the maximum power of the PV decrease when the irradiance decreases. The figure 15 is the power-voltage curve, which shows that the current decreases significantly when the irradiance decreases.

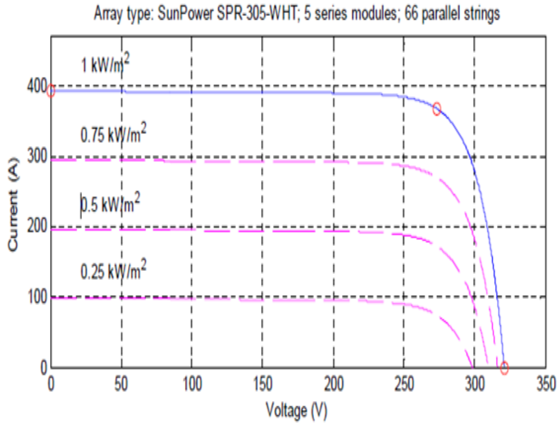

Fig.14. I-V characteristics at various irradiance

The P-V Characteristics at various irradiance level is shown in figure15 shown below. It is observed that as the irradiance level decreases the output power of PV array also decreases.

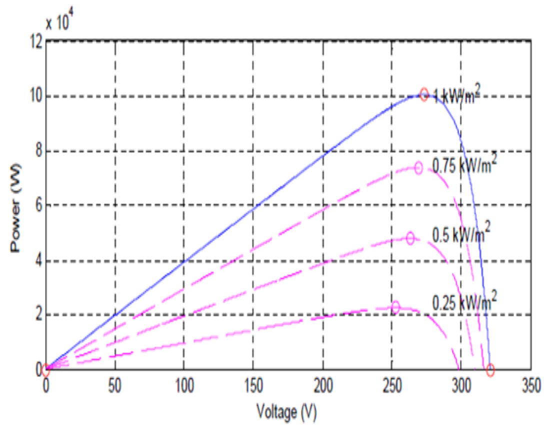

Fig.15. P-V characteristics at various irradiance

In figure.11. the variations in irradiance level are taken a step variation from 0.5sec to 0.7sec and a ramp down from 0.7 to 1.2 sec is taken. From t=0 sec to t= 0.05 sec, pulses to Boost and VSC converters are blocked. PV voltage corresponds to open-circuit voltage (Nser*Voc=5*64.2=321 V). The three-level bridge operates as a diode rectifier and DC link capacitors are charged above 500 V.

At t=0.05 sec, Boost and VSC converters are de-blocked. DC link voltage is regulated at Vdc=500V. Duty cycle of boost converter is fixed 0.5 and sun irradiance is set to 1000 W/m2. Steady state is reached at t=0.25 sec. Resulting PV voltage is therefore V_PV = (1-D)*Vdc= (1-0.5)*500=250 V (see V trace on Scope Boost).

The PV array output power is 960kW whereas maximum power with 1000 W/m2 irradiance is 1000.7 kW. Observe on Scope Grid that phase a voltage and current at 25 kV bus are in phase (unity power factor).

At t=0.4 sec MPPT is enabled. The MPPT regulator starts regulating PV voltage by varying duty cycle in order to extract maximum power. Maximum power (100.7 kW) is obtained when duty cycle is D=0.453. At t=0.6 sec, PV mean voltage =274 V as expected from PV module specifications (Nser*Vmp=5*54.7= 273.5 V).

From t=0.7 sec to t=1.2 sec, sun irradiance is ramped down from 1000 W/m2 to 250 W/m2. MPPT continues tracking maximum power. At t=1.2 sec when irradiance has decreased to 250 W/m2, duty cycle is D=0.485. Corresponding PV voltage and power are Vmean= 255 V and Pmean=22.6 kW. Note that the MMPT continues tracking maximum power during this fast irradiance change.

From t=1.5 sec to 3 sec various irradiance changes are applied in order to illustrate the good performance of the MPPT controller.

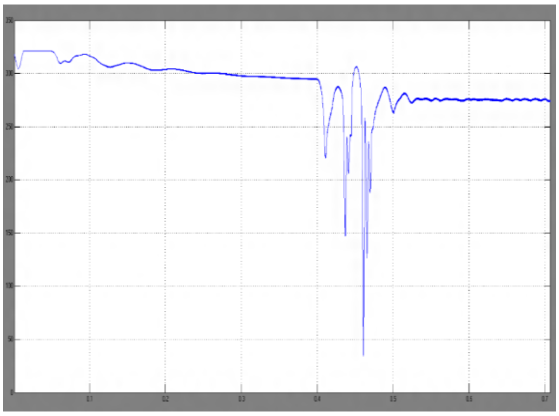

Fig.16. PV panel voltage for 0.7 sec

Maximum power point controller is used to control the boost converter. Incremental conductance algorithm is implemented to track the maximum power of the PV module .The power output of PV panel and along with the variations in irradiation level is shown in figure 6.9 below. The simulation is run at t=0s to 3.0 s. At the beginning, the irradiation is set at G=1000 [W/m2] and at t=0.7 s a ramp change of irradiation to 250 [W/m2] is performed. Figure 6.9 represented the output power of the PV array. The output power of the PV varies from 1000KW to 450KW. The PV array operates at maximum power when there is a variation of the irradiance.

After 1.5sec if there is further variation in irradiance level the PV power and PV voltage also changes.

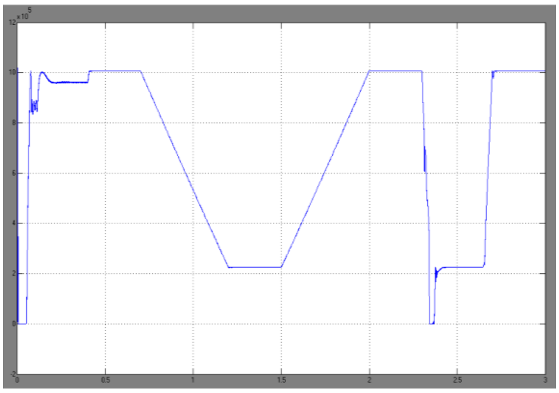

Fig.17. PV power output

VII. CONCLUSION

In this paper, the study of the photovoltaic system with maximum power point controller has been developed. From the theory of the photovoltaic, a mathematic model of the PV has been presented. Then, the photovoltaic system with DC-DC boost converter, maximum power point controller and VSC have been designed. Finally, the system has been simulated with Simulink MATLAB.

The accurate prediction of the power generation is very important for the operation planning of the entire electric power systems when large size PV systems are being incorporated. Tracking the maximum power point of a PV array is an essential part of any PV system. First, the simulations of the PV panels showed that the simulated models were accurate to determine the characteristics voltage current because the current voltage characteristics are the same as the characteristics given from the data sheet. In addition, when the irradiance or temperature varies, the PV models output voltage current change. Then, the simulation showed that Incremental Conductance algorithm can track the maximum power point of the PV, it always runs at maximum power no matter what the operation condition is. The results showed that the Incremental Conductance delivered an efficiency close to 100% in steady state.

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