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Photovoltaic Solar Plant As A Statcom During Dark Periods In A Distribution Network

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Abstract - Photovoltaic (PV) energy is supposed to be one of the cleanest forms of renewable energy. PV solar plants produce real power only during day time whereas in the nights they are completely idle. PV technology is expensive. Such an expensive asset thus remains entirely unutilized in the night time and brings no revenue to the solar plant owner. A key component of the PV solar plant is a voltage source converter which is also a core element of STATCOM. Using this fact we present a simple open-loop control method of using PV solar plant as STATCOM, in dark periods without sunlight, for load reactive power compensation and voltage control. The simulation work is carried out in MATLAB Simulink. The results show that the method is effective in mitigating voltage sags and swells with improved voltage regulation and power factor.

Index Terms: Solar energy, PV cells, STATCOM, Power Quality

I. INTRODUCTION

Utilization of renewable energy comes from the perspective of environmental conservation and fossil fuel shortage. Recent studies suggest that in medium and long terms, photovoltaic (PV) generator will become commercially so attractive that large-scale implementation of this type can be seen in many parts of the world [1], [2]. A large-scale PV generation system includes photovoltaic array, DC/AC converter and the associated controllers. It is a multivariable and non-linear system, and its performance depends on environmental conditions. Recently, the increasing penetration levels of PV plants are raising concerns to utilities due to possible negative impacts on power system stability as speculated by a number of studies. Thus, the thorough investigation of power system stability with large-scale PV is an urgent task.

Among stability issues, voltage instability has been a major concern for power system. Several major power interruptions have been linked to power system voltage instability in recent past. It has been proved that inadequate reactive power compensation during stressed operating condition can lead to voltage instability. Although large-scale PV is capable of generating reactive power, however, the operation of PV in terminal voltage mode has the potential for adverse interaction with other voltage controllers [8]. Therefore, grid code requires operation at power factors equal or greater than 0.95 for PV generators. Moreover, the size and position of large-scale PV generator can introduce detrimental effect on power system voltage stability as the level of PV penetration increased.

Furthermore, the technical regulations or specific standards are trying to shape the conventional control strategies to allow the flawless integration of renewable energy based distributed generation (DG) in main grid. According to technical regulations or standards the post fault voltage recovery time at DG bus is crucial as it requires DG to trip, if recovery time exceeds certain limits [9], [10]. With increased penetration of renewable energy DG, early tripping of DG due to local disturbance can further risk the stability of the system. Hence system operator becomes responsible to maintain the voltage profile under all operating conditions. As a result, fault tolerant control algorithm based on dynamic VAr planning (e.g. placement of FACTS devices) is applied in DG integrated system. The most common, or preferred, dynamic VAr planning with multiple DGs is the placement of dynamic VAr device at the point of common coupling of DG.

Nowadays solar energy using PV technology is becoming popular due to government subsidies. Obviously solar forms generate energy during sunny periods only. When sunlight is not bright enough they remain idle. To make the PV technology cost effective with higher utilization factor it is to be used throughout day and night. Efforts are being made in this direction [7,11]. Power quality is an important aspect of power distribution. Power is to be distributed with tolerable voltage sags and swells. Here Flexible AC Transmission Systems (FACTS) devices play a vital role. It is well known that STATic synchronous COMpensator (STATCOM) is a FACTS device which acts as a shunt compensating device. A key component of the PV solar plant is a voltage source inverter which is also a core element of STATCOM. Using this fact we present a simple open-loop control method of using PV solar plant as STATCOM, in dark periods without sunlight, for load reactive power compensation and voltage control. Due to improvement in power factor load current reduces. Also the

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system remains balanced with better efficiency (less transmission losses) and power quality.

II. ABOUT PHOTO VOLTAIC SYSTEMS

A photovoltaic (PV) system directly converts sunlight into electricity. The basic device of a PV system is the PV cell. Cells may be grouped to form panels or arrays. The voltage and current available at the terminals of a PV device may directly feed small loads such as lighting systems and dc motors. [7] A photovoltaic cell is basically a semiconductor diode whose *p–n* junction is exposed to light. Photovoltaic cells are made of several types of semiconductors using different manufacturing processes. The incidence of light on the cell generates charge carriers that originate an electric current if the cell is short circuited.

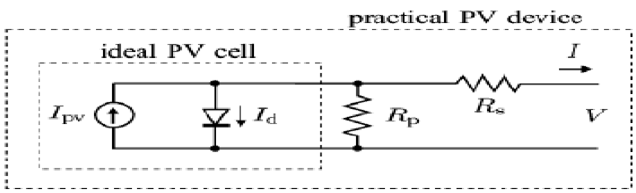

Fig. 1: Equivalent Circuit of a PV Device including the series and parallel Resistances.

The equivalent circuit of PV cell is shown in Fig. 1. In the above diagram the PV cell is represented by a current source in parallel with diode. Rs and Rp represent series and parallel resistance respectively. The output current and voltage from PV cell are represented by I and V

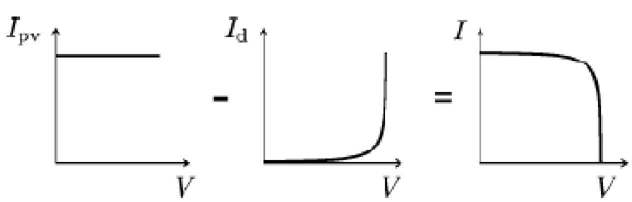

Fig. 2. V-I Characteristic of PV Cell

The I-V Characteristics of PV cell [7] is shown in Fig.2. The net cell current I is composed of the light- generated current Ipv and the diode current Id

$$I = Ipv - Id \qquad (1)$$

Where

$$I_d = I_o \exp(qV/akT)$$

I_o = leakage current of the diode
q= electron charge
k = Boltzmann constant
T= temperature of pn junction
a= diode ideality constant

The basic equation (1) of the PV cell does not represent the *I-V* characteristic of a practical PV array. Practical arrays are composed of several connected PV cells and the observation of the characteristic at the terminals of the PV array requires the inclusion of additional parameters to the basic equation.

$$I = Ipv - \left[\exp\left(V + \frac{R_{sI}}{Vta}\right) - 1\right] - \frac{V + R_{sI}}{R\ \ p} \qquad (2)$$

where

$$Vt = NskT/q$$

is the thermal voltage of the array with N_s cells connected in series. Cells connected in series provide greater output voltages. The I-V characteristic of a practical PV cell with maximum power point (MPP), Short circuit current (I_{sc}) and Open circuit voltage (V_{oc}) is shown in Fig. 3. The MPP represents the point at which maximum power is obtained.

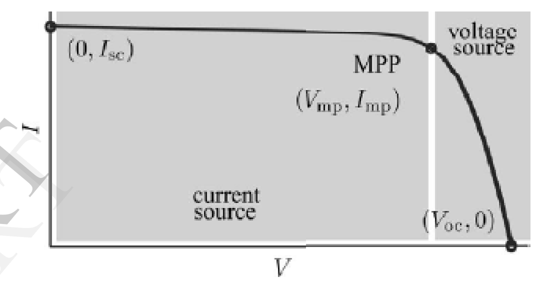

Fig. 3. I-V Characteristic of Practical PV Module

V_{mp} and I_{mp} are voltage and current at MPP respectively. The output from PV cell is not the same throughout the day; it varies with varying temperature and insulation (amount of radiation). Hence with varying temperature and insolation maximum power should be tracked so as to achieve the efficient operation of PV system.

III. OPERATOIN OF A PV SOLAR SYSTEM

Fig.4 shows the typical real power output from a tracking system based system for a cloudy day.

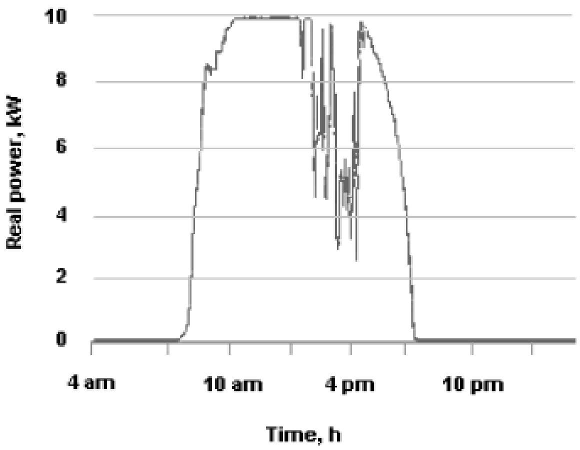

Fig.4 Typical output of a solar system

It is clearly seen that the entire capacity of the inverter is avilable in the night from 6 pm to 6 am to be utilized for reactive power support as STATCOM. During the day in early mornings and late evenings a substantial amount of reactive power capability is still avilable for the PV system to operate as STATCOM.

IV. PV SOLAR SYSTEM CONTROLLER DESIGN

The controller design for a PV solar system to be operated as a STATCOM is presented in this section. The objectives of this control are to improve voltage regulation and power factor. The simulation model for the controller is built using MATLAB software. Fig.5 shows the power circuit of the PV solar farm model together with the components parameters. The PV solar panels are lumped together and presented as a dc source, interfaced with the grid by means of a IGBT based, 6-pulse voltage source inverter(VSI) and inductors L. The interface inductors L together with the filter capacitors C are used to filter out the switching harmonics produced by inverter. A three phase coupling transformer T is used to match the inverter and grid voltages. The dc side capacitor C_{DC} serves two main purposes in steady state it maintains the dc voltage constant and during the transients it serves as an energy storage element to supply real power. The dc source is employed when the solar farm injects active power into the grid. In case when only reactive power is injected into the grid the dc source is disconnected.

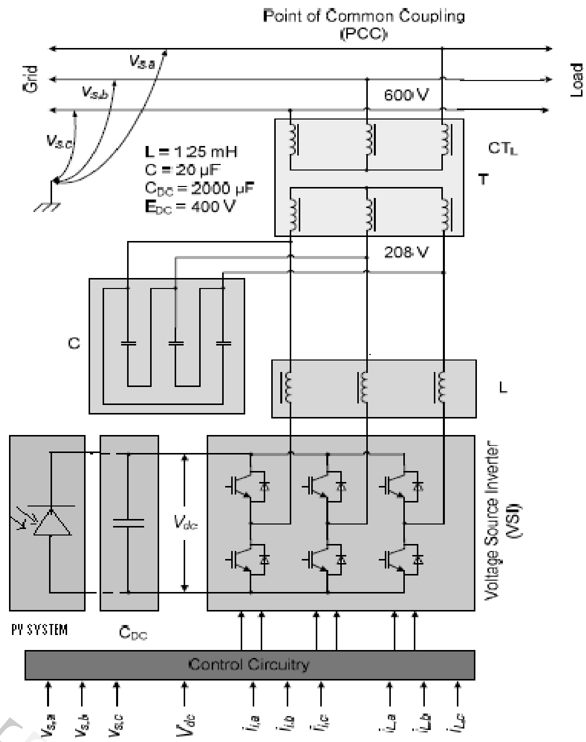

Fig. 5: Power Circuit

The control circuit together with the control parameters is shown in Fig.6.The inverter is controlled in current control mode, using the hysteresis band modulation technique. The current injected by inverter into the grid is split into two separately regulated components active I_a and reactive I_r. A proportional integral (PI) controller is employed for the regulation of I_a and I_r. The parameters of these PI controllers are tuned using the method proposed in [12]. A phase locked loop (PLL) circuit used for synchronizing the injected current with the voltage in the point of common coupling (PCC).

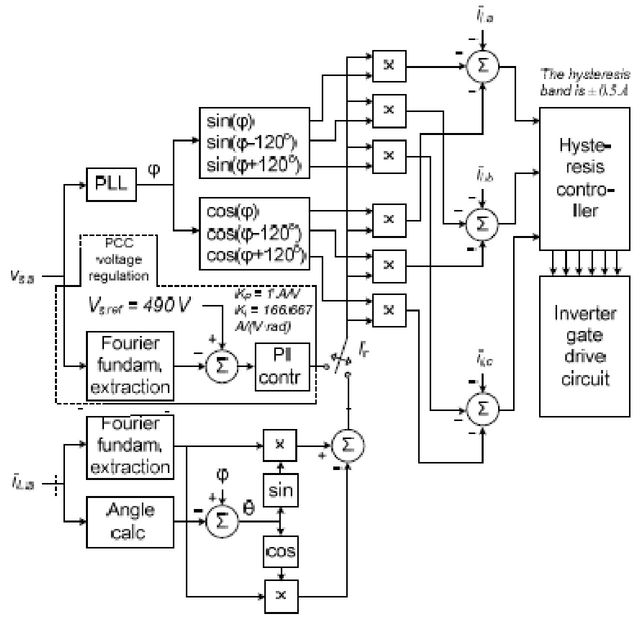

Fig.6 Control circuit

In STATCOM mode of operation, the average voltage across the dc capacitor C_{DC} is maintained constant, at 400 V, by means of the PI controller. Regulating the amount of active current I_a drawn by inverter from the system. This active current component compensates for losses associated with the STATCOM operation. In case when the solar system injects active power into the grid, the dc voltage V_{DC} is maintained by the dc voltage source and an appropriate pre-calculated active current I_a is imposed. The reactive component Ir of the current injected into the grid is regulated to achieve either voltage regulation at the PCC or power factor correction.

V SIMULATION RESULTS

CASE1: Without STATCOM

In this case the simulation circuit model is shown without the STATCOM. The circuit performance without it is shown here. The circuit breaker used in RL load closes at 0.1s, opens at 0.2s and then closes at 0.3s.

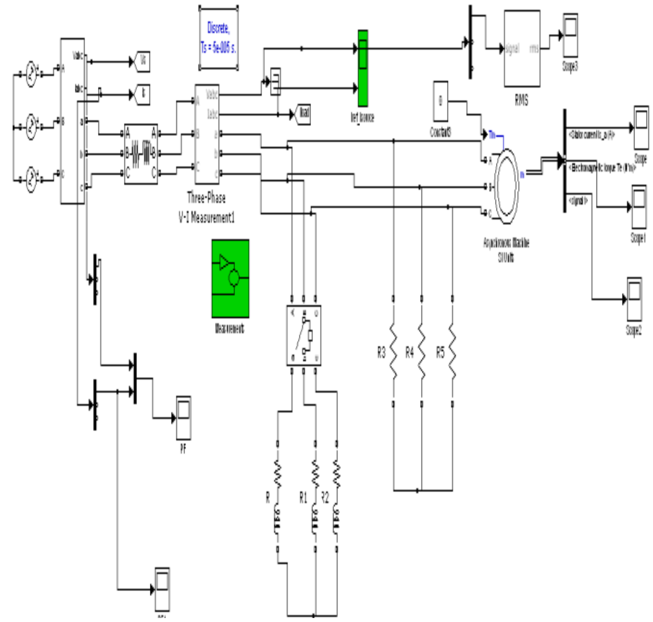

Fig.7 Simulation circuit without STATCOM

Fig.7 shows the simulation circuit model of the power system without the STATCOM

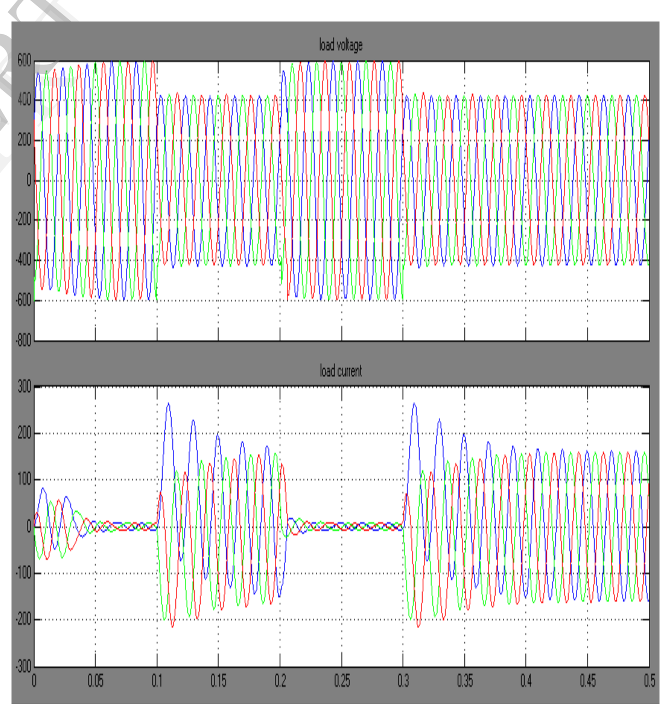

Fig.8 Load voltage and load current

Fig.8 shows the load voltage and load current as per the CB operation. At 0.1s a voltage sag is observed as RL load is switched on. At 0.2s a voltage swell is observed as RL load is switched off. Again at 0.3s sag is observed as RL load is on. Accordingly load current changes.

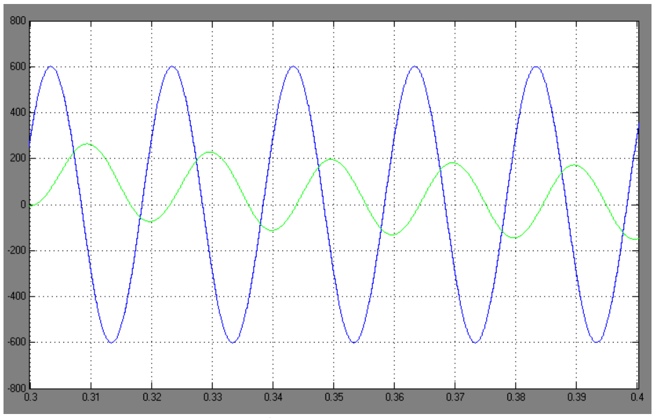

Fig.9 Power factor without STATCOM

Fig.9 shows the voltage and current waveforms are not in phase.

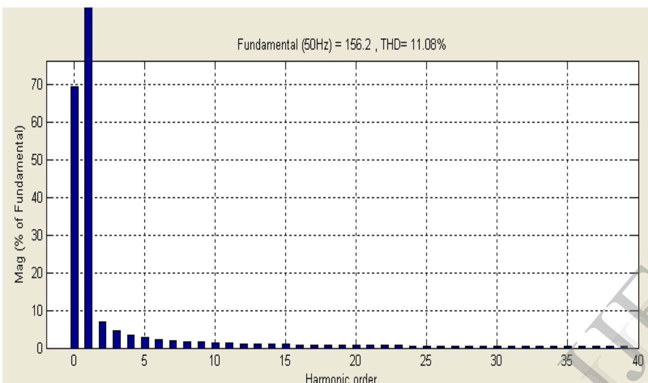

Fig.10 Spectrum analysis of the source current

Fig.10 shows the spectrum analysis of the load current without the STATCOM. The THD is 11.08%.

Case 2: STATCOM with PI controller

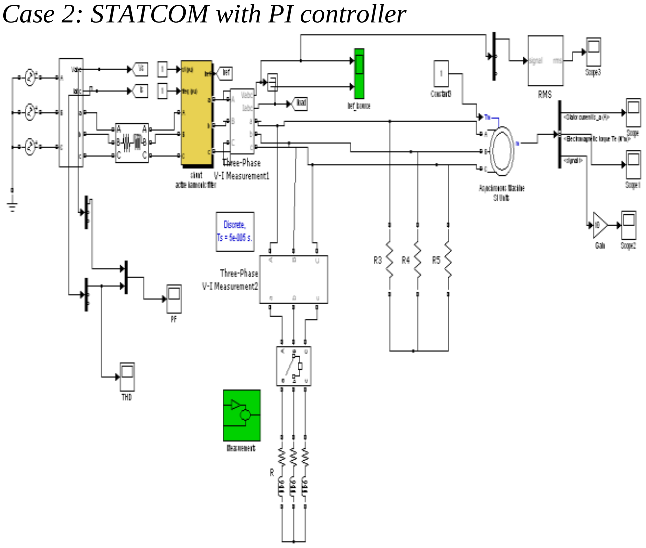

Fig.11 Simulink model with STATCOM

Fig.11 shows the simulink model of the power system with STATCOM

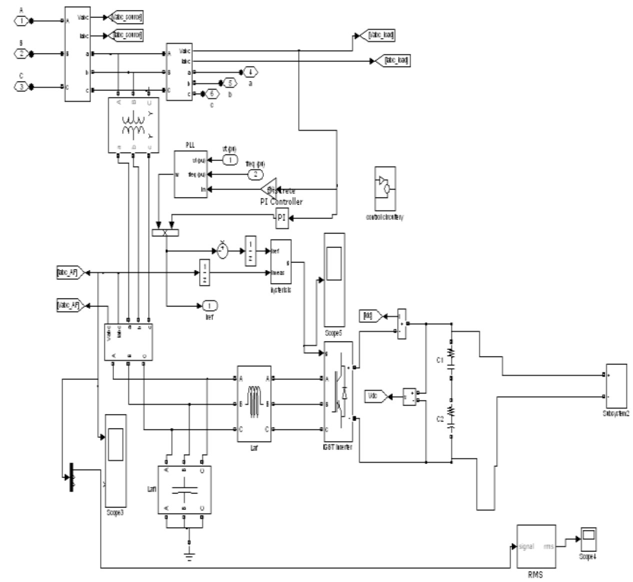

Fig.12 Simulink model of the Control circuit

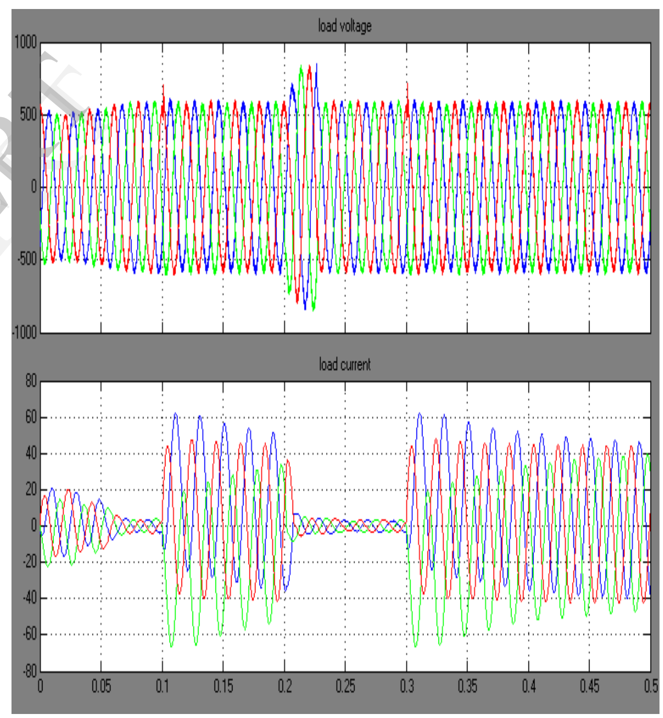

Fig.13 Load Voltage and Load current

Fig.13 shows the load voltage and load current. When the system is disturbed at 0 to 0.1 and 0.2 to 0.3, the load voltage is remains constant.

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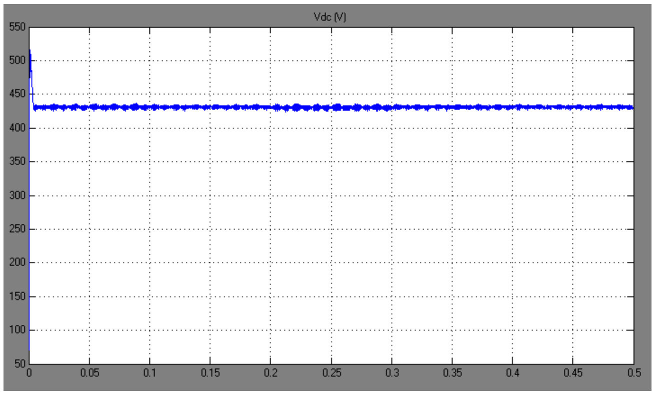

Fig.14 Capacitor voltage

Fig.14 shows the voltage across the capacitor, at the initial stage the capacitor voltage is varied, it takes some time to settle.

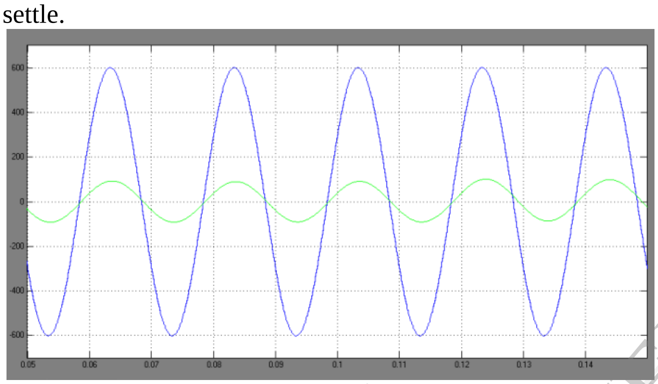
Fig.15 Power factor

Fig.15 shows the power factor of the system with the STATCOM using PI controller.

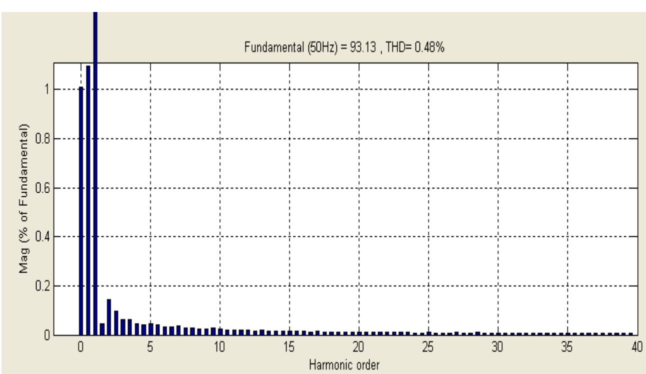

Fig.16 Spectrum analysis of the source current with STATCOM

Fig.16 shows the spectrum analysis of the power system with PI controlled STATCOM. The THD value is 0.48%

Case 3: STATCOM with PID controller.

In this case the PI controller is replaced with a PID controller and the system performance is observed.

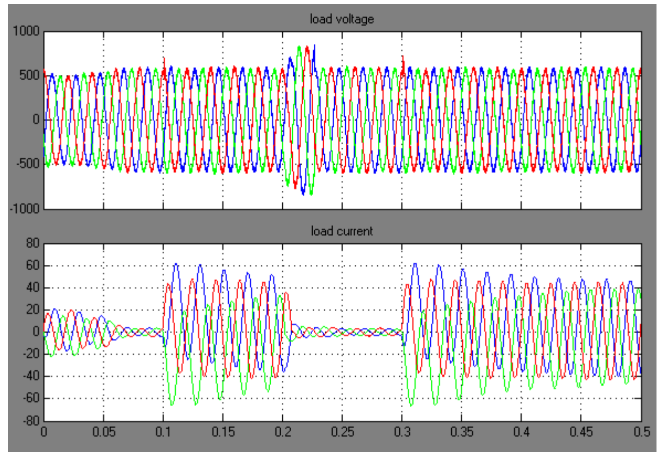

Fig.17 Load voltage and load current

Fig.17 shows the load voltage and Load current of the power system with the STATCOM using PID controller. At the instant 0 to 0.1 and 0.2 to 0.3 seconds when the disturbances have occurred the load voltage is remains constant.

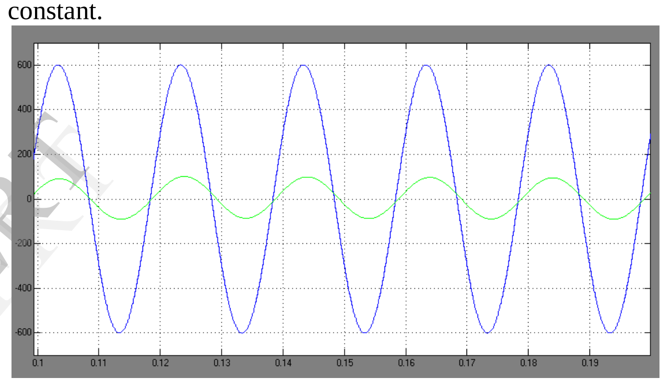
Fig.18 Power factor

Fig.18 shows the improved power factor (source voltage and current are in phase) of the system with STATCOM using PID controller. It is better than with PI controller.

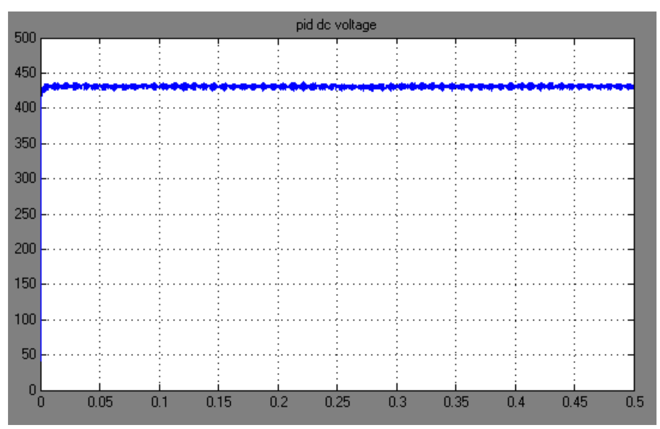

Fig.19. Capacitor voltage

Fig.19 shows the capacitor voltage which remains constant and it is better than with PI controller.

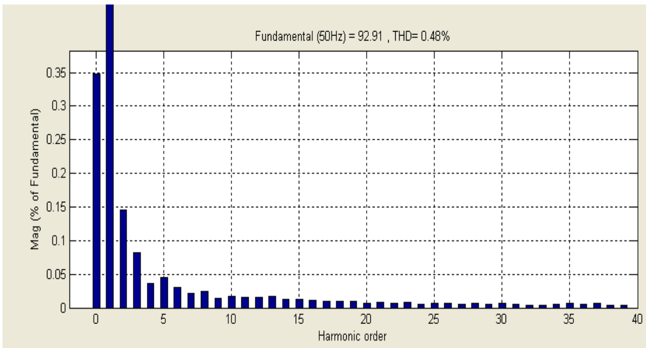

Fig.20 Spectrum analysis of the source current

Fig.20 shows the spectrum analysis of the source current of the power system with PID controller. The THD value is 0.48%

VI CONCLUSION

A normal solar plant remains idle when sunlight is not good. Voltage source inverter is a key component of both solar plant and STATCOM. Hence solar plant is used as STATCOM during dark periods to improve voltage regulation and power factor. Due to improvement in power factor load current reduces. Also the system remains balanced with better efficiency and less transmission losses. Simulated distribution system's results validate these points. Hence the power quality of the distribution system is improved.

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