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A futuristic digital interface with a glowing Earth globe in the center. The interface is overlaid on a background of a person's hands reaching out towards the screen. The interface includes various data visualizations such as bar charts, line graphs, and pie charts. Text elements include "BUSINESS", "NETWORK SEARCH", "LOADING 100%", "MEDIA", and "WORLD". The overall color scheme is dark blue and purple with bright highlights from the digital elements.

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# Power Quality Improvement for Grid Connected PV System Using DSTATCOM with Controllers

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**ABSTRACT:** This paper presents a new method for PQ enrichment in a grid-connected PV system using a distribution static compensator. The paper consists of two-step management processes. In the initial stage, the DC-DC converter uses an Incremental Conductance controller with an Integral Regulator Technique (IRT) controller that separates the peak power point of the PV panel, where the ICC-IRT provides a switching signal to the DC-DC converter. In the secondary step, the DSTATCOM-based controller is implemented in the DC-AC converter VSC. The input to this VSC is an amplified DC voltage that comes from PV panel as a result of DC-DC conversion. Mains bypassed VSC is known as DSTATCOM which can maintain PQ of the distribution system. The DSTATCOM controller performs several tasks such as maintaining a sinusoidal source current, achieving approximately unity power factor and reactive compensation. A 100 kW solar energy system incorporated with a  $3\phi$  distribution system via VSC is designed in MATLAB/Simulink. The performance of ICC- and DSTATCOM-based controllers was demonstrated under different irradiances and under constant temperature and non-linear load conditions.

**KEYWORDS:** Incremental Conductance Controller, Integral Regulator Technique, Photovoltaic, Voltage Source inverter, Distribution Static Compensator.

## I. INTRODUCTION

As traditional energy resources are limited, the need for renewable energy resources is growing exponentially. The demand for renewable energy sources is increasing due to their inherent low-cost properties such as regenerability, continuous availability, non-polluting properties and low maintenance costs after deployment [1]. The PV system is considered the most important source of RE worldwide, used both in production and grid integration [4]. However, the most important issues in solar energy systems are their efficiency, grid integration, uninterrupted power quality and grid stability. Incremental conductance and P and O are the most commonly used MPPT methods due to their simplicity and ease of use. However, these methods have disadvantages such as slow convergence, fixed disturbance phases, low efficiency under dynamic conditions, and oscillation around the end point [1]. Among its excellent features, the Incremental Conductance Controller (ICC) has shown excellent performance in nonlinear system tuning. ICC is simpler in nature and adapts to changing environments. It requires no prior knowledge and has faster convergence. Some studies have investigated ways to increase output power & enrich PV systems to feed active power into grid, but few have PQ issues such as harmonic elimination, reactive power loading, phase unbalance, and power factor degradation. inverters are the main means of transferring energy from solar energy systems to the electrical grid. DSTATCOM is an interface device between PV systems and the grid and helps mitigate power quality problems caused by non-linear loads such as computers and fluorescent lamps [8]. Connecting PV systems to the grid with a DSTATCOM can decisively solve PQ problems such as harmonics, reactive power loads and phase unbalance [8]. On the consumer's side, in case of continuous load changes, the need for reactive power and the quality of network electricity also change. Several controllers have been used to improve the characteristics of DSTATCOM, including SRF theory [8], PLL is the basic parts of SRF-PLL, traditional controllers. PLLs must also be configured using the SRF method. If the surface design is not sufficient, the performance will deteriorate in dynamic situations. Thus, in dynamic situations, this control

method is ineffective.

In this paper, a DSTATCOM-based controller is used to control DSTATCOM to obtain the best power qualities of the proposed controller.

## II. GRID CONNECTED PV SYSTEM WITH DSTATCOM

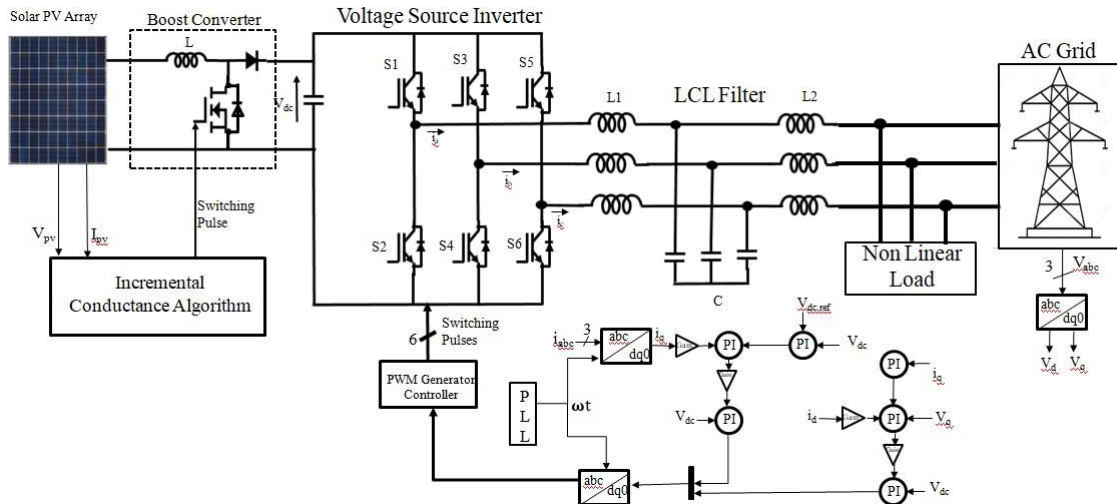


Figure.1 Schematic circuit diagram of SPV-DSTATCOM proposed system

The circuit layout of a PV panel integrated in a three-phase network using a DSTATCOM is shown in Figure 1. This system uses two-phase controllers, a larger DC-DC in the first stage and a DC-AC (VSI) in second stage. The circuit comprises a 100 kW PV panel, a DC-DC boost converter, a VSC, a grid, and various loads. The boost converter has one IGBT-based switch S0, filter coil L1, ripple-free absorption filter C1 and diode D1.  $I_{pv}$  and  $V_{pv}$  are the output current & voltage of PV panel and  $C_{dc1}$  DC link capacitors that connect boost converter and VSC for voltage transfer. The VSC topology consists of eight IGBT/diode switches S1-S6 in the DC-AC converter. The LCL filter of interface compensates the current harmonics of the DC-AC converter.  $V_{dc}$  is the DC link capacitor voltage;  $R_s$  and  $L_s$  are the resistance and inductance of the network, respectively. The  $3\phi$  source currents and reference currents generated by the designed controller.

### (A) Solar PV system :

The solar system is formed by a PV array with a Boost converter. ICC with Integral Regulator Technique, the MPP is tracked using MPPT in the solar PV system.

Using Kirchoff 's current law :

$$I_{pv} = I_{ph} - I_{diode} - I_r \quad (1)$$

$$I_{pv} = I_{ph} - I_0 \left( e^{\frac{V+I R_s}{a}} - 1 \right) \quad (2)$$

This single-diode model is intensive for determining the I-V and P-V characteristics of different PVs based on different parameters associated with each PV. Relationship between  $I_{diode}$ , the current flowing through the diode,  $R_p$ , shunt resistance, and  $I_{ph}$ , current produced by the PV panel, yields output current,  $I_{pv}$ , of the PV cell.  $I_r$  stands for the current flowing through  $R_{sh}$ ,  $a$  for the modified ideality factor, and  $R_2$  for the load resistance. The I-V and P-V curves of the PV system with discrete irradiances at standard temperature of 25



°C. The standard set of irradiance and constant temperature values can also be found in this figure 1. Each curve has a certain peak at a different magnitude. This means that as the irradiance output power changes, the PV voltage also changes. When the PV operates at an irradiance of 1 kW/m<sup>2</sup>, it generates a maximum output power of 300 W and decreases continuously with a decrease in irradiance.

The point at which the PV produces its peak power is called the peak power point, which varies depending on the output voltage. Thus, developing a mechanism that holds the MPP of the PV at a standard level under dynamic environmental conditions is essential. This mechanism is called the MPPT.

(B) Design of PV panel:

The maximum output power under standard test conditions (STCs) of 1000 W/m<sup>2</sup> is obtained by

$$P_{mp} = (N_s V_{mp}) * (N_p I_{mp}) \quad (1)$$

The number of series-connected module by  $N_s$ ,

$$N_s = 66 \quad (2)$$

The voltage at the maximum power under STCs is  $V_{mp}$ ,

$$V_{mp} = 54.7 \text{ V}, \quad (3)$$

The number of parallel connected modules is denoted by  $N_p$ ,

$$N_p = 5, \quad (4)$$

The current at the maximum power under STCs is denoted by  $I_{mp}$ ,

$$I_{mp} = 5.58 \text{ A}. \quad (5)$$

Equation (2),(3),(4),(5) substitute in (1)

$$P_{mp} = (66 \times 54.7 \text{ V}) \times (5 \times 5.58 \text{ A}) = 100724.58 \text{ W} \approx 100 \text{ kW}$$

$$P_{mp} \approx 100 \text{ kW}$$

### III GRID-CONNECTED PERFORMANCE OF SPV-DSTATCOM SYSTEM

This paper proposed to design PQ enrichment for grid integrated PV array with DSTATCOM. The solar PV panel integrated with a 3 $\phi$  grid through DSTATCOM is shown in Fig.1. Two-stage controllers are employed in this system, a DC-DC in the primary stage and a VSI in the second stage. The circuit comprises a 100-kW rated PV panel, DC-DC boost converter, VSC, grid, and various types of loads. The boost converter has one IGBT based switch  $S_0$ , a filter inductor  $L_1$ , a ripple-free absorbing filter  $C_1$ , and a diode  $D_1$ . The PV panel's output current and voltage are, respectively,  $I_{pv}$  and  $V_{pv}$ . and  $C_{dc1}$  DC link capacitors that connect boost converter and VSC for voltage transfer. A VSC topology is formed by six IGBT/ diode switches  $S_1$ - $S_6$  of the DC-AC converter. The interface LCL filter compensates for the current harmonics of the DC-AC conversion.  $V_{dc}$  is the voltage of a DC-link capacitor.  $R_s$  and  $L_s$  are resistance and inductance of grid, respectively. 3 $\phi$  source currents and reference currents generated by proposed controller.

**IV. FIRST-STAGE CONVERTER CONTROLLER**

(A) Schematic of PV panel with an MPPT/ICC controlled boost converter:

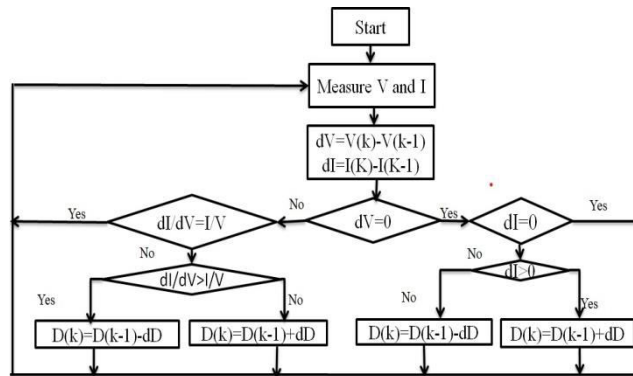


Figure.2 Flowchart of ICC

Using a DC-DC converter with MPPT in this study enables for more effective use solar panel by optimizing power generated. Duty cycle of the boost converter must be checked first. The DC voltage of the PV array must first be gradually increased to the high DC voltage required by the load. This whole process is carried out by the pulse input of the gate. Therefore, duty cycle management is critical. The next phase is to maximize the PV array's output despite temperature and ambient factors. The two most important parameters for obtaining maximum power and voltage from a photovoltaic system are irradiance and temperature. The maximum output of the PV array must be monitored using MPPT/ICC-IRT technology. Therefore, to solve the problem of step size under dynamic conditions, an MPPT controller based on integrated regulation technology is selected, which enables higher efficiency. This controller has a shorter response time, is more robust and can perform tasks in an imprecise input range.

*Integral Regulator Technique;*

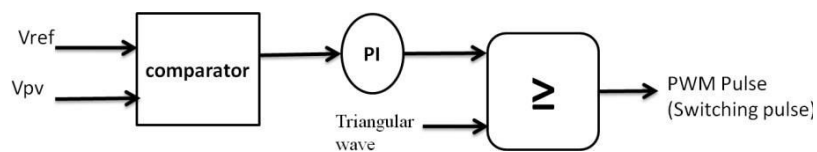


Figure.3 Block Diagram of IRT

The switching pulse ratio is optimized by an MPPT controller that uses a step-up converter with an IRT. This MPPT technique spontaneously changes to produce the voltage required to deliver maximum power. The first stage control block is shown in Figure 3. The DC-DC conversion is controlled with duty cycle evaluated by ICC-IRT, MPPT method. The ICC approach is simple to use and necessitates far less complicated arithmetic. Vref is evaluated by detecting electrical parameter,  $V_{pv}$  &  $I_{pv}$  of solar panel. Vref represents solar panel voltage in MPP. The evaluated Vref value & detected VDC are used to evaluate duty ratio, which is correlated with a high-frequency triangular wave to create a gate pulse to the boost converter.

V. SECOND-STAGE CONVERTER CONTROLLER

(A) DSTATCOM based controller:

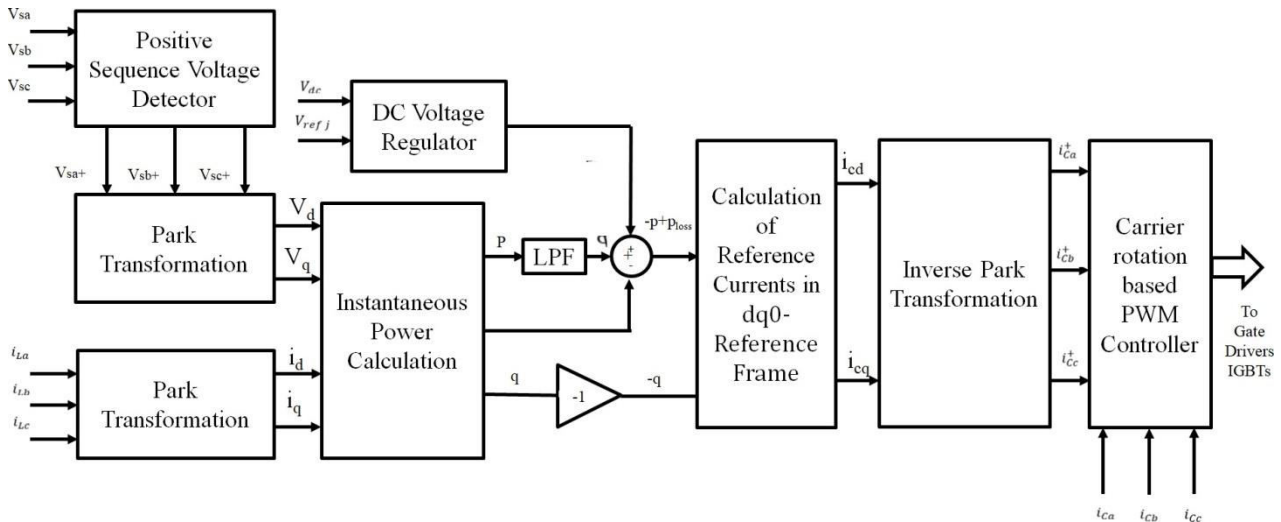


Figure.4 DSTATCOM based controller

The fundamental phase locking variant based on the Park transform is known as a PLL synchronous reference frame. The SRF-PLL is made up of a Park transformer that serves as a phase detector and low-pass filter, typically in the form of a PI. Usually consisting of an integrator, a regulator and voltage-controlled oscillator. Therefore, this PLL's goal is to reduce the direct or square axis reference voltage. So, the phase angle of the parking transformer's revolving reference frame will always coincide with phase angle of the mains voltage vector.

(i) PLL:

A PLL is a type of feedback control device. It contrasts phases of the input and output signals. This enables faster dynamic response and eliminates harmonics using PLL control techniques. In a grid system, the power factor is brought close to unity by using a PLL to synchronize instantaneous phase angle of VSI with phase angle of grid potential drop.

(ii) Synchronous Reference Frame Theory:

An extensively used technique for frequency-sensitive network synchronization in 3φ systems is the SRF-PLL. The root intention of a PLL is a feedback system with a PI controller that controls phase angle. In this case, input of the main voltage is 3 φ and the output of PLL is one phase angle of 3 φ. There are two options: either line voltages are balanced, just one of the three phases is monitored, and then each of other two phases is shifted by 120°; or there are three PLL systems, one for each phase. Using Park transform, the 3φ voltage vector in SRF-PLL is transformed from reference frame abc to stationary reference frame dq & from stationary reference frame dq to rotating reference frame dq. The angular position of dqreference frame is controlled by a feedback loop so that d-axis coincides with network voltage vector. At steady state, q-axis component stands for amplitude of voltage vector & output of d-axis feedback loop stands for frequency & phase of voltage vector. The SRF-PLL is most extensively used PLL, which consists of a phase detector, a filter and an oscillator, whose main purpose is to converge and phase of voltage vector.

The VSC control system uses two control circuits. These are the inner and outer control loops.

$$V_q \rightarrow 0 \tag{1}$$

where  $V_q$  is quadratic component in the dq0 frame. From the SRF-PLL linearized model,  $V_q$  can be represented as follows

$$V_q = V_m \sin[(\theta - \theta^*)] \tag{2}$$

where  $V_m$ ,  $\theta$  represent the maximum voltage, phase information & control feedback, respectively.

From (2)  $V_m \sin[(\theta - \theta^*)] = 0$  (3)

Utilizing a PI controller, the error in (1) converges. When the gains are set concurrently, the dynamic response can be modified by selecting a certain time constant due to the PI controller's filtering properties. The SRF-PLL's closed-loop transfer function is

$$G(s) = \frac{F(s)V_m}{V_m(s) + F(s)V_m(s)} \tag{4}$$

Where,  $F(s) = K_p + K_i/s$  . can be alternatively given by

$$G(s) = \frac{K_p V_m(s) K_i V_m}{s^2 + K_p V_m(s) + K_i V_m} \tag{5}$$

The grid voltage in the dq frame is checked by the SRF-PLL to keep track of the grid phase. The d-axis voltage and the  $3\phi$  line voltage vector are lined up when the phase is properly locked, and the q-axis voltage is zero. The PLL system has a balanced point because, under  $3\phi$  balanced network conditions, the dq frame voltages are both constant. The SRF-PLL small-signal model can be derived using a PI controller & integrator. The output of PI controller is enhanced and output signal is restored by adding natural frequency of the gate. The d-axis voltage  $V_d$  is constant, and the system is linearly time invariant. For PLL analysis, this is the fundamental and well-known small-signal model.

(iii) Grid-connected PV System Performance Controller :

Figures 6 and 7 displays grid voltage and current at sun irradiances. Voltage and current are in phase at each irradiance incident point, demonstrating that the power factor improves with non-linear loading. When the irradiance varies at intervals of 0.7, 1.2, and 1.5 seconds, for example, the voltage and current are in phase. It demonstrates how controllers for nonlinear loads based on ICC-IRT and DSTATCOM have improved power factor.

**VI. DISCUSSION OF SIMULATION RESULTS**

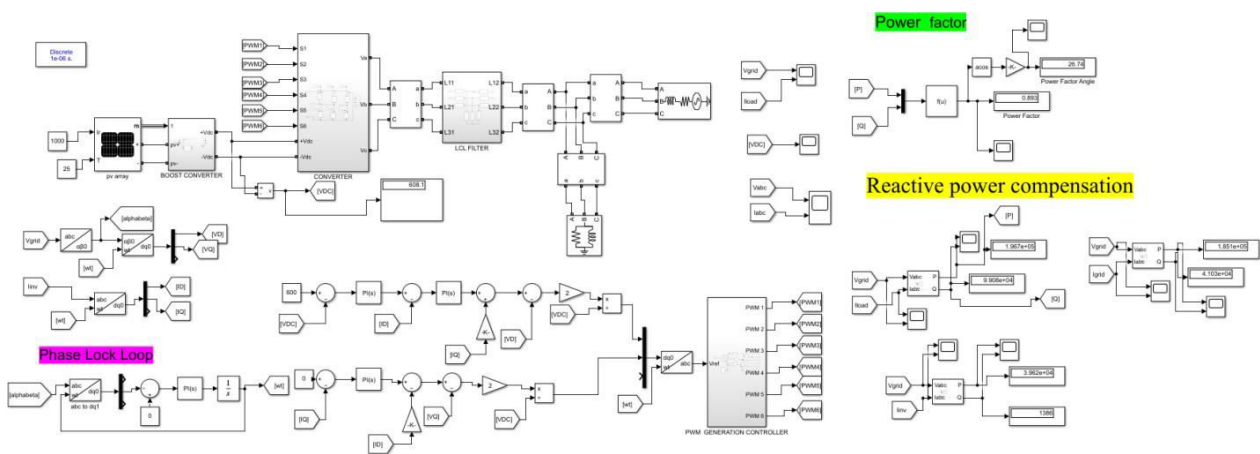


Figure.5 Simulation model of SPV-DSTATCOM proposed system

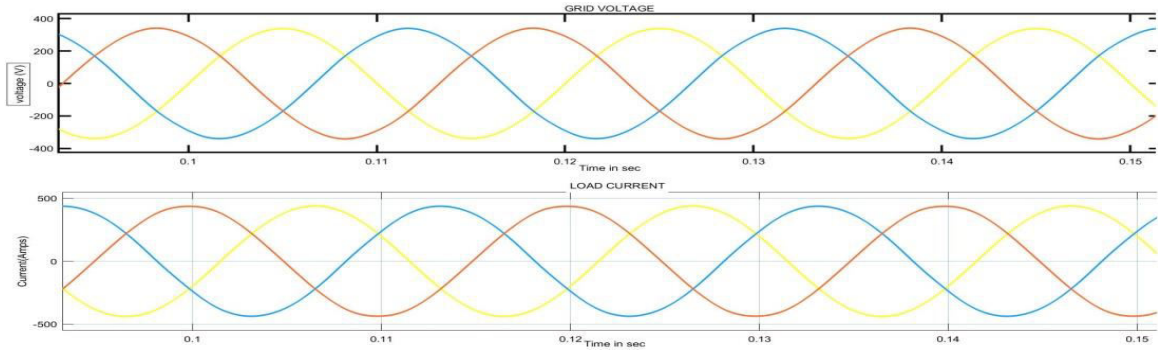


Figure.6 Grid voltage 380 V and load current 415A(line to line)

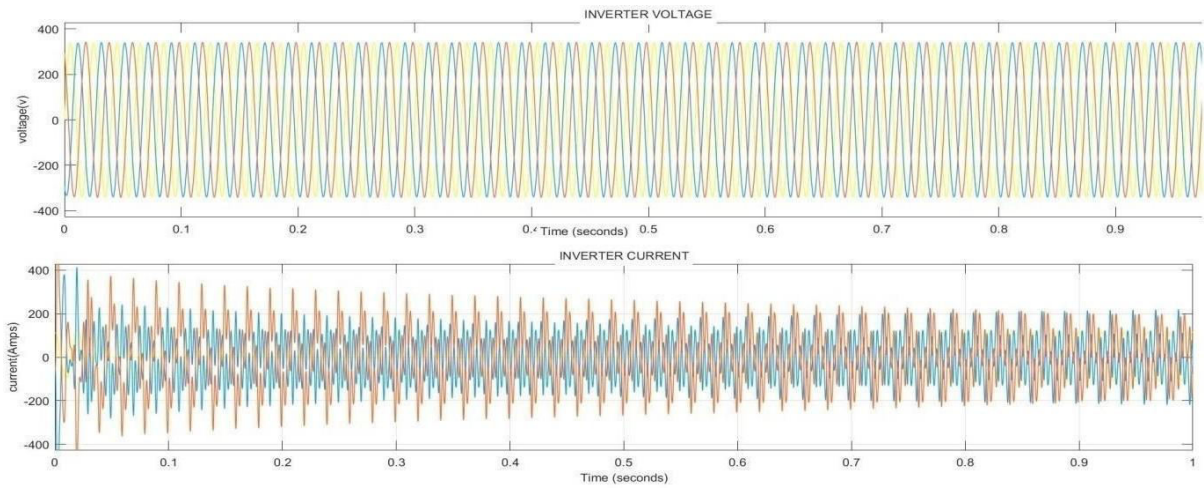


Figure.7 Inverted voltage is 330 V and current is 230 A.

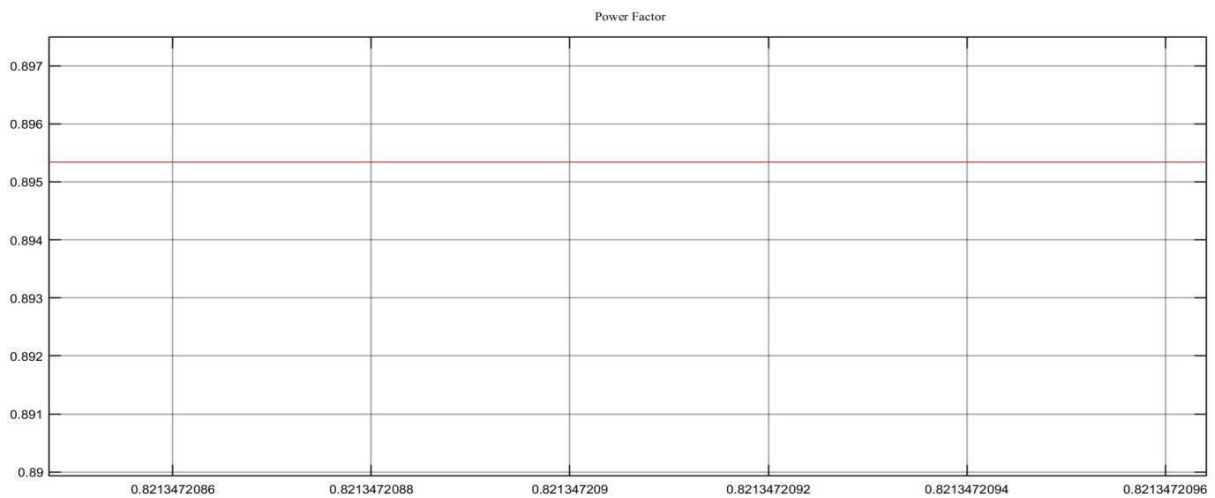


Figure.8 The overall system Power factor



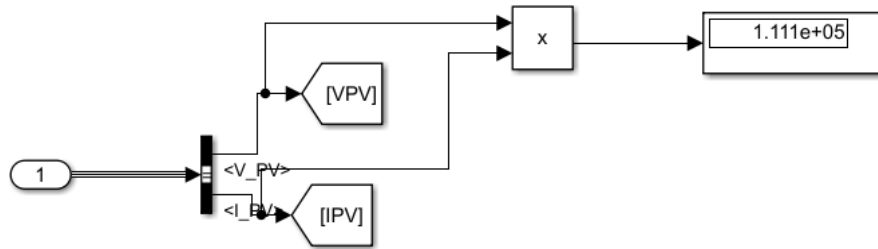


Figure.9 Simulation result of maximum power from 100kW solar PV panel

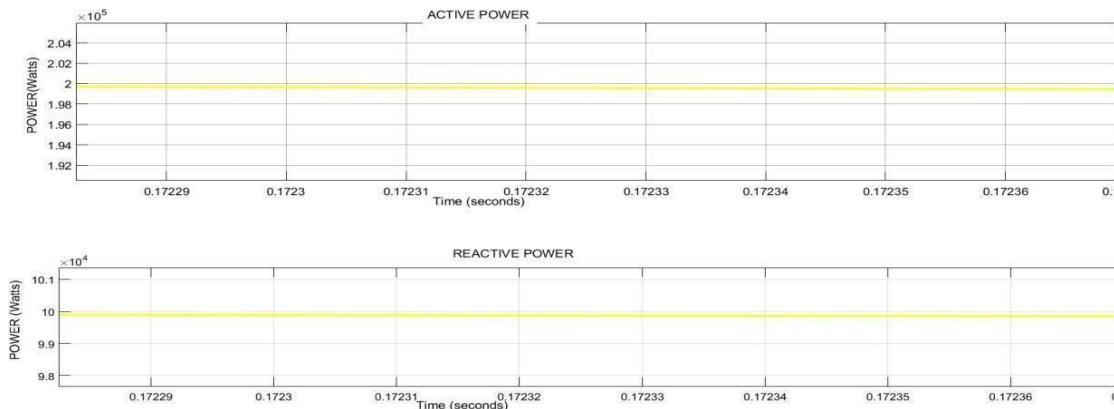


Figure .10 Active power at 1.9kW and also shows reactive power from grid to load

Figures 10 shows simulation results of reactive power compensation to maintain active power at 200kW approximately from grid to load.

## VII. CONCLUSION

In this work, a  $3\phi$  grid-integrated solar energy system using DSTATCOM is proposed to mitigate PQ problems caused by non-linear loads. An MPPT controller based on ICC controller technology with an integrated controller is implemented to monitor the peak power point. The results show that the MPPT controller based on ICC-IRT is more dynamic and less dependent on the result in different environments. In addition, a PLL-SRF based DSTATCOM controller is to control operation of the DSTATCOM system. The DSTATCOM-based controller has advanced functionality in mitigating PQ problems caused by non-linear loads. An SRF-PLL coupled network is proposed. The proposed system not only feeds existing solar energy into the grid, reducing voltages & improving power quality. These are achieved through a designed control technique. The simulation results confirm the two-stage conversion performance technique.

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