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Reactive Power Compensation Through Grid Connected PV System Using STATCOM

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Abstract : Integration of Distributed Energy Resources (DER) in conventional power system has increased all over the world. The main aim of connecting DERs is to fulfill supply demand gap at the same time they can be used for ancillary services like reactive power support. Conventionally equipment's like fixed capacitors are being used for reactive power compensation and power quality improvement. STATic COMpensators (STATCOM) have been lately used for dynamic reactive power compensation. This paper focuses upon integration of solar PV with STATCOM for reactive power compensation as well as the active power sharing with grid. Control technique called IcosΦ algorithm has been implemented for the control of the STATCOM.

Keywords —Distributed Energy Resources, IcosΦ Algorithm, STATCOM, Reactive Power Compensation.

I. INTRODUCTION

India has a cumulative installed grid connected solar power capacity of 8,062 MW (8 GW) as of June 2016, and promises to grow further in coming years [1]. Due to the rapid growth of the power electronics technique, the photovoltaic (PV) power generation system has been developed worldwide. By changing the duty cycle, the load impedance as seen by the source is varied and matched at the point of the peak power with the source so as to transfer the maximum power, the term coined as Maximum Power Point Tracking (MPPT). There are many MPPT techniques like Perturb and Observe (P&O) methods, Incremental Conductance (IC) methods, Fuzzy Logic Method, etc.[2] In this paper the most popular of MPPT technique (Perturb and Observe (P&O) method has been implemented in MATLAB Simulink. The utilization efficiency can be improved (at the cost of a small increase in implementation cost) by employing this hill- climbing MPPT technique. This is a simple algorithm that does not require previous knowledge of the PV generator characteristics or the measurement of solar intensity and cell temperature and is easy to implement with analogue and digital circuits. The algorithm perturbs the operating point of the PV generator by increasing or decreasing a voltage by a small amount (step size) and measures the PV array output power before and after the perturbation. If the power increases, the algorithm continues to perturb the system in the same direction; otherwise the system is perturbed in the opposite direction. The number of perturbations made by the MPPT algorithm per second is known as the perturbation frequency or the MPPT frequency [2][3]. Both active and reactive power control can be achieved with distributed generation units coupled through an Inverter. Reactive power flow control envisages distributed generation units to be used as static var compensation units besides conventionally being used just as energy sources.

The theme of the paper is to improve the power quality of supply in locations where electric grids are weak or sensitive loads need to be protected against problems such as low power factor, voltage regulation, and reactive power compensation. It is done using a STATCOM whose DC link is supplied through a PV module. IcosΦ algorithm for STATCOM control has been applied to a inverter to provide reactive power compensation as demanded by the linear reactive load. The experimental results show that the control algorithm is effective for harmonic as well as reactive power compensation, so that it is necessary for the source to supply only the real power demanded by the load [4]. The topology of three- phase four-wire Shunt Active Filter not only compensates power quality problems but also allows interface renewable energy sources with gird. The inverter stage of the active filter is based in two-level four-leg inverter and its control is based in the theory of Instantaneous reactive power (p-q Theory). The filter is capable of compensating power factor, unbalance, and current harmonics. Additionally it can also make the interface between renewable energy sources and the

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electrical system, injecting balanced practically sinusoidal currents (with low THD)[6].

Mathematical model of PV module, the Perturb and Observe (P&O) method for control of PV and IcosΦ control of STATCOM are treated in this paper. The system configuration comprises of Three phase source of 415 V 50 Hz, a linear R-L load of 50 kW and 30 kVAr, 29 kWp solar system has been implemented.

II. MATHEMATICAL MODEL FOR PHOTOVOLTAIC MODULE

A solar cell is basically a p-n junction fabricated in a thin wafer of semiconductor. The electromagnetic radiation of solar energy can be directly converted to electricity through photovoltaic effect. Being exposed to the sunlight, photons with energy greater than the band-gap energy of the semi-conductor creates some electron-hole pairs proportional to the incident irradiation. The equivalent circuit of a PV cell is as shown in Figure 1. The current source I_{ph} represents the cell photocurrent. R_{sh} and R_s are the intrinsic shunt and series resistances of the cell, respectively. Usually the value of Rsh is very large and that of Rs is very small, hence they may be neglected to simplify the analysis. PV cells are grouped in larger units called PV modules which are further interconnected in a parallel-series configuration to form PV arrays. The photovoltaic panel can be modeled mathematically as given in following equations[7].

Module photo-current:

$$I_{ph} = \left[I_{sc_r} + K_t \left(T - 298 \right) * \lambda / 1000 \right] \qquad (1)$$

Module reverse saturation current – I_{rs}:

$$I_{rs} = I_{sc_r} / \left[\exp(qV_{oc} / N_s kAT) - 1 \right] \qquad (2)$$

The module saturation current I_0 varies with the cell temperature, which is given by

$$I_o = I_{rs} [\frac{T}{T_r}]^3 [\exp \left\{ \frac{q * (V_{pv} + I_{pv} R_s)}{N_s AkT} \right\} - 1] \qquad (3)$$

The current output of PV module is

$$I_{pv} = N_p * I_{ph} - N_p * I_0 [\exp\{ \frac{q * (V_{pv} + I_{pv} R_s)}{N_s AkT} \} - 1] \qquad (4)$$

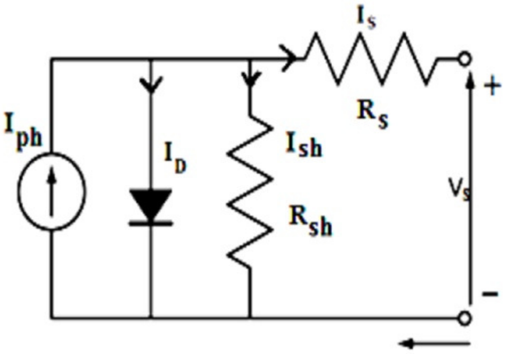

Fig. 1. Equivalent Circuit of Solar Cell

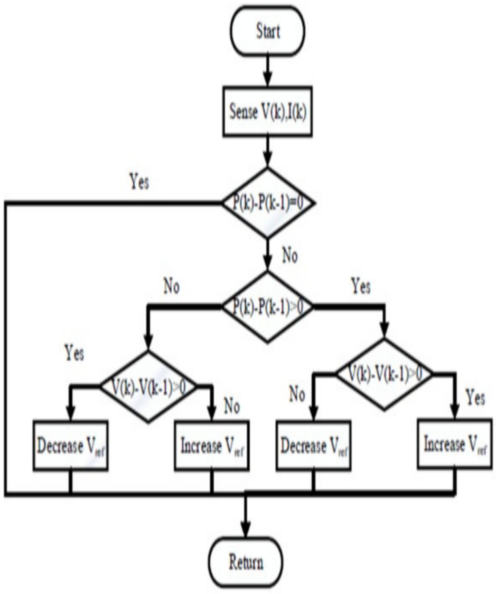

Fig. 2. An Algorithm of Perturb and Observe Method

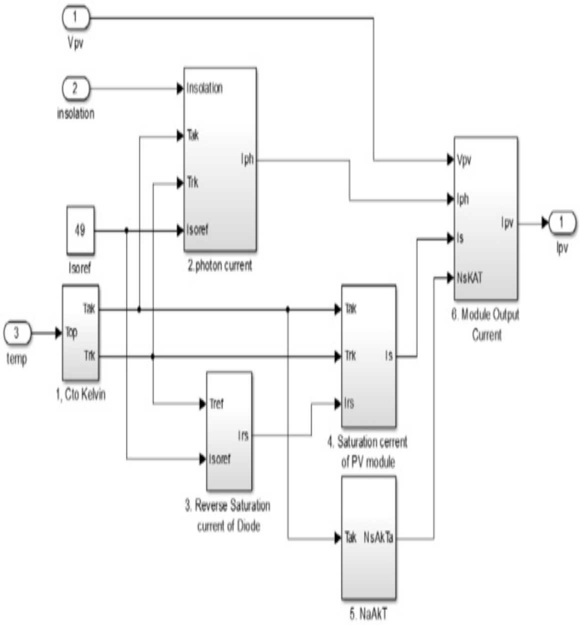

Fig. 3. Solar PV Module

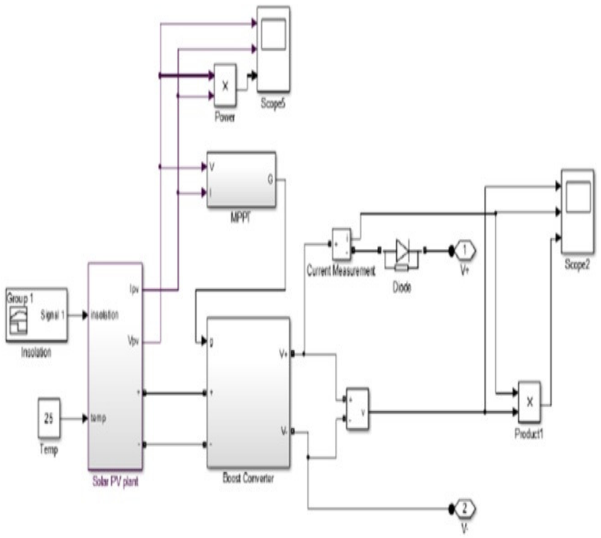

Fig. 4. Solar PV Plant with MPPT

III. ICOS Ø TECHNIQUE

In 'IcosØ' algorithm, the fundamental component of the active part of the load current, i.e., IcosØ, is deduced from the load current in each phase using a second order low pass filter tuned to fundamental frequency and sample & hold circuits.

This gives the amplitude of the desired mains current in each phase. The three-phase mains voltages are used as templates to generate unit amplitude sine waves in phase with the mains voltages. The desired mains currents are then computed as the product of the amplitude 'IcosØ' and the unit sine wave for each phase. Considering the requirement for a self-supporting

DC bus for the inverter, the capacitor voltage fluctuations are used to calculate the extra power loss in the inverter and the interface transformer. The corresponding current amplitude is calculated and added to the active component of the fundamental load current in each phase. The reference compensation currants for the shunt active filter are therefore computed as the difference between the actual load currents and the desired mains currents for the three phase.

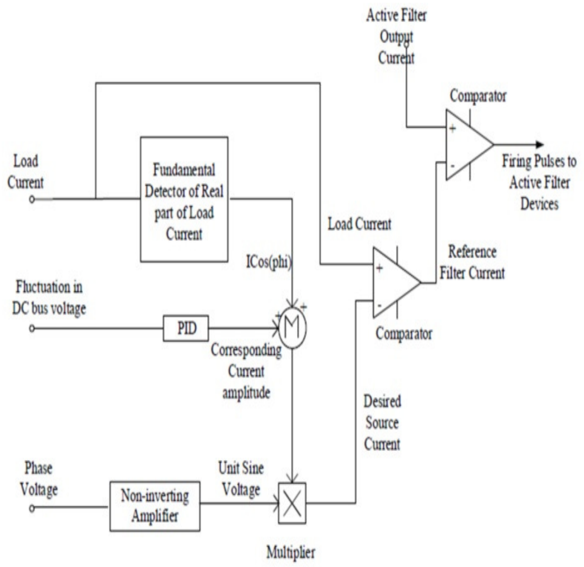

Fig. 5.Block Diagram of IcosØ Implementation

The IcosØ algorithm generates reference compensation currents for the three-phase shunt active filter based on the real part of the load current. This ensures that the current drawn from the supply mains is purely sinusoidal with no reactive component i.e. at unity power factor. The three-phase system includes a three-phase balanced supply connected to a IGBT-controlled converts feeding a resistive load. Firing of the IGBT is adjusted to 0 -60^{o} so that the load currents are highly non-linear and reactive. A three-phase voltage source inverter with a self- supporting DC bus capacitor generates the required harmonics and reactive power compensation. Fig.2 shows the block diagram representation of the IcosØ control scheme. The load currents in the three phases are sensed and the amplitude of the active part alone is detected using second order low pass filters. This forms the amplitude IcosØ of the desired source currents in the three phases. The fluctuation in the dc bus voltage is used to calculate the corresponding power loss occurring in the switching devices of the active filter and/or the interface transformer. The amplitude of the current equivalent to the power loss is added to the IcosØ component in each phase to arrive at the required magnitude of the source circuit. The three-phase mains voltages are used as templates to generate unit amplitude sine waves in phase with the mains voltages. The product of the two i.e. the amplitude IcosØ of the reference source current and the unit sine wave gives the desired source current waveform in each phase[3][4][6].

IV. SIMULATION AND RESULTS

The simulation of the three phase grid system supplying linear L-load and STATCOM interface for renewable energy source as been done using MATLAB Simulink. The STATCOM acts as an effective interfacing link between the renewable energy source and grid system. The STATCOM unit performs regular role of delivering the required amount of reactive power and power factor correction, which works with the gating pulses generated from the modified IcosØ based controller circuit. In addition to merely being an interfacing unit, another imperative function of a STATCOM is the ability of real power exchange from renewable energy source to load and grid. Fig 6 shows the

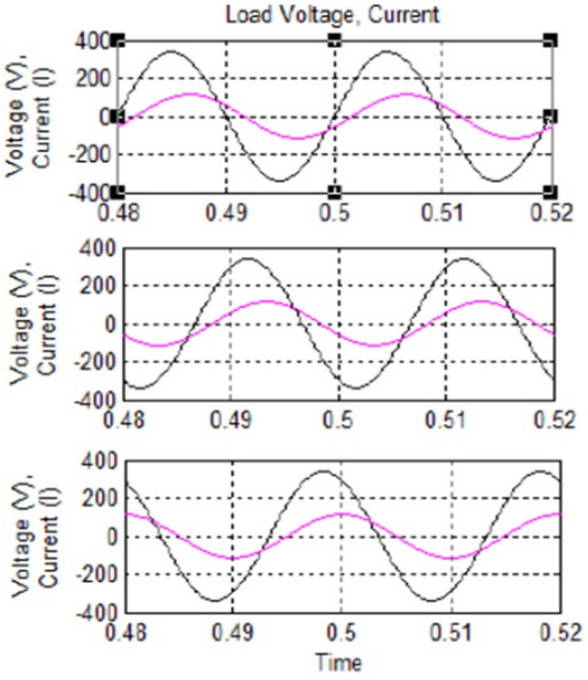

Fig. 6. Load Voltage and Current

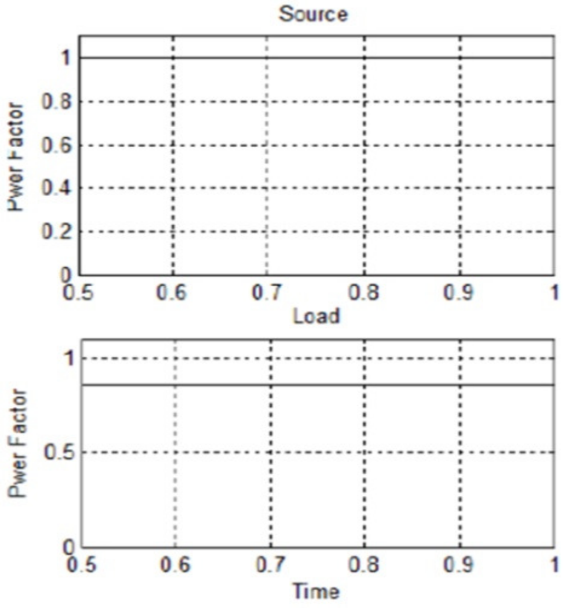

Fig. 7. Power Factor

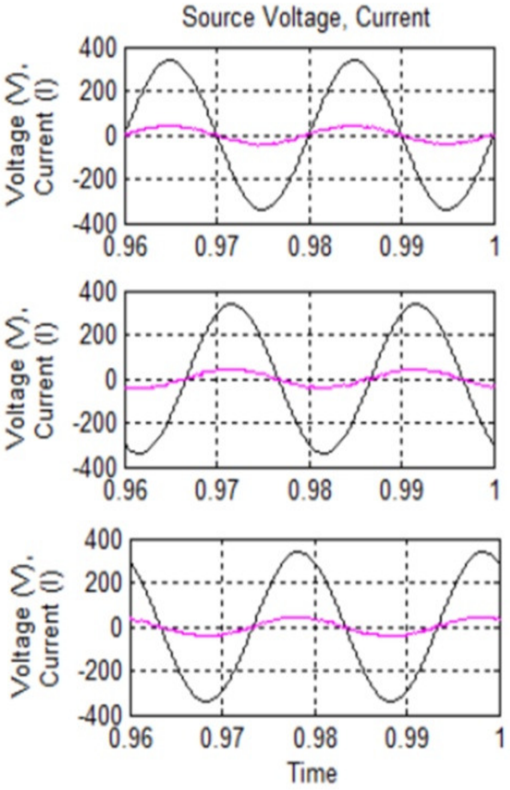

Fig.8. Source Voltage and Current with 1000 W/m^2 Irradiation

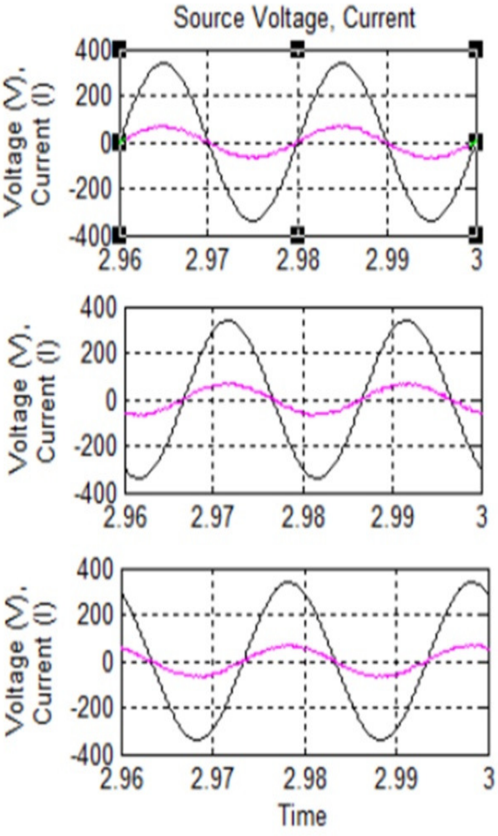

Fig.9. Source Voltage and Current with 600 W/m^2 Irradiation

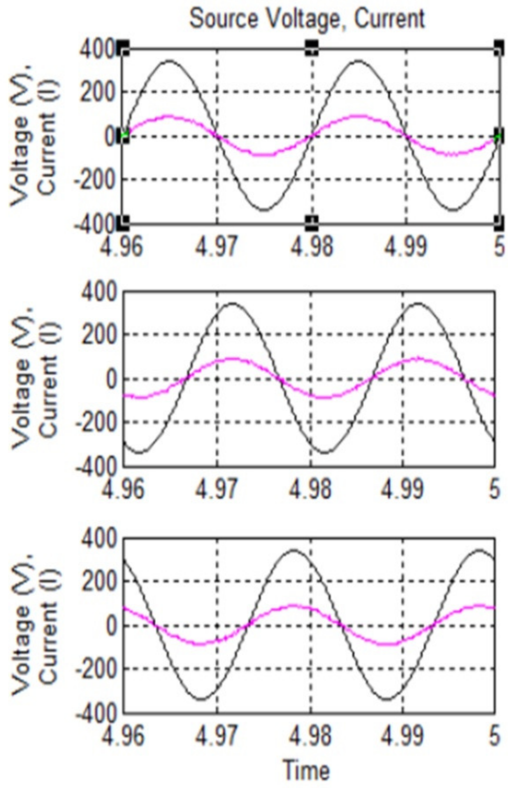

Fig.10. Source Voltage and Current with 200 W/m^2 Irradiation

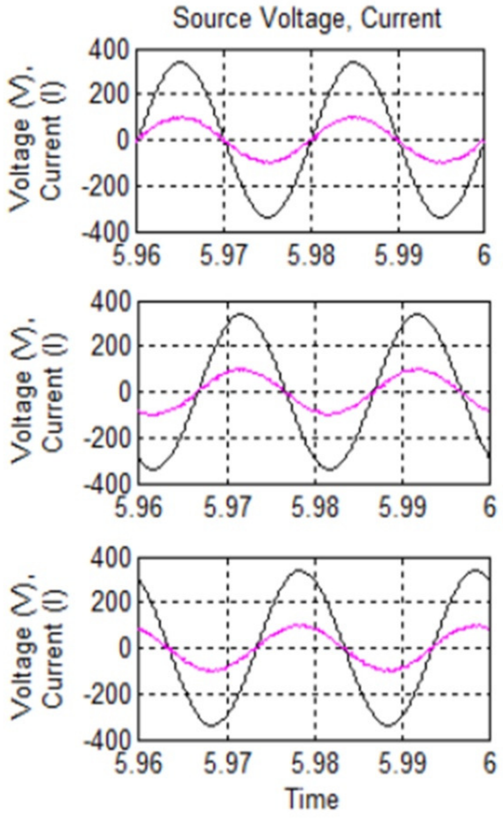

Fig.11. Source Voltage and Current with 0 W/m^2 Irradiation

Table 1 Simulation Analysis of Statcom with Solar PV System

	Irradiation (W/m^2)	Voltage (v)	Current (A)	Active power(kW)	Reactive Power (kVar)	Power Factor
Source	1000	$240\angle 0^{0}$	$29.69\angle 1.2^{0}$	21.3	-0.45	0.999Lead
	800	$240\angle 0^{0}$	$38.53\angle 0.9^{0}$	27.7	-0.40	0.999Lead
	600	$240\angle 0^{0}$	$46.52\angle 0.6^{0}$	33.4	-0.35	1
	400	$240\angle 0^{0}$	$53.38\angle 0.4^{0}$	38.3	-0.30	1
	200	$240\angle 0^{0}$	$61.66\angle 0.3^{0}$	44.3	-0.25	1
	0	$240\angle 0^{0}$	$69.65\angle 0.2^{0}$	50	-0.20	1
Load	1000	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
	800	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
	600	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
	400	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
	200	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
	0	$240\angle 0^{0}$	$81.12\angle -30.95^{0}$	50.0	30.0	0.857Lag
STAT COM	1000	$282.1\angle 7.7^{0}$	$58.26\angle 46.70^{0}$	28.7	30.45	
	800	$281.0\angle 6^{0}$	$52.46\angle 53.65^{0}$	22.3	30.40	
	600	$280.3\angle 4.5^{0}$	$48.08\angle 61.35^{0}$	16.6	30.35	
	400	$279.6\angle 3.5^{0}$	$45.04\angle 68.95^{0}$	11.7	30.30	
	200	$279.3\angle 1.5^{0}$	$42.77\angle 79.25^{0}$	5.7	30.25	
	0	$279.3\angle 0^{0}$	$42.00\angle 90^{0}$	0	30.20	

From Table 1 the following points are pretty evident

- The Change in the irradiation is done, and accordingly power from the solar PV system is changed. The change in irradiation cause the change in the output voltage and current, the change in voltage is improved by the changing the duty ratio of boost converter for giving constant output voltage.
- The use of STATCOM provides all/partial reactive power required by load which reduced the reactive power drawn from the source which improved the power factor of source to unity
- The active power produced by the solar PV plant is fed to the grid through STATCOM, which further reduced the current from the source to 29.69 A. The reduced demand form load results in increasing the load capacity of the source.

V. CONCLUSION

Implementation of Icos∅ algorithm for reactive power compensation with solar PV has been represented in this paper. Integration of Solar PV with STATCOM improves the power quality of supply in locations where electric grids are weak or sensitive loads need to be protected against problems such as low power factor, voltage regulation and reactive power compensation in addition to delivering real power to the grid. In future, this scheme may not only be used to deliver real power to load by solar but can also prove as a source reactive power at times of highly reactive loadings.

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