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Design and Implementation of Photovoltaic Distribution Static Compensator

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Abstract:- Solar photovoltaic (PV) systems are increasingly being installed in the distribution systems because of their decreasing cost and various advantages. This paper deals with the design and implementation of Photovoltaic Distribution Static Compensator(PV-DSTATCOM). The work has been done in MATLAB/SIMULINK. Perturb and Observe algorithm is used to simulate the proposed work. Maximum Power Point Tracking (MPPT) using Perturb and Observe algorithm is used to obtain duty-ratio for controlling the switching devices of DSTATCOM. The results have been given showing the waveforms of three-phase voltages, currents, capacitor voltage and instantaneous power, both for the case of constant irradiance and for the case of varying irradiance.

Keywords:- *Solar Photovoltaic Cell, PV-DSTATCOM, Perturb and Observe Algorithm, MPPT.*

I. INTRODUCTION

Solar-based devices have gained wide popularity due to their innumerable advantages. Solar energy is freely available, omnipresent and is renewable energy source. Solar PV-DSTATCOM can be used to supply active power to the grid. It can also be used for voltage regulation, power factor correction, and load balancing. A comprehensive review of solar PV-DSTATCOM has been given by Nimita et al. [1].

Perturb and Observe control algorithm based PV-DSTATCOM with multi-directional power flow has been demonstrated by Bhim Singh et al. [2] for power supply to the grid and connected loads. Load balancing and power quality improvement confirming to IEEE-519 and IEEE-1547 have also been shown.

An adaptive control algorithm for a multi-objective grid tied solar PV-DSTATCOM has been demonstrated in [3],where the authors have explained the methodology to improve the grid currents power quality by estimating fundamental component of load current. This algorithm has been shown to improve tracking accuracy, reduce steady-state error and oscillation from the desired output.

Meenakshi et al. have demonstrated performance investigation of two-level reduced-switch DSTATCOM in grid-tied solar PV array with stepped perturb and observe maximum power point tracking algorithm and modified synchronous reference frame strategy [4]. This paper demonstrated the maintenance of unity power factor along with feeding active power to the grid and feeding active and reactive power requirements of an unbalanced load. Modified synchronous reference frame theory was proposed in this paper, where it has been shown that the voltage across capacitors have been balanced along with sustaining the DC link voltage.

Application of PV-DSTATCOM for power quality improvement employing active current control has been explained by Nirav et al. [5]. Along with active current control, this paper has also demonstrated the use of feed-forward control loop. Zero current harmonic suppression, load reactive current compensation, zero sequence content mitigation and power factor correction were obtained using PV-DSTATCOM. This configuration is computationally efficient and unconditionally stable.

Synchronous reference frame based PV-DSTATCOM with battery energy storage has been demonstrated in for 11kV/440V system for real power injection and improvement and power quality [6]. In this paper, incremental conductance method has been used to track the highest power of PV module. DC bus voltage was preserved using Bidirectional DC-DC converter.

The proposed work deals with design and implementation of PV-DSTATCOM connected to the grid using Perturb and Observe algorithm. Perturb and Observe algorithm is explained along with its implementation. The design of the system is explained along with its implementation. MATLAB/SIMULINK is used to implement the proposed work.

II. MPPT ALGORITHM

MPPT with Perturb and Observe algorithm gives outstanding performance because of its inherent adaptive capabilities [6]. Perturb and Observe algorithm is also easy to implement [7]. MPPT algorithm flowchart is shown in Fig.1. Initially, v(n) and i(n) are measured. Then, the power p(n) is computed. If p(n)-p(n-1) is equal to zero, then the algorithm does not do anything. Whereas, if p(n)-p(n-1) is not equal to zero, two conditions arise. The first condition is p(n)-p(n-1) greater than zero. If yes, then it is further checked if v(n)-v(n-1) is greater than zero. If yes, the reference voltage V_{ref} is increased. Otherwise, V_{ref} will be decreased. The second condition is when p(n)-p(n-1) is lesser than zero. If yes, then further checking is done if v(n)-v(n-1) is greater than zero. If yes, the reference voltage V_{ref} is decreased. Otherwise, V_{ref} will be increased.

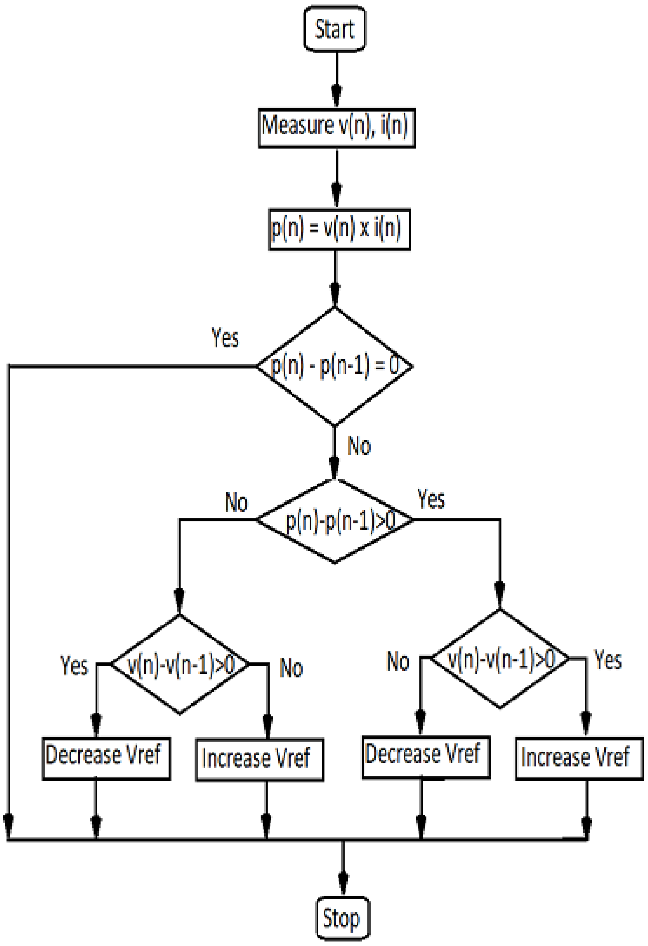

Fig 1 MPPT Algorithm Flowchart

III. SOLAR PV-DSTATCOM

In a PV-DSTATCOM, solar PV panel is connected in parallel to the DC capacitor of a DSTATCOM as shown in Fig.2. V_pv and I_pv are the voltage across the solar panel and current generated by solar panel, respectively. V_pv and I_pv are measured and fed to MPPT block. The MPPT block calculates the reference voltage V_{ref}, which is given to a comparator. A high frequency triangular carrier signal is also given to the comparator block. The comparator block compares the reference voltage V_{ref} and the high frequency triangular carrier signal in order to determine the duty-ratio of switching device SW. Pulses generated by the comparator block are fed to the gate terminal of the IGBT which is acting as the switching device SW. Several other methods such as sliding mode controller have also been reported in the literature [8] for the generation of pulses.

IV. DESIGN OF THE SYSTEM

Input voltage of the system, i.e. voltage generated by solar photovoltaic cell, is in the range of 250-350V depending on the solar irradiance. PV module can be used to regulate the desired voltage at the DC link[9]. Output voltage is around 600V. Rated power of the system is 100kW. Switching frequency of the high carrier triangular wave is 5 kHz. Acceptable values of current ripple and voltage ripple are chosen to be 5 per cent and 1 per cent, respectively.

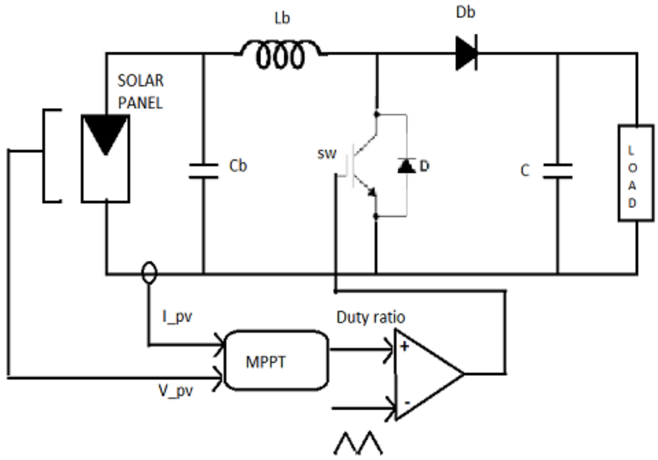

Fig 2 Solar Inverter Acting as Solar PV-DSTATCOM

The solar PV array is chosen to be consisting of ten modules connected in series to form a string. Forty seven such strings are connected in parallel. Each module has sixty cells. This array is connected in parallel to the DC capacitor of DSTATCOM. Temperature and solar irradiance are given as inputs to the PV array.

Design aspects pertaining to some of the parameters used in PV-DSTATCOM are given below [10]:

- *Input current*

$$Input\ current\ I_{ip} = \frac{P}{V} = \frac{100x\,10^3}{250} = 400A$$

- *Current ripple*

$$\text{Current ripple}\ , \Delta I = 5\%\ \text{of}\ 400 = 20A$$

- *Voltage ripple*

$$\text{Voltage ripple}\ , \Delta V = 1\%\ \text{of}\ 600 = 6V$$

- *Output current*

$$\text{Output current}\ , I_{op} = \frac{100\ x\ 10^3}{600} = 166A$$

- *Booster converter inductance*

$$\text{Boost converter inductance}, L = \frac{V_{ip}(V_{op} - V_{ip})}{f_{sw}\ x\ \Delta I\ x\ V_{op}}$$

Substituting the values of different parameters, the inductance value comes to L = 1.45 mH.

- *Boost converter capacitance*

$$\text{Boost converter capacitance}, C = \frac{I_{op}(V_{op} - V_{ip})}{f_{sw}\ x\ \Delta V\ x\ V_{op}}$$

Substituting the values different parameters, the capacitance values comes to C = 3227 µF.

V. MODELLING OF THE SYSTEM

The MATLAB/SIMULINK model of the PV-DSTATCOM connected to the grid is given in Fig.3.

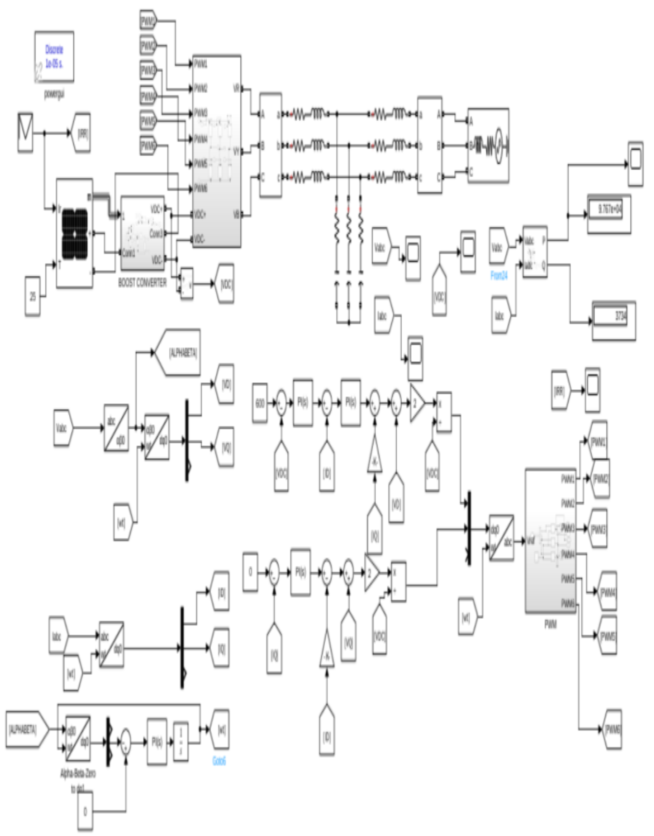

Fig 3 SIMULINK Model of the Complete System

For the sake of clarity, the SIMULINK model of PV-DSTATCOM connected to the grid is given in Fig.4. This figure does not include the control block which generates the pulses for switching device of PV-DSTATCOM. The control block that generates pulses for the IGBT of the PV-DSTATCOM is shown in Fig.5.

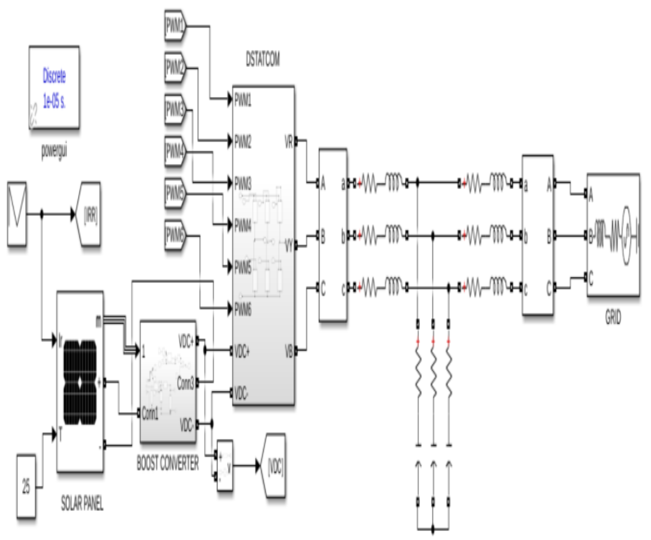

Fig 4 PV-DSTATCOM Connected to the Grid

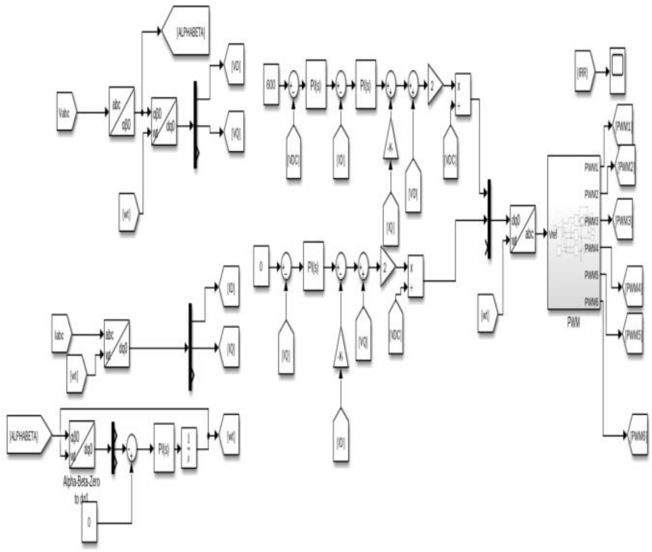

Fig 5 PWM Generation Block

VI. RESULTS AND DISCUSSION

Initially, the solar PV array is considered as a stand-alone unit. Its current versus voltage and power versus voltage are as shown in Fig.6 for irradiance values of 1000W/m^2, 500W/m^2 and 100W/m^2 at a constant temperature of 25^{o}C.

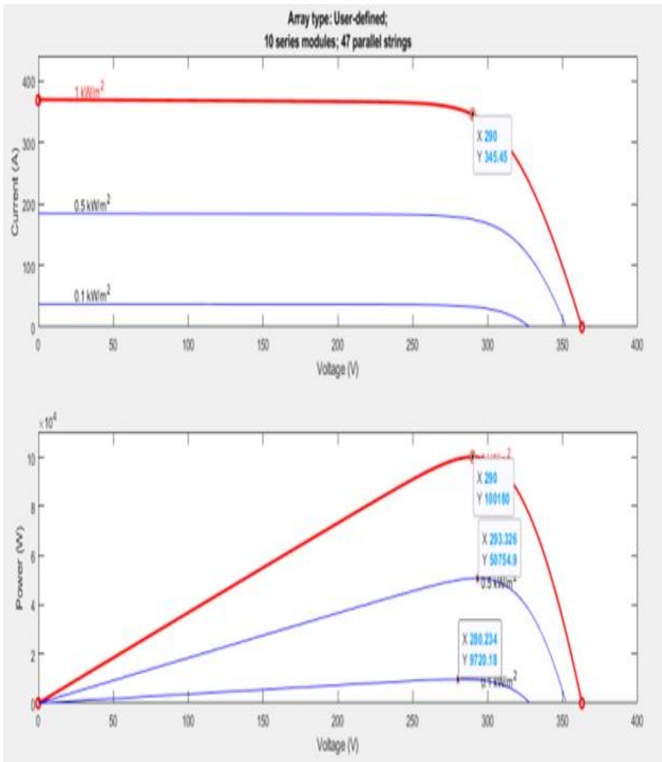

Fig 6 Power and Current Versus Voltage for Varying Irradiance

The MPPT points for the corresponding values of irradiance are also depicted in Fig.6. Further results are displayed for two cases of irradiance. The first one corresponds to constant irradiance and the second one is for varying irradiance.

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➢ *Case (i): Constant irradiance*

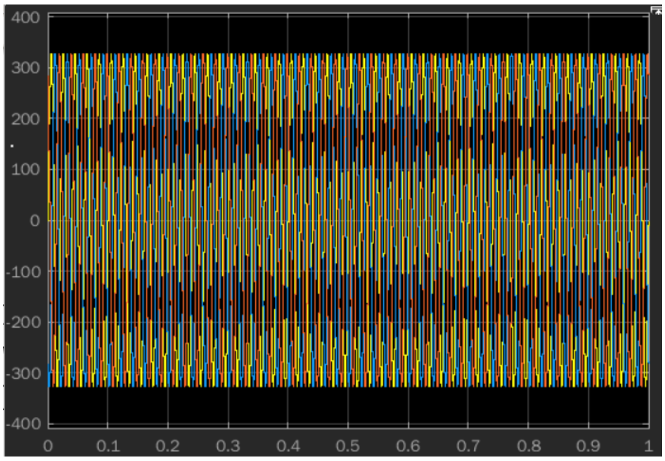

Fig 7 Three-Phase Voltages for Constant Irradiance

In this case, the irradiance is assumed to remain constant at 1000W/m^2 at a constant temperature of 25°C. The waveforms pertaining to output voltage are shown in Fig.7. Three-phase current waveforms for the case of constant irradiance are shown in Fig.8.

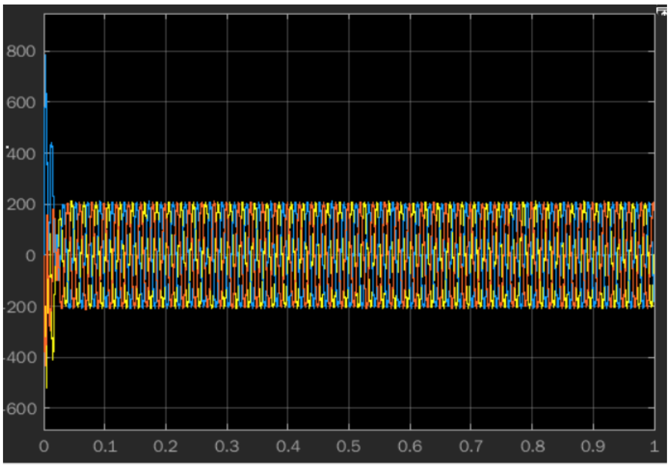

Fig 8 Three-Phase Currents for Constant Irradiance

DC capacitor voltage for the case of constant irradiance is shown in Fig.9. It can be seen that the DC capacitor voltage is being maintained constant at 600V.

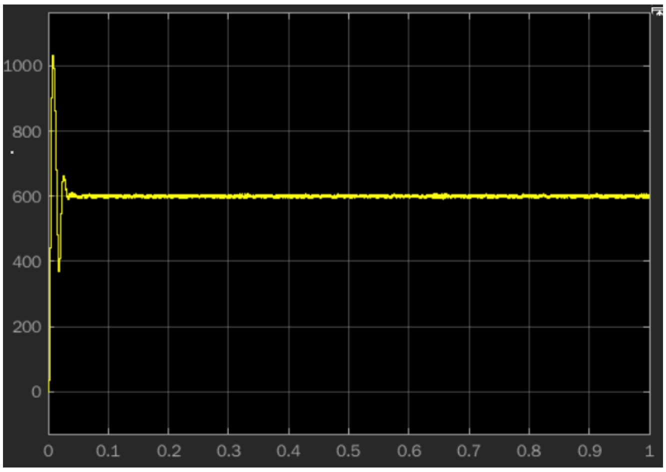

Fig 9 DC Capacitor Voltage for Constant Irradiance

Three-phase instantaneous power waveform for the case of constant irradiance is shown in Fig.10. From this figure, it can be inferred that the power is being maintained at MPPT value of 100kW.

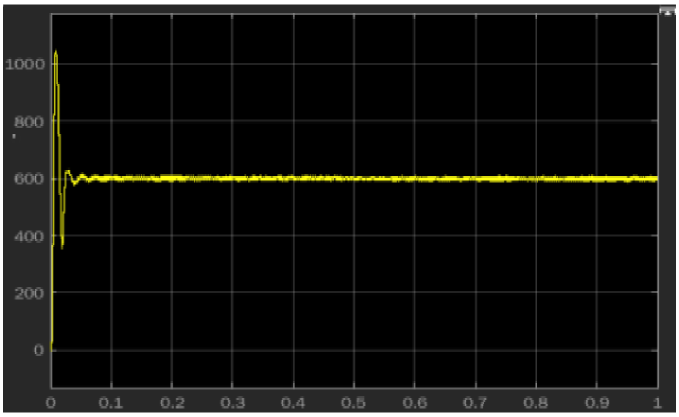

Fig 10 Three-Phase Instantaneous Current for Constant Irradiance

➢ *Case (ii): Varying irradiance*

This sub-section shows the results for the case of varying irradiance (shown in Fig.11).

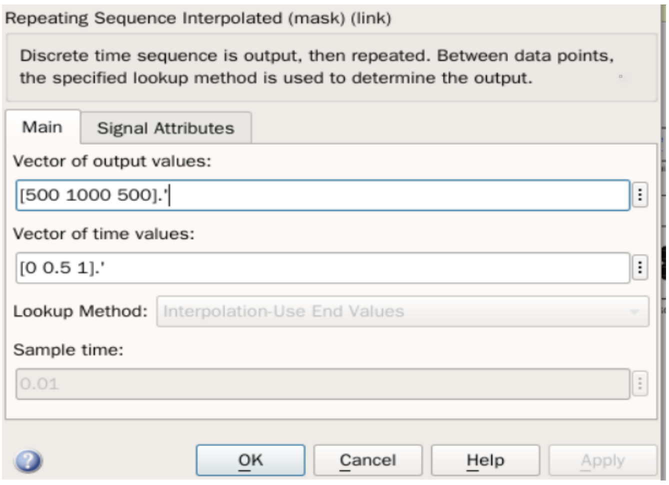

Fig 11 Variation of Irradiance

The same variation of irradiance with respect to time is shown graphically in Fig.12.

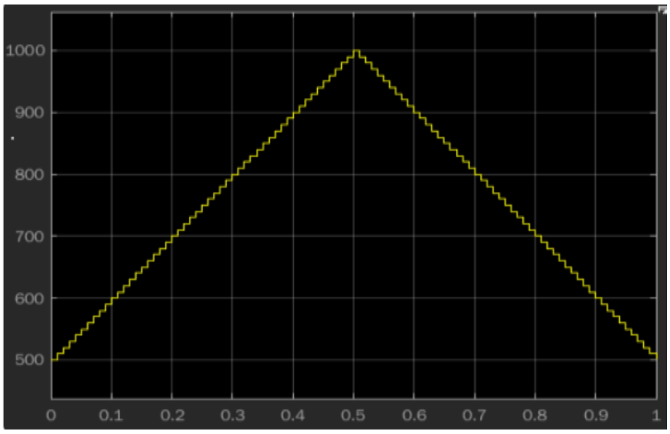

Fig 12 Variation of Irradiance with Time

In this case, the waveforms of three-phase voltage are shown in Fig.13.

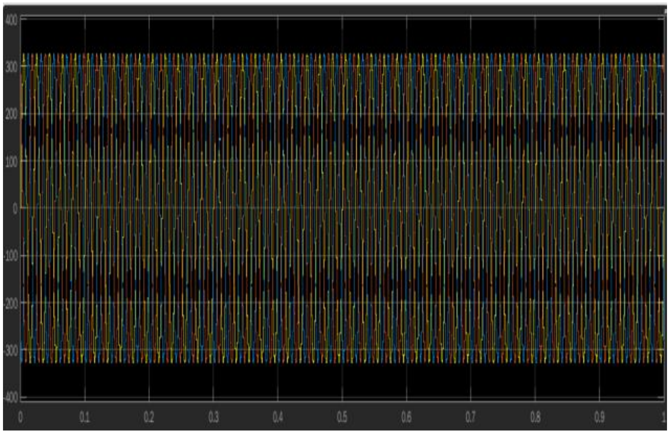

Fig 13 Three-Phase Voltages for Varying Irradiance

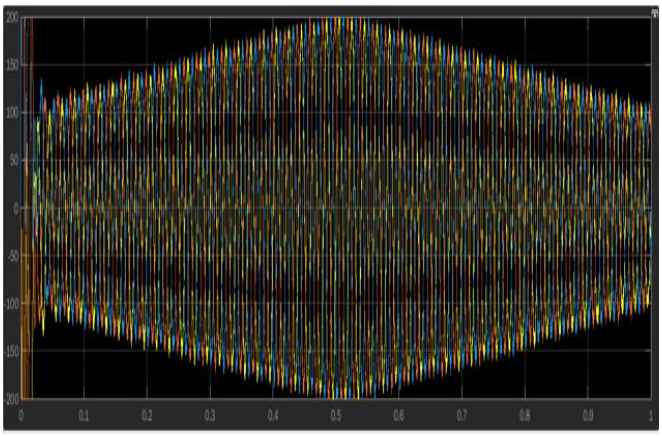

Fig 14 Three-Phase Currents for Varying Irradiance

Three-phase current waveforms for the case of varying irradiance are shown in Fig.14. It is clearly evident that the current generated is directly proportional to the value of irradiance.

DC capacitor voltage for the case of varying irradiance is shown in Fig.15. It can be seen from Fig.14that, inspite of variation in irradiance, the DC capacitor voltage is being maintained constant at 600V.

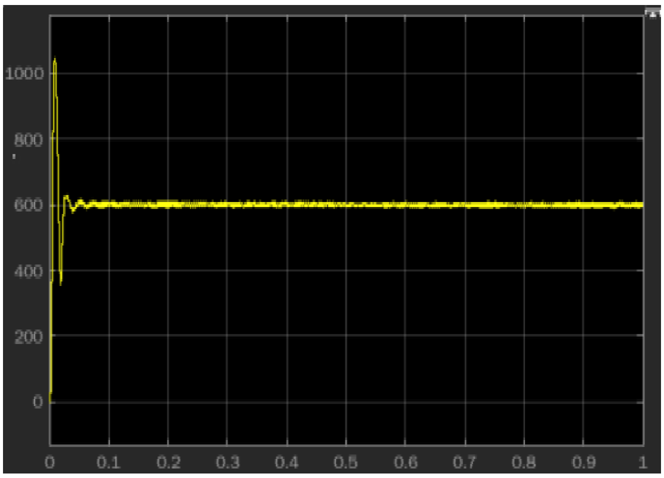

Fig 15 DC Capacitor Voltage for Varying Irradiance

Three-phase instantaneous power graph for the case of varying irradiance is shown in Fig.16. It can be seen from this graph that the power is directly proportional to the irradiance.

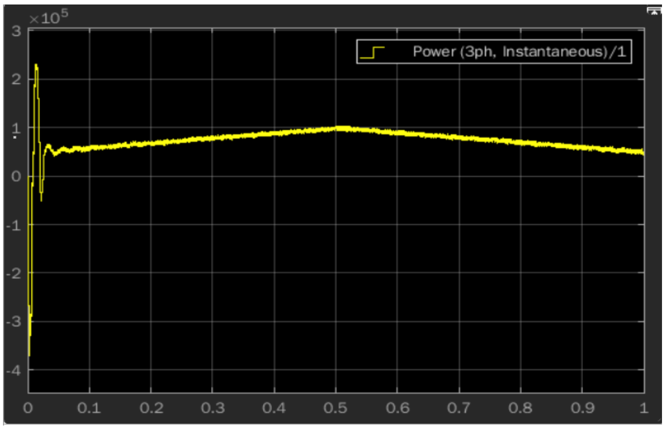

Fig 16 Three-Phase Instantaneous Power For Varying Irradiance

VII. CONCLUSION

This paper gives a bird's-eye view into the design aspects pertaining to a solar PV-DSTATCOM based on MPPT implemented by Perturb and Observe algorithm. All the aspects pertaining to the design of PV-DSTATCOM were discussed in detail. The PV-DSTATCOM, so designed, is connected to the grid and results are observed in MATLAB/SIMULINK. The results pertaining to the waveforms of three-phase voltages, three-phase current, DC capacitor voltage and three-phase instantaneous power are shown. The results are given for the case of constant irradiance and for the case of varying irradiance. It was also inferred that the DC capacitor voltage can be controlled independent of the level of irradiance, whereas the three-phase currents and instantaneous three-phase power are directly proportional to the value of irradiance at a constant temperature.

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