Integration of Photovoltaic Cell Power in Distribution Grid with Enhancement of Power Quality Using Multilevel D-Statcom

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Abstract-In this paper the importance of power quality and Photovoltaic cell – power generation discussed. The conventional energy sources like coal, hydro, nuclear etc., have been producing power at large scale. Power stations are generally away from load centres because of geographical constraints and pollution. Photovoltaic cell power is an emerging power generation technique which can be used to produce power at any location especially load centres i.e. best suitable for Distribution Generation. As PV power is pollution free and solar energy is abundantly available at free of cost, it became an excellent alternative to fossil fuels. Whenever we integrate PV system to the low voltage distributed grid in order to supply PV generated electricity to grid , it causes the problems of mismatch in voltage and frequency with the existing grid, perhaps caused by non linear loads, producing harmonics. The Distribution-STATCOM controls the parameters of the distribution generation system like voltage, power and frequency while compensating harmonics, currents both line and neutral and provides load balancing in the gird currents. The simulation of the proposed system is carried out in the MATLAB environment using Simulink and power system toolboxes.

Key words: D-Statcom, Compensation of Harmonics, Voltage Regulation, PV cell, Distributed Generation, Matlab

I. INTRODUCTION

In present day's power distribution systems is suffering from severe power quality problems. These power quality problems include high reactive power burden, harmonics currents, load unbalance, excessive neutral current etc. Some remedies to these power quality problems are reported in the literature. A group of controllers together called Custom Power Devices (CPD), which include the DSTATCOM (distribution static compensator), The DSTATCOM, is a shunt-connected device, which takes care of the power quality problems in the currents. Three phase four-wire distribution systems are used to supply single-phase low voltage loads such as computer The proposed DSTATCOM is modelled and its performance is simulated and verified for power factor correction and voltage regulation along with neutral current compensation, harmonic elimination and load balancing with linear loads and non-linear loads. When the STATCOM is applied in distribution system is called DSTACOM (Distribution-STACOM) and its configuration is the same, or with small modifications, oriented to a possible future amplification of its possibilities in the distribution network

At low and medium voltage, implementing the function so that we can describe as flicker damping, harmonic filtering and hole and short interruption compensation. Distribution STATCOM (DSTATCOM) exhibits high speed control of reactive power to provide voltage stabilization, flicker suppression, and other types of system control. The DSTATCOM utilizes a design consisting of a GTO- or IGBT-based voltage sourced converter connected to the power system via a multi-stage converter transformer The DSTATCOM protects the utility transmission or distribution system from voltage sags and/or flicker caused by rapidly varying reactive current demand. In utility applications, a DSTATCOM provides leading or lagging reactive power to achieve system stability during transient conditions. The DSTATCOM can also be applied to industrial facilities to compensate for voltage sag and flicker caused by non-linear dynamic loads, enabling such problem loads to co-exist on the same feeder as more sensitive loads. The DSTATCOM instantaneously exchanges reactive power with the distribution system without the use of bulky capacitors or reactors. A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Fig.1, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages.

These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the DSTATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power. The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:

1. Voltage regulation and compensation of reactive power;

2. Correction of power factor; and

3. Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

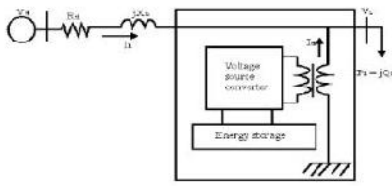


Fig. 1 DSTATCOM

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 2.

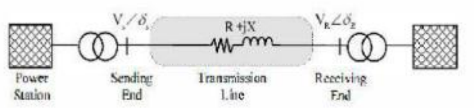


Fig 2: Simple line presentation of generating distribution network

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

$$P_S = \frac{V_S V_r}{X} \sin(\delta_S - \delta_R) \quad (1)$$

$$Q_S = \frac{V_S^2 - V_S V_r \cos(\delta_S - \delta_R)}{X} \quad (2)$$

It can be seen from the above approximated power components that power flow is dependent on four controlling variables VS, VR, X and bs-bR. 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

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

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

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

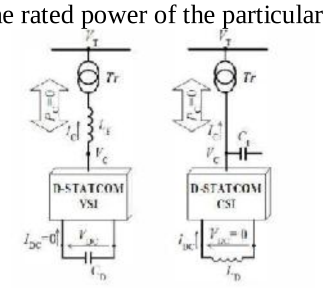
$$Pser = \frac{V^2}{(1-r)X} \sin(\delta s - \delta R) \quad (5)$$

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

where r is the degree of series compensation (O ≤ r≤I).

II OPERATION OF D-STATCOM

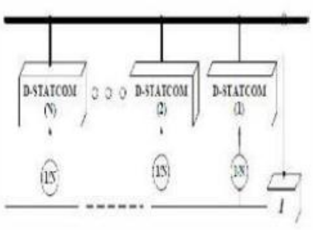
D-STATCOM controllers can be constructed based on both VSI topology and Current Source Inverter (CSI) topology (Fig 3). Regardless of topology, a controller is a compound of an array of semiconductor devices with turn off capability (i.e., IGBT, GTO, IGCT etc.) connected to the feeder via a relative 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 DSTATCOM. 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 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 4. In the parallel configuration (Fig 4a) 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.



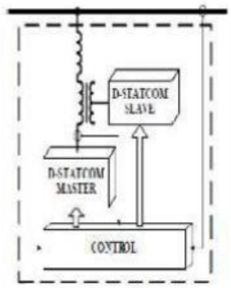
(a) (b)

Fig 3: General topology of VSI-based and CSI-based DSTATCOM

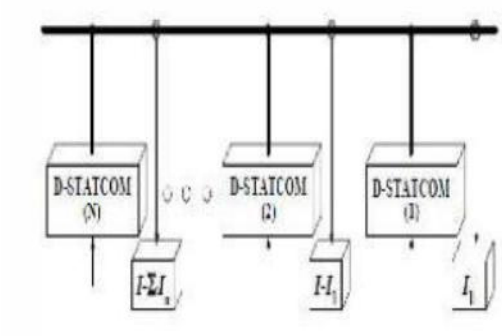
In this solution it is necessary to provide inter converter communication at the control level to distribute information about set controller power or currents. The cascade multi converter topology (Fig 4b) is similar to the parallel configuration, but in this case the constituent converters do not share 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 4c, d are presented series and parallel master-slave typologies, respectively. The master-slave topologies require a high degree of integration between constituent converts including a control system, and are treated and realised 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 seal superposition of voltages (Fig 4 c) or parallel superposition of currents (Fig 4 d).



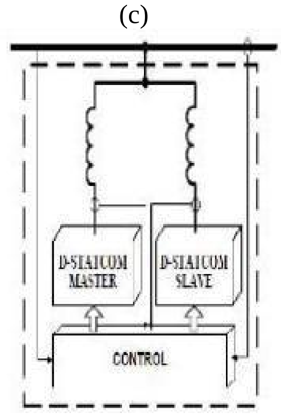
(a)



(b)



(c)



(d)

Fig 4: Multi converter topologies of D-ST ATCOM Controller: a parallel; b cascade; c master - slave series; d master - slave parallel

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 5. 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 5: 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 modelling 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 5 is presented an exemplary limit for AC voltage, which depends on VSI DC voltage VDC

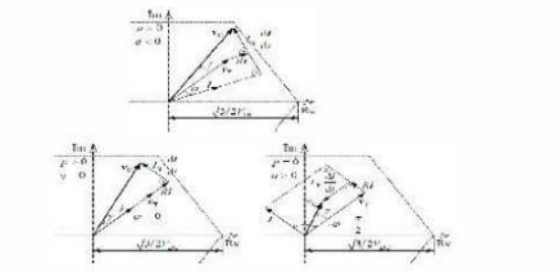


Fig 5: Principle of control of D-STATCOM instantaneous active and reactive power

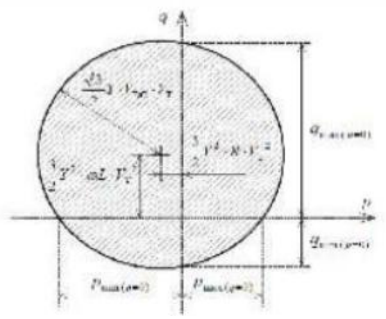


Fig 6: operating region of two-level VSI-based D-STATCOM

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 6. 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 7).

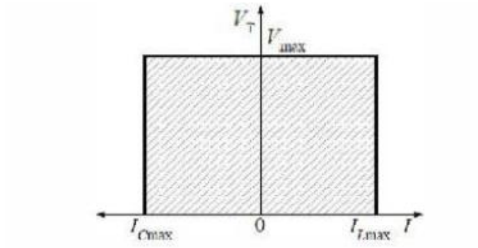


Fig 7: The V-I characteristic of D-STATCOM

The active power is consumed by the D-ST ATCOM 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.

III PHOTOVOLTAIC CELL

The world constraint of fossil fuels reserves and the ever rising environmental pollution have impelled strongly during last decades the development of renewable energy sources (RES). The need of having available sustainable energy systems for replacing gradually conventional ones demands the improvement of structures of energy supply based mostly on clean and renewable resources. At present, photovoltaic (PV) generation is assenting increased importance as a RES application because of distinctive advantages such as simplicity of allocation, high dependability, absence of fuel cost, low maintenance and lack of noise and wear due to the absence of moving parts. Furthermore, the solar energy characterizes a clean, pollution free and inexhaustible energy source. In addition to these factors are the declining cost and prices of solar modules, an increasing efficiency of solar cells, manufacturing-technology improvements and economies of scale. 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 favourable 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. This paper presents a full detailed mathematical model of a three-phase grid-connected photovoltaic energy conversion system, including the PV array and the electronic power Conditioning (PCS) system, based on the Matlab/Simulink software.

Mathematical model for P V cell:

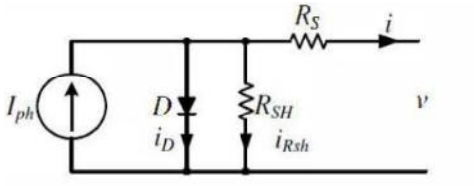


Fig 8: Electrical characteristics of PV Cell model.

A. Open circuit voltage:

$$V = ((NKT)/Q)\ ln\ ((I_L-I_o)/I_o)+1) \quad (6)$$

Where
V is the open circuit voltage
N is diode ideality constant or (nwn
ber of cell connected in series or parallel)
K is the Boltzmann constant (l.381 * lQ1'-23 11K)
T is temperature in Kelvin
Q is electron charge (1.602*1Q1'-19 c)
IL is the light generated current(A)
I_O is the saturation diode current(A)

B.Light generated current:

$$I_L = (G/G_{ref}) * (I_{Lref} + \alpha_{ISC} (T_C - T_{Cref})) \quad (7)$$

Where
G is the radiation (W/m2)
Gref is the radiation under standard condition 1000(W/m2)=ILref is the Photoelectric current under standard condition 0.15(A)T
Cref is the module temperature under standard condition 298(K)
α_{ISC} = ki is the temperature co-efficient of the short circuit current (A/K)=0.0065/K

C. Reverse saturation current:

$$I_0 = I_{or}(T/T_{ref})\text{^}3exp((QE_G)/(K*N)*(1/T_{ref})-(1/T))$$
$$Ior = Iscn / exp (Vocn/ N*Vtn) \quad (8)$$

Where
Vocn = normal open circuit voltage under standard condition(0.5)volt
Iscn = short circuit current under standard condition (0.15)amp
lor is the saturation current
N is the ideality factor 1 to 2;
Eo is the band gap for silicon 1.10ev
Vtn=Thermal voltage= (NKT)/Q) in volts

D. Short circuit current:

Ish = h. It is the greatest value of the current generated by a cell. It is produce by the short circuit conditions: V = O.

$$I_{sh}=I_L-I_0((exp(Q(V-IRs)/(NKT))-1)))$$

E. Irradiation:
G=radiation W/m2
Under standard condition
G =1000W/m2
Temperature = 298 K

IV.FUEL CELL

In 1839, William Grove discovered that by combining Oxygen and hydrogen in a particular configuration, electricity could be generated. Although this discovery was made more than 160 years ago, the basic operating principle discovered still applies. A basic schematic diagram of a fuel cell is shown in Fig.9. Hydrogen is applied to the anode where a catalyst separates the hydrogen into electrons and positive hydrogen ions. A membrane separating the anode and cathode allows the positive hydrogen ions to permeate through while rejecting the electrons. This forces the electrons to take the provided electrical path, or circuit, to the cathode. Once the electrons reach the cathode, they recombine with the oxygen and hydrogen ions to form water. The following basic reactions demonstrate the process:

Anode side: $2H_2 \rightarrow 4H^+ + 4e^-$

Cathode side: $O_2 + 4H^+ + 4e^- \rightarrow 2H_2O$

Net reaction: $2H_2 + O_2 \rightarrow 2H_2O$

When pure hydrogen is used as the fuel, only electricity and water are generated from the fuel cell. This attributes the fuel cell as an environmentally friendly source of energy.

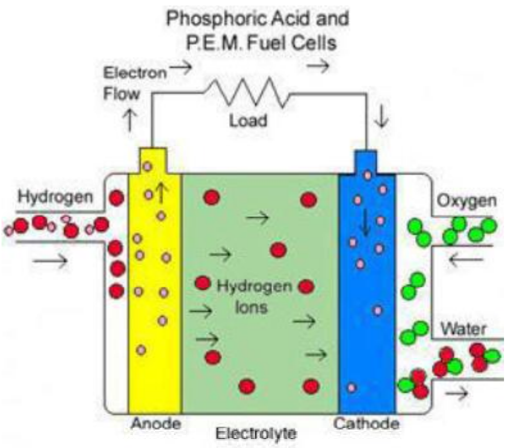


Fig.9. Basic schematic of fuel cell operation

V. MATALB/SIMULINK 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 Multilevel DStatcom.

Case 1: Proposed Grid Connected PV System with DStatcom

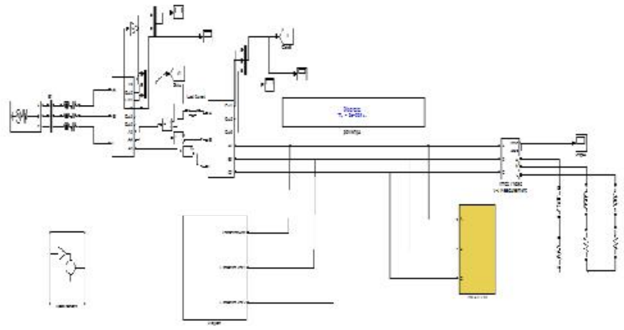


Fig. 10 Matlab/Simulink Model of proposed Grid Connected Pv System with DSTATCOM

Fig.10 shows the Matlab/Simulink Model of proposed Grid Connected Pv System with DSTATCOM.

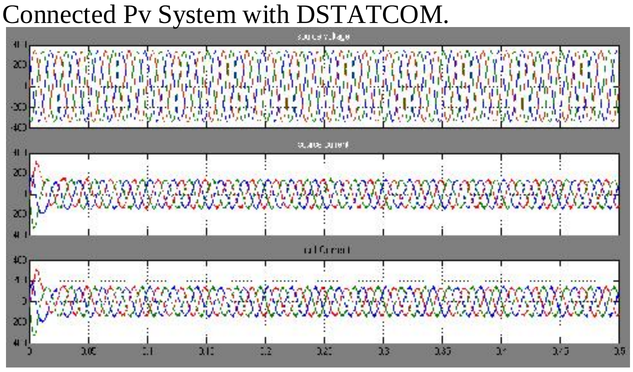


Fig. 11 Source Voltage, Source Current, Load Current with Compensator

Fig.11 shows the Source Voltage, Source Current, Load Current with Compensator, due to linear load our source & Load side parameters are sinusoidal nature.

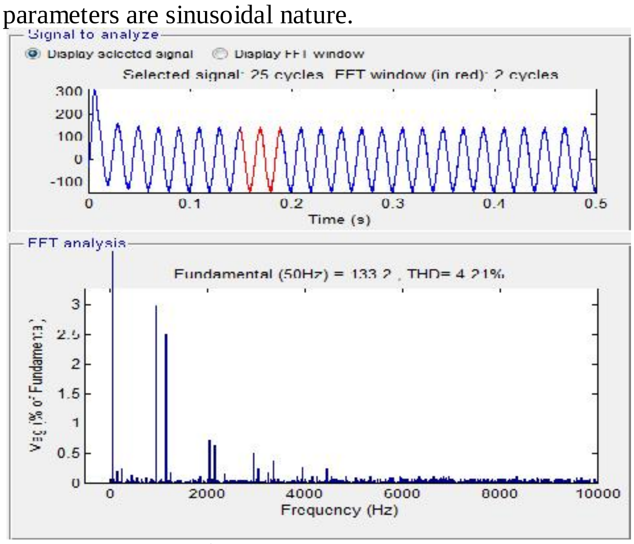


Fig.12 FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM

Fig.12 FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM

Fig.12 shows the FFT Analysis of Source Current A –Phase with Grid Connected system with DSTATCOM we get 4.21%.

Case 2: Proposed Grid Connected PV System with DStatcom

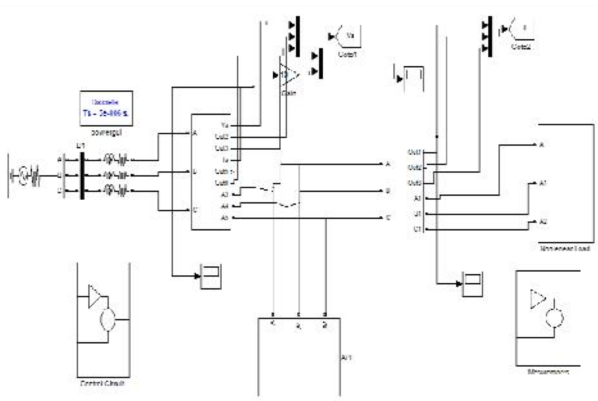


Fig. 13 Matlab/Simulink Model of proposed Grid Connected Pv System with Multilevel DSTATCOM

Fig.13 shows the Matlab/Simulink Model of proposed Grid Connected Pv System with Multilevel DSTATCOM.

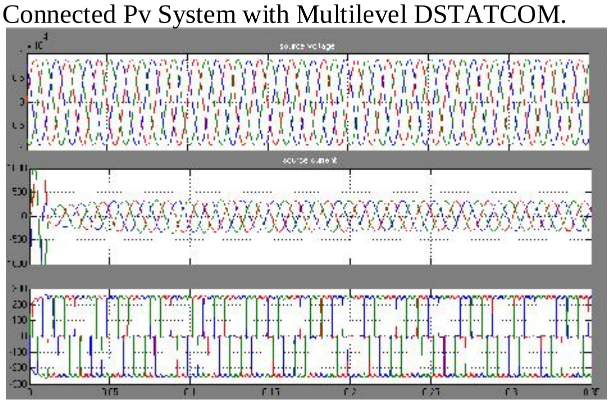


Fig 14 Source voltage, Source current, Load current

Fig. 14 shows the three phase source voltages, three phase source currents and load currents respectively with Cascaded Multilevel Seven level DSTATCOM.

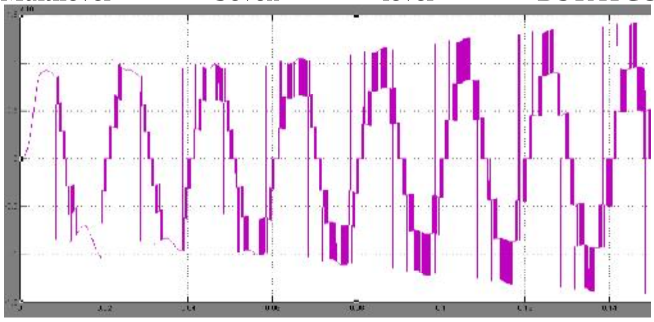


Fig 15 Seven level output Voltage

Fig 15 Shows the Seven level output voltage , when system is connected to cascaded seven level multilevel DSTATCOM.

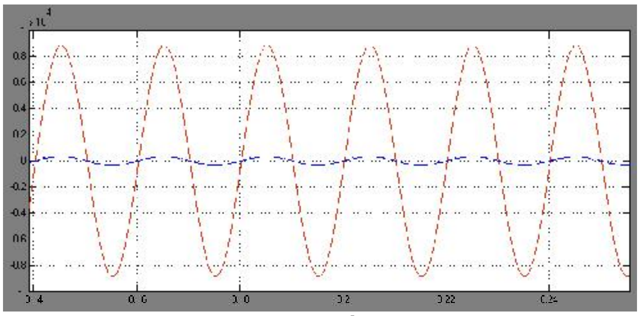


Fig.16 Source Side Power Factor

Fig.16 shows the Source side Power Factor, both voltage & current are maintained sinusoidal and in phase condition.

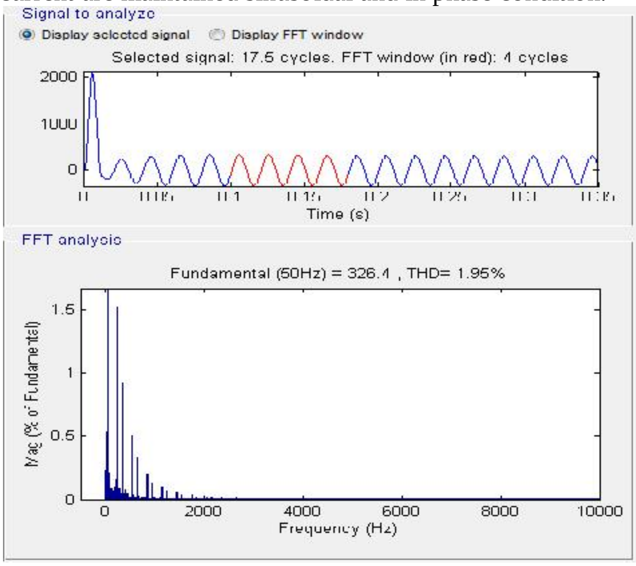


Fig.17 FFT Analysis of source current with compensator using MLI based DSTATCOM

Fig.17 shows the FFT Analysis of source current with compensator using MLI based DSTATCOM Technique, we get THD is 1.95%.

VI.CONCLUSION

DSTATCOM with suitable control technique compensates harmonics and achieves reactive power compensation, it makes source currents sinusoidal and power factor near to unity is also possible. in this work a seven level cascaded multilevel voltage sourced inverter based D-STATCOM using proposed control technique is found to be an effective solution for power line conditioning. This approach uses minimal calculations compared to conventional. It provides a dynamic performance under transient and steady state conditions. The control signals for Inverter are generated based on line power quality requirement. In this work we have analysed and modelled the PV Power system and fuel cell being integrated to low voltage distribution grid near to load centre. D-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, it compensates harmonics such that power quality is maintained as per standards.

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