Improvement of Power Quality Using D-Statcom Based PV Distribution System with Various Load Conditions

T. Naveen
ASSISTANT PROFESSOR
Department Of Electrical & Electronics Engineering,
vignana bharathi institute of technology College,
Ghatkesar,Rangareddy (Dt); A.P, India

Abstract- **Photovoltaic systems have been increasingly used in the generation of electrical energy because of the cost of energy produced from fossil fuels is rising day to-day and there by photovoltaic energy becomes a promising alternative source for fossil fuels. The most important operational requirement in power network at both transmission and distribution levels. Whenever there is a penetration of photovoltaic cell power to the low voltage distributed grid. Power quality is the major problem that occurs between grid to end user transmission lines. In this paper one of the FACTS controller devices D-ST A TCOM is used to improve the voltage regulation thereby the power system stability. DSTATCOM is the one of the power quality compensating device which will rectifies the power quality problems such as voltage sag and swell which occurs in high voltage power transmission lines. The use of distributed energy resources is increasingly being pursued as a supplement and an alternative to large conventional central power stations. Distribution Static Compensator (DSTATCOM) is proposed for compensation of reactive power and unbalance caused by various loads in distribution system.**

Key words- **D-STATCOM, FACTS Controller, Photovoltaic Systems, Voltage Regulation.**

I. INTRODUCTION

In the recent years a number of changes have been observed in electrical power networks which aim at the increasing share of distributed energy sources (DESs) in total energy production. Main factors influencing the common application of DESs are costs and efficiency. Although investment costs are still high, energy produced from DESs may be cheaper than the one from conventional energy sources. Different types of DG technologies are in use today. They can be grouped dependently on the fuel applied: micro turbines, fuel cells or reciprocating engines are based on gas, photovoltaic's, wind or hydro sources use renewable energy. Optimization of DG sources efficiency requires interconnection to the electrical power network, converting energy available at the moment and transmitting it into the grid. It can be presumed that the integration of considerable number of DERs into the grid may cause difficulties with maintaining the required power quality (PQ). DERs may generate disturbances such as voltage variations, asymmetry or harmonics. The problems may be heightened by disturbing loads if they are installed in the grid. The total apparent (complex) power that is injected into a transmission line is made up of two components, namely active and reactive. The active power P component is the part of energy that is converted into physical energy form.

Micro-grids are the centralized alternative to distributed one to supply electrical energy to homes in isolated communities. The main advantages are relative lesser maintenance cost and best exploration of the installed power. Photovoltaic solar panels are becoming accepted as an important mean of power generation. And, the production rate will reach tens of giga watts in the next 40-50 years. Within the category of renewable energies and compared to wind conversion, this Photovoltaic (PV) conversion approach is silent, modular, easily transportable and quickly installed. Photovoltaic systems (cell, module, and network) require minimal maintenance.

At the end of the life cycle, photovoltaic modules can almost be completely recycled. Photovoltaic modules bring electricity to rural areas where there is no electric power grid, and thus increase the life value of these areas. Photovoltaic systems will continue the future development in a direction to become a key factor in the production of electricity for households and buildings in general. Actually, terrestrial applications of photovoltaic panels provide auxiliary means of power generation. Although its penetration is limited because of its high capital cost and low efficiency, ongoing research is continuously lowering these barriers and the use of PV electrical sources is increasing. Research on distributed electrical resources connected to the grid is the major issue for installing mega Watts of PV farms and for increasing its use. Continuously monitoring these installations is a very important matter because it gives feedback information on how to improve the connectivity performance, how to increase the production and how to optimize control strategies.

II. POWER INJECTION PRINCIPLE

The active power P component is the part of energy that is converted into physical energy form. The reactive power Q component helps create the indispensable magnetic medium needed for most of today's electromagnetic energy conversion devices and systems. For example, the AC electric motor absorbs both active and reactive power components once it is energized by the AC source. The absorbed reactive component creates the needed magnetic field to allow the energy conversion process to take place inside the motor. The active power component is absorbed and converted into mechanical power that moves the coupled mechanical load such as a mechanical conveyor.

The active power component is absorbed and converted into mechanical power that moves the coupled mechanical load such as a mechanical conveyor. The electric motor will store the reactive power as fluctuating magnetic energy in its windings as long as the conversion process continues. The majority of industrial and commercial appliances require both active and reactive power components for operation. Both P and Q are needed instantly and in different quantities to meet the requirement of the electrical energy converting device connected to the AC source. To understand P and Q flow in a transmission system, consider a simple system that is made up of sending and receiving buses with a transmission cable in between as shown in Fig 1.

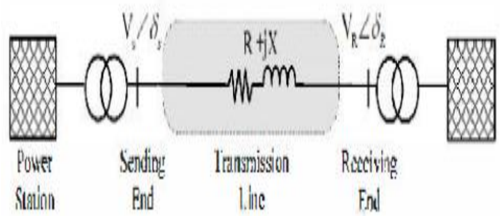

Fig1: Simple line presentation of generating distribution network

Thus for small line resistances, R< <X, the active and reactive power components can be approximated to

$$Ps = \frac{VsVr}{X} Sin(\delta s - \delta R) \tag{1}$$

$$Qs = \frac{Vs^2 - VsVr\cos(\delta s - \delta R)}{X} \tag{2}$$

It can be seen from the above approximated power components that power flow is dependent on four controlling variables VS, VR, X and δs-δR. Employing shunt compensation at midpoint in the transmission line increases both the active and reactive components of the injected power. For lossless compensator and transmission lines VS= VR= V, the injected power at midpoint is now given by

$$Psh = \frac{2V^2}{X}\left(\frac{Sin(\delta s - \delta R)}{2}\right) \tag{3}$$

$$Qsh = \frac{4V^2}{X}\left(1 - \frac{\cos(\delta s - \delta R)}{2}\right) \tag{4}$$

Meanwhile, employing series compensation at midpoint with voltage VC in quadrature with respect to the line current allows the compensating elements to assist only in the reactive power control. The result in the injected power is given by

$$Pser = \frac{V^2}{(1-r)X} \sin(\delta s - \delta R) \tag{5}$$

$$Qser = \frac{2V^2}{X} \frac{r}{(1-r)^2} \sin(\delta s - \delta R) \tag{6}$$

Where r is the degree of series compensation (0 ≤ r ≤ 1).

III. OPERATION OF D-STATCOM

D-ST ATCOM controllers can be constructed based on both VSI topology and Current Source Inverter (CSI) topology (Fig 2).

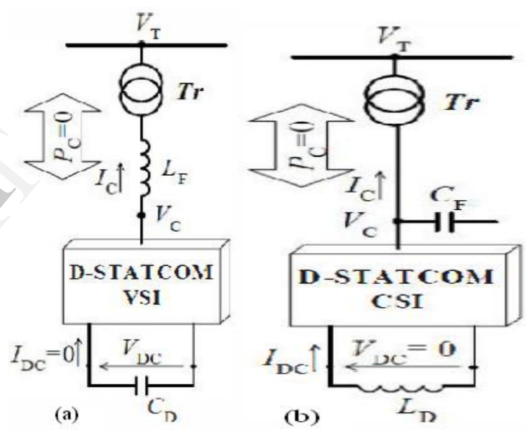

Fig 2: General topology of VSI-based and CSI-based DSTATCOM

Regardless of topology, a controller is a compound of an array of semiconductor devices with turn off capability (i.e., IGBT, GTO, IGCT etc.) connected to the feeder via a relative small reactive filter. The VSI converter is connected to the feeder via reactor LF and has a voltage source (capacitor CD) on the DC side. The CSI converter is connected on the AC side via capacitor CF and has a current source (inductor LD) on the DC side. In practice, CSI topology is not used for DST A TCOM. The reason for this is related to the higher losses on the DC reactor of CSI compared to the DC capacitor of VSI. Moreover, a CSI converter requires reverse-blocking, moreover; a CSI converter requires reverse-blocking semiconductor switches, which have higher losses than reverse conducting switches of VSI. And, finally, the VSI-based topology has the advantage because an inductance of a coupling transformer (Tr) (if present) can constitute, partially or completely, the inductance of an AC filter. The following text will describe the properties of VSI-topology based DSTATCOM only, but in many respects they are the same as for CSI-based controllers. The VSI converters for D-STATCOM are constructed based on multi-level topologies, with or without use of a transformer. These solutions provide support for operation with a high level of terminal voltage. Additionally, DSTATCOM controllers can be a compound of several converters conFigd to various topologies, to achieve higher rated power or lower PWM-related current ripples. The exemplary topologies are presented in Fig 3. In the parallel configuration (Fig 3a) converters are controlled to share the generated power equally, or at a given ratio, for example proportional to the rated power of the particular converter.

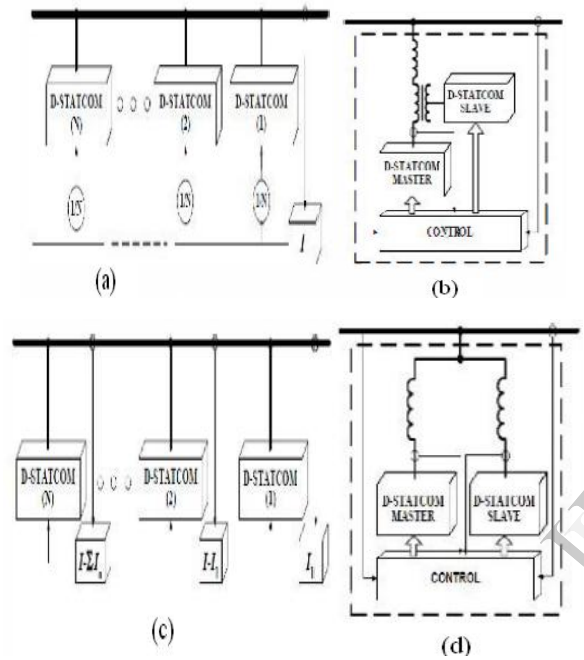

Fig 3: Multi converter topologies of D-ST ATCOM controller: (a)parallel; (b) cascade; (c) master - slave series; (d) master - slave parallel

In this solution it is necessary to provide interconverter communication at the control level to distribute information about set controller power or currents. The cascade multi converter topology (Fig 3b) is similar to the parallel configuration, but in this case the constituent converters do not share power equally, but successively, depending on the requirement. In this case, no communication between constituent converters is required, but on the other hand it is also not possible to use common PWM strategy. The converters in this case are exactly the same as for standalone operation.

In Fig 3c, d are presented series and parallel master-slave topologies, respectively. The master-slave topologies require a high degree of integration between constituent converts including a control system, and are treated and realized as single, multi converter controller. The master converter (called a "slow converter") has substantially higher rated power and, in consequence, considerably lowers PWM carrier frequency than the slave converter (called a "fast converter"). The task of the master converter is to cover the requirements for power, while the slave has to compensate AC current/voltage ripples using series superposition of voltages (Fig 3 c) or parallel superposition of currents (Fig 3 d).

A. *Principle of Operation*

For the operation analysis of the D-STATCOM converter, it is possible to represent its PWM-controlled VSI with an instantaneous (averaged for PWM period) voltage source. The principle of generating instantaneous active and reactive powers by D-STATCOM is shown in Fig 4. In this Fig, voltages and currents are represented with instantaneous space vectors obtained using a power-invariant Clarke transform. Three cases are presented in Fig 4: the general one, for reactive power equal to zero and for active power equal to zero.

From this Fig it is clear that, by generating an appropriate AC voltage, it is possible to generate arbitrary instantaneous vectors of both active and reactive power. The real component of current is related to the equivalent series resistance modeling losses on the AC side. The possible active and reactive powers that can be generated or absorbed by DSTATCOM are limited. This limitation is related to circuit parameters and maximum ratings of VSI components. In Fig 4 is presented an exemplary limit for AC voltage, which depends on VSI DC voltage VDC.

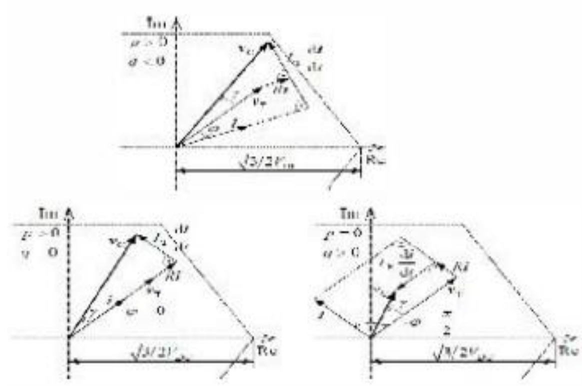

Fig 4: Principle of control of D-STATCOM instantaneous active and reactive power

This limit, together with filter inductance LF and terminal voltage VT, defines the operating region of a D-ST ATCOM controller. The operating region of a two level VSI-based controller is presented in Fig 5. In this Fig, Y denotes the modulus of admittance on the AC side of VSI. In practice, the operating region does not limit the maximum ratings of VSI semiconductors, so the static V-I characteristic of DSTATCOM reactive power is symmetrical (Fig 6).

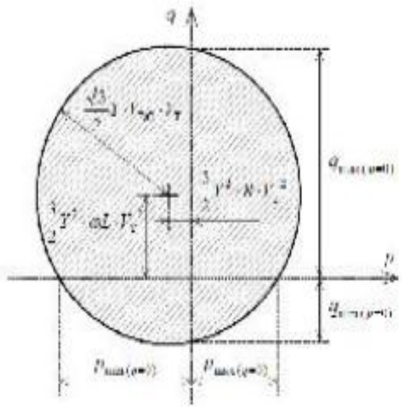

Fig.5.Operating Region of a two level VSI-based STATCOM

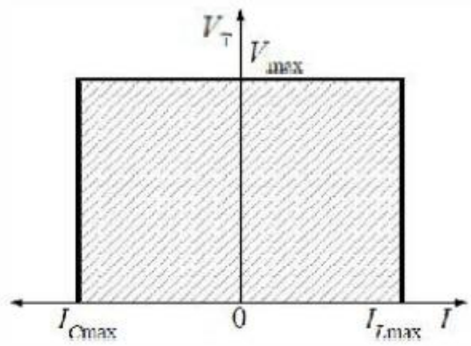

Fig 6: The V-I Characteristic of D-STATCOM

The active power is consumed by the D-ST A TCOM only to cover internal losses. Assuming lossless operation, the averaged (but not instantaneous) active power has to be zero. There are no similar limitations for reactive power, because it is only exchanged between phases, and is not converted between the AC and DC sides of D-STATCOM VSI.

IV. GRID CONNECTED PHOTOVOLTAIC SYSTEM

The photovoltaic (PV) power generation systems are renewable energy sources that expected to play a promising role in fulfilling the future electricity requirements. The PV systems principally classified into stand-alone, grid connected or hybrid systems. The grid-connected PV systems generally shape the grid current to follow a predetermined sinusoidal reference using hysteresis-band current controller, which has the advantages of inherent peak current limiting and fast dynamic performance. Fig.7 shows the schematic diagram of a grid connected PV system. It typically consists of two main parts: the PV array and the power conditioning unit (PCU). The PCU typically includes:

- A Maximum Power Tracking (MPPT) circuit, which allows the maximum output power of the PV array.
- A Power Factor (PF) control unit, which tracks the phase of the utility voltage and provides to the inverter a current reference synchronized with the utility voltage.
- A converter, which can consist of a DC/DC converter to increase the voltage, a DC/AC inverter stage, an isolation transformer to ensure that the DC is not injected into the network, an output filter to restrict the harmonic currents into the network.

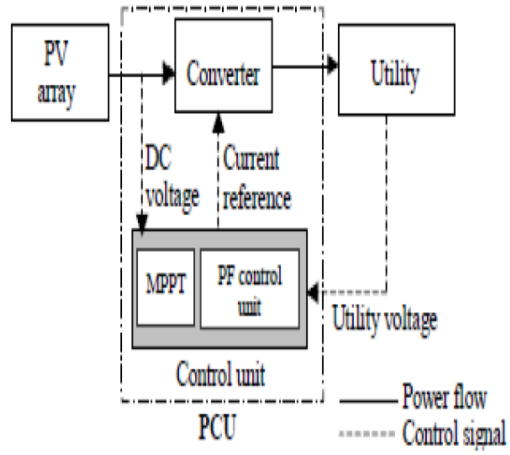

Fig 7: Schematic Diagram of Grid-Connected PV System

The model of grid connected photovoltaic system to control active and reactive power injected in the grid is presented. The proposed multilevel power converter uses two single-phase voltage source inverters and a four wire voltage source inverter. The structural design of this new power converter allows a seven level shaped output voltage wave at the output of multilevel inverter. The MPPT algorithm, the synchronization of the inverter and the connection to the grid are discussed.

A. *Photovoltaic Array Modeling*

Numerous PV cells are connected in series and parallel circuits on a panel for obtaining high power, which is a PV module. A PV array is defined as group of several modules electrically connected in series-parallel combinations to generate the required current and voltage. The building block of PV arrays is the solar cell, which is basically a p-n semiconductor junction that directly converts solar radiation into dc current using photovoltaic effect. The simplest equivalent circuit of a solar cell is a current source in parallel with a diode, shown in Fig. 8

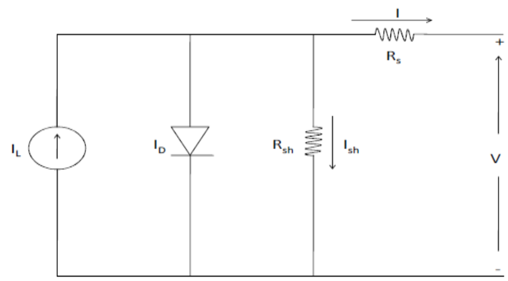

Fig 8: Circuit Diagram of a Solar Cell

The series resistance RS represents the internal losses due to the current flow. Shunt resistance Rsh, in parallel with diode, this corresponds to the leakage current to the ground. The single exponential equation which models a PV cell is extracted from the physics of the PN junction and is widely agreed as echoing the behavior of the PV cell. The grid integration of RES applications based on photovoltaic systems is becoming today the most important application of PV systems, gaining interest over traditional stand-alone systems. This trend is being increased because of the many benefits of using RES in distributed (aka dispersed, embedded or decentralized) generation (DG) power systems.

These advantages include the favorable incentives in many countries that impact straightforwardly on the commercial acceptance of grid-connected PV systems. This condition imposes the necessity of having good quality designing tools and a way to accurately predict the dynamic performance of three-phase grid-connected PV systems under different operating conditions in order to make a sound decision on whether or not to incorporate this technology into the electric utility grid. This implies not only to identify the current-voltage (I-V) characteristics of PV modules or arrays but also the dynamic performance of the power conditioning system (PCS) required to convert the energy produced into useful electricity and to provide requirements for power grid interconnection.

V. MATLAB MODELING AND SIMULATION RESULTS

The grid connected PV system as shown in below, power transmission voltage feed to step down transformer for distribution level to the consumer. The Photovoltaic power system has been design and penetrates the PV power to power grid at near consumer distribution. Here simulation is carried out in four cases 1). Proposed Grid Connected PV System with DStatcom. 2). Proposed Grid Connected PV System with DStatcom operated in different load conditions.

Case 1: Proposed Grid Connected PV System with DStatcom

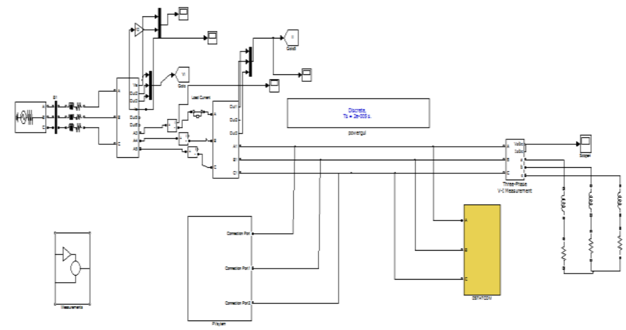

Fig. 9 Matlab/Simulink Model of proposed Grid Connected Pv System with DSTATCOM

Fig.9 shows the Matlab/Simulink Model of proposed Grid Connected Pv System with DSTATCOM.

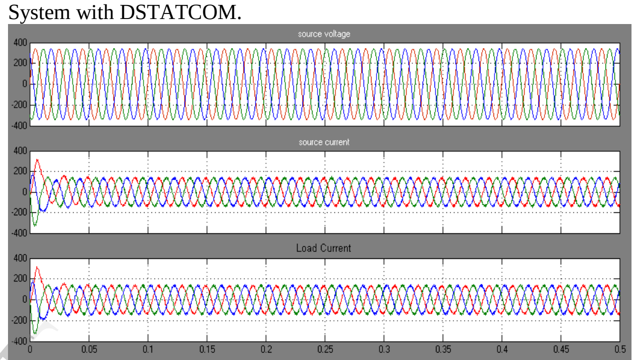

Fig. 10 Source Voltage, Source Current, Load Current with Compensator

Fig.10 shows the Source Voltage, Source Current, Load Current with Compensator, due to linear load our source & Load side parameters are sinusoidal nature.

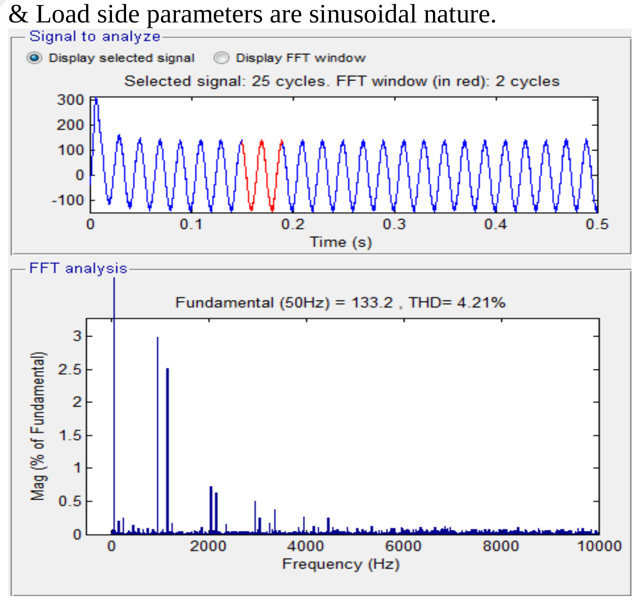

Fig.11 FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM

Fig.11 shows the FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM we get 4.21%.

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Case 2: Proposed Grid Connected PV System with DStatcom operated in different load conditions.

A. Balanced Non-Linear Load Condition

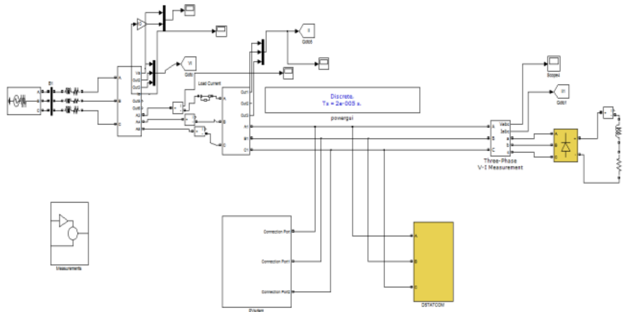

Fig. 12 Matlab/Simulink Model of proposed Grid Connected PV System Based DSTATCOM with Non-Linear load

Fig.12 shows the Matlab/Simulink Model of proposed Grid Connected PV System based DSTATCOM with Non-Linear load.

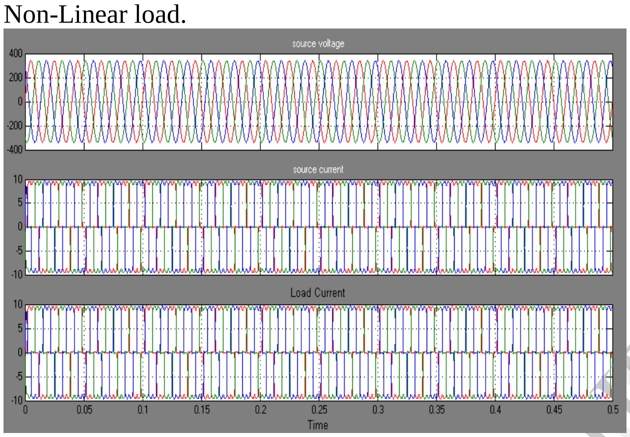

Fig. 13 Source Voltage, Source Current, Load Current without Compensator

Fig.13 shows the Source Voltage, Source Current, Load Current without Compensator, due to non-linear diode rectifier pollutes source side current, without compensator load current is equal to source current.

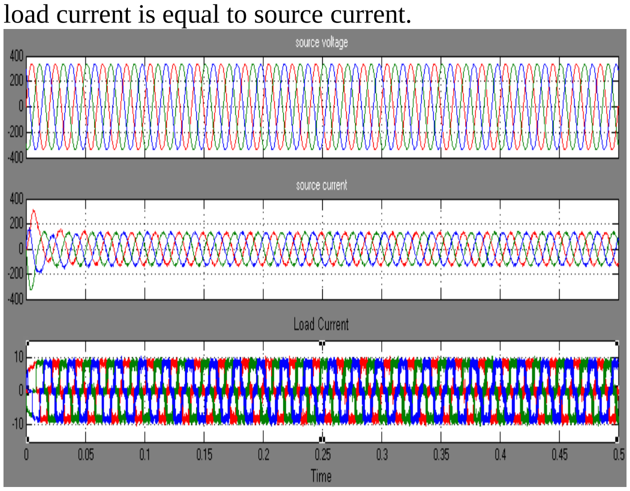

Fig. 14 Source Voltage, Source Current, Load Current with Compensator

Fig.14 shows the Source Voltage, Source Current, Load Current with Compensator, due to non-linear diode rectifier pollutes source side current, with compensator source current is compensated and load current goes to distort.

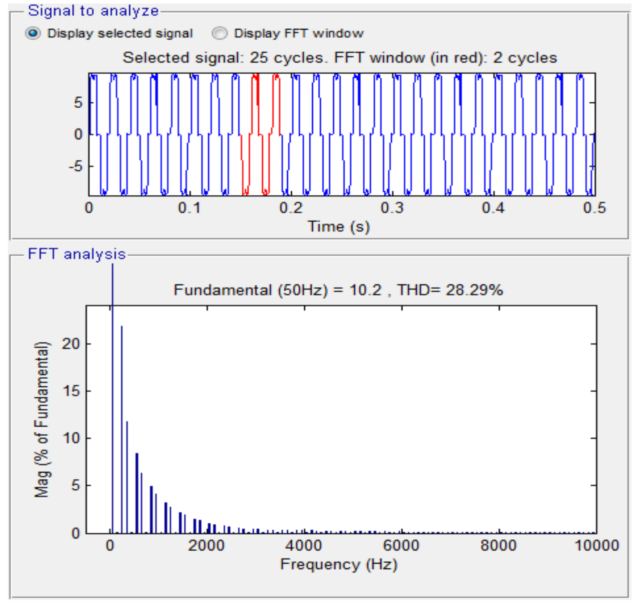

Fig.15 FFT Analysis of Source Current A –Phase with Grid Connected system without DSTATCOM with Non-Linear Load.

Fig.15 shows the FFT Analysis of Source Current A –Phase with Grid Connected system without DSTATCOM with Non-Linear Load we get 28.29%.

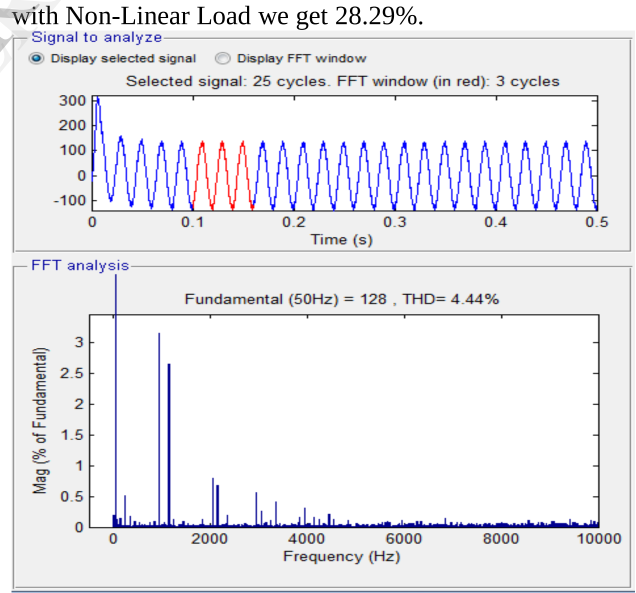

Fig.16 FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM with Non-Linear Load.

Fig.16 shows the FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM with Non-Linear Load we get 4.44%.

B. Un-Balanced Load Condition:

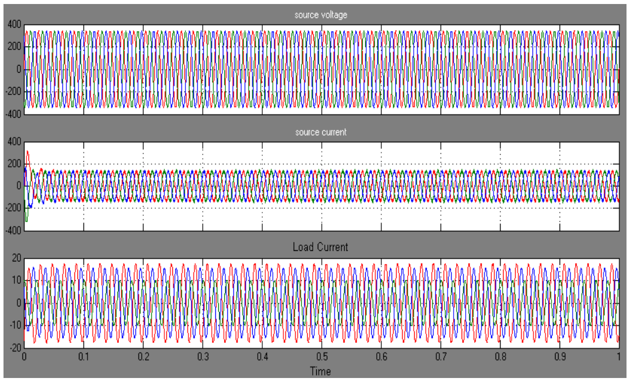

Fig. 17 Source Voltage, Source Current, Load Current with Compensator

Fig.17 shows the Source Voltage, Source Current, Load Current with Compensator, due to unbalanced linear load with compensator source current is compensated and load current goes to unbalances.

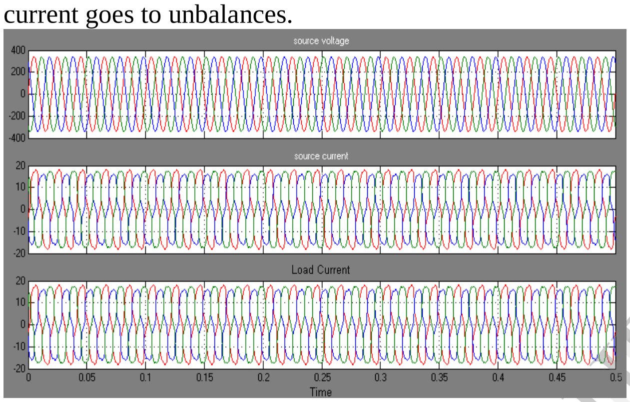

Fig. 18 Source Voltage, Source Current, Load Current without Compensator

Fig.18 shows the Source Voltage, Source Current, Load Current without Compensator, due to Un-balanced non-linear diode rectifier pollutes source side current, without compensator load current is equal to source current.

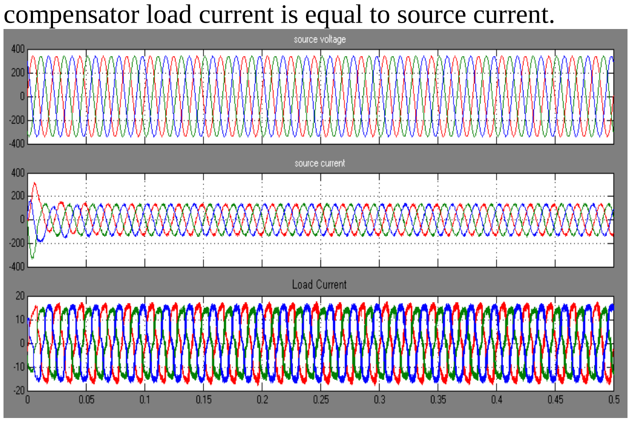

Fig. 19 Source Voltage, Source Current, Load Current with Compensator

Fig.19 shows the Source Voltage, Source Current, Load Current with Compensator, due to Un-Balanced non-linear diode rectifier pollutes source side current, with compensator source current is compensated and load current goes to distort and unbalances.

VI. CONCLUSION

In this paper we have modelled and analysed the Photovoltaic power system being integrated to low voltage distribution power grid near to consumer end by using Distributed Statcom to compensate the harmonics coming from the grid side Inverter and other side we have some loads in that, most of the non-linear loads inject harmonic currents to source side. In this paper we have studied and analysed the operation and performance of D-Statcom at various load conditions such as balanced & unbalanced linear & non-linear loads. This proposed model is implemented using Matlab Simulink software and the obtained resultant waveforms were evaluated and the effectiveness of the system stability and performance of power system have been established.

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