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Improvement of Power Quality by Multilevel Cascaded Inverter type D-STATCOM

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ABSTRACT

To provide high power quality at power distribution systems, elimination of the power quality problems is indispensably necessary. Different methods are proposed in literature for solving the power quality problems. One of these methods, the Active Power Filters (APFs) technique has been studied and developed in the recent years to solve the power quality problems. This project proposes multilevel inverter type DSTATCOM for mitigating voltage sags at the load side. Cascaded H-bridge configuration for multilevel inverter with phase shifted pulse width modulation technique is presented. First addresses with the three phase, five-level cascaded inverter, second addresses with the seven-level cascaded based on the shunt active power filter for mitigating the voltage disturbances. The proposed multilevel topology is simulated using Matlab. The simulations results of the Five-level and Seven-level cascaded multilevel inverter DSTATCOM are presented with respect to their dc storage required in inverter.

KEYWORDS:

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I. Introduction

Traditionally, a multi pulse like 6-pulse or 12-pulse inverter consisting of several voltage- source inverters connected together through zigzag arrangement of transformers is used for both harmonic and reactive power (VAR) compensations. These transformers: 1) are the most expensive equipment in the system; 2) produce about 50% of the total losses of the system; 3) occupy a large area of real estate, about 40% of the total system; 4) cause difficulties in control due to dc magnetizing and surge over voltage problems resulting from saturation of the transformers; and 5) are unreliable. Correspondingly, Pulse Width Modulated (PWM) inverters (with 10 kHz of high switching frequency) have been used for both harmonic compensation and static VAR compensation. However, the high initial and running costs have been hindering their practical use in power distribution systems.

A cascade multilevel inverter has been proposed for both harmonics and static VAR compensation applications. The new cascade inverter eliminates the bulky transformers required by Static VAR Compensators (SVC's) that employ the multi pulse inverter and can respond much faster. This inverter generates almost sinusoidal staircase voltage with only one time switching per line cycle. Its superior suitability has been demonstrated for VAR compensation. When the cascade inverter is applied to line conditioning and active power filtering of a distribution system, it is expected that the initial and running costs and the EMI will be dramatically reduced below that of the traditional PWM inverter. The new-cascaded multilevel inverter, however, poses challenging problems for both harmonic filtering and reactive power (VAR) compensation, such as voltage control and balance of each dc capacitor.

One of the most common power quality problems today is voltage dips. A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage dip magnitude is ranged from 10% to 90% of nominal voltage (which corresponds to 90% to 10% remaining voltage) and with duration from half a cycle to 1 min. In a three-phase system a voltage dip is by nature a three-phase phenomenon, which affects both the phase-to- ground and phase-to-phase voltages. A voltage dip is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing. Typical faults are single-phase or multiple-phase short circuits, which leads to high currents. The high current results in a voltage drop over the network impedance. At the fault location the voltage in the faulted phases drops close to zero, whereas in the non-faulted phases it remains more or less unchanged.

Voltage sags are one of the most dominating power quality assets, which dragged the attention of many researchers as the sensitivity of loads are increasing due extensive usage of power electronic devices. Fault at distribution level, sudden increase of loads, motor starting are some of the causes of the voltage sags. Such sudden variations of voltage are undesirable for sensitive loads. These undesirable voltage sags can be mitigated by connecting controlled devices either in series or shunt to the load. A few of such devices are dynamic voltage restorer (DVR) and DSTATCOM (Distribution Static Compensator). Both these devices require voltage source converters to satisfactory operation. Many topologies have been proposed in recent past for voltage source converters.

Multilevel inverter has drawn attention of many researchers. There are three topologies of multilevel inverters-cascaded, flying capacitor and diode clamped, each having its own advantages in various applications. Cascaded H-Bridge multilevel inverter is one of the popular converter topologies used in high-power-medium-voltage (MV) drives. H-Bridge cascaded inverter [1] is one of the popularly used converter topology. The cascaded inverter type dynamic voltage restorer with neural control strategy is proposed [2] The H-Bridge cells are normally connected in cascade on their ac side to achieve medium-voltage operation and low harmonics distortion. The CHB inverter using 5 multilevel topology offers the following advantages.

- ✓ Its structure will be simple and requires fewer components
- ✓ Simplicity of structure so the packaging layout is much easier.

To reaches high voltage and reduce harmonics by their own structure. Generates multistep staircase voltage waveform similar to pure sinusoidal output voltage by increasing the number of levels.

A new PWM-based control scheme has been implemented to control the electronic values in the two-level VSC used in the D-STATCOM [3-4] various control strategies have been proposed for voltage source PWM converters mainly [5-10] The Multilevel inverters require advanced PWM strategies like level shift, phase-shift or phase deposition. Among these PWM strategies phase-shifted PWM is described in this project.

In the early days of power transmission in the late 19th century problems like voltage deviation during load changes and power transfer limitation were observed due to reactive power unbalances. Today these Problems have even higher impact on reliable and secure power supply in the world of Globalization and Privatization of electrical systems and energy transfer. The development in fast and reliable semiconductors devices (GTO and IGBT) allowed new power electronic Configurations to be introduced to the tasks of power Transmission and load flow control. The FACTS devices offer a fast and reliable control over the transmission parameters, i.e. Voltage, line impedance, and phase angle between the sending end voltage and receiving end voltage. On the other hand the custom power is for low voltage distribution, and improving the poor quality and reliability of supply affecting sensitive loads. Custom power devices are very similar to the FACTS. Most widely known custom power devices are DSTATCOM, UPQC, DVR. Among them DSTATCOM is very well known and can provide cost effective solution for the compensation of reactive power and unbalance loading in distribution system.

The performance of the DSTATCOM depends on the control algorithm i.e. the extraction of the current components. For this purpose there are many control schemes which are reported in the literature and some of these are instantaneous reactive power (IRP) theory, instantaneous compensation, instantaneous symmetrical components, synchronous reference frame (SRF) theory, computation based on per phase basis, and scheme based on neural network. Among these control schemes instantaneous reactive power theory and synchronous rotating reference frame are most widely used. This paper focuses on the compensating the voltage sag, swells and momentary interruptions. The dynamic performance is analyzed and verified through simulation

OBJ ECTIVE OF THE PROJECT

The causes of power quality problems are generally complex and difficult to detect. Technically speaking, the ideal AC line supply by the utility system should be a pure sine wave of fundamental frequency (50/60Hz).Different power quality problems, their characterization methods and possible causes are discussed above and which are responsible for the lack of quality power which affects the customer in many ways. We can therefore conclude that the lack of quality power can cause loss of production, damage of equipment or appliances or can even be detrimental to human health. It is therefore imperative that a high standard of power quality is maintained. This project demonstrates that the power electronic based power conditioning using custom power devices like DSTATCOM can be effectively utilized to improve the quality of power supplied to the customers.

The aim of the project is to implement DSTATCOM with control strategies in the MATLAB, simulink using Simpower systems tool box and to verify the results through various case studies applying different loads and study them in detail.

II. Distribution Static Compensator

The Distribution Static Compensator (DSTATCOM) is a voltage source inverter based static compensator that is used for the correction of bus voltage sags. Connection (shunt) to the distribution network is via a standard power distribution transformer. The DSTATCOM is capable of generating continuously variable inductive or capacitive shunt compensation at a level up its maximum MVA rating. The DSTATCOM continuously checks the line waveform with respect to a reference ac signal, and therefore, it can provide the correct amount of leading or lagging reactive current compensation to reduce the amount of voltage fluctuations. The major components of a DSTATCOM are shown in Fig. 2.4.2. It consists of a dc capacitor, one or more inverter modules, an ac filter, a transformer to match the inverter output to the line voltage, and a PWM control strategy. In this DSTATCOM implementation, a voltage-source inverter converts a dc voltage into a three-phase ac voltage that is synchronized with, and connected to, the ac line through a small tie reactor and capacitor (ac filter).

Circuit diagram for pulse generator for five-level inverter:

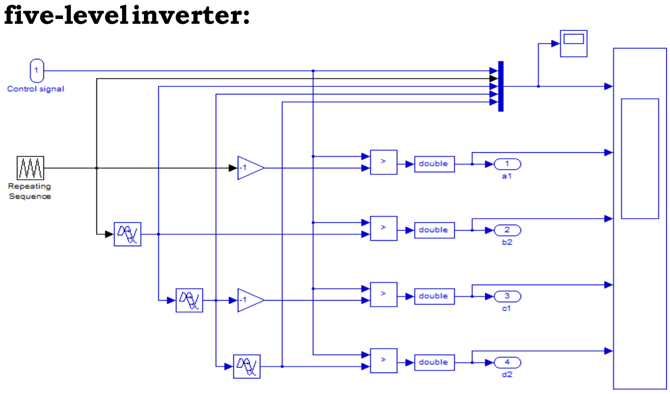

Fig.Pulse Generator

Circuit diagram for pulse generator inverter for Seven-level:

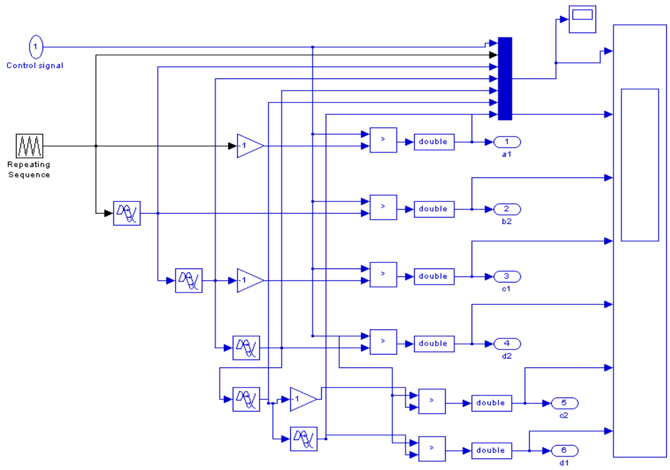

Fig.Pulse Generator

Output waveform for pulse generator for five-level:

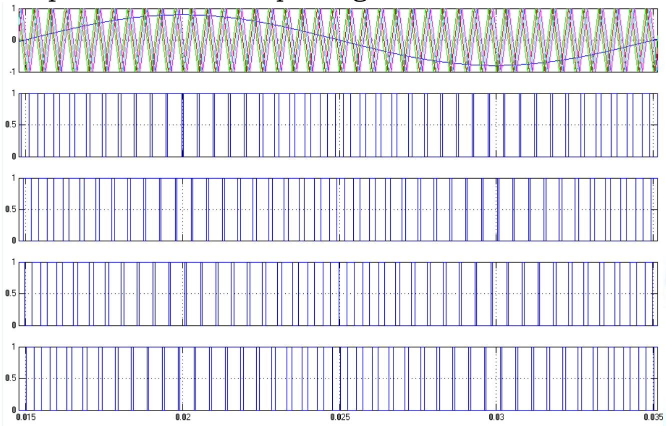

Fig.pulses for one phase of 5-level MLI

Output waveform for pulse generator for Seven-level:

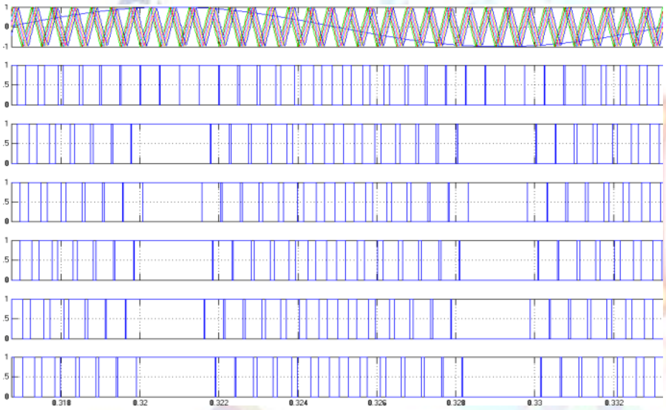

Fig.Pulses for one phase of 7-level MLI

In the previous chapter we have discussed about the custom power device DSTATCOM which is the most effective device to solve many power quality problems. The device have voltage source converter in it, and the operation of this voltage source converter is depends on the switching pulses of IGBT gates. Till today there are so many control schemes are proposed for the control of voltage source converter. In this work a direct voltage controller is simulated for control of switching pulses for DSTATCOM. Although a directly controlled converter is more difficult and expensive to implement than an indirectly controlled converter, which requires only measurement of the rms voltage at load point, the former presents superior dynamic performance with measurements of rms voltage and current at load point.

III. Simulation of DSTATCOM

In this work, the performance of VSC based power devices acting as a voltage controller is investigated. Moreover, it is assumed that the converter is directly controlled (i.e., both the angular position and the magnitude of the output voltage are controllable by appropriate on/off signals) for this it requires measurement of the rms voltage and current at the load point.

PWM Based Model of VSC

In the PWM based model, the switching elements–IGBTs/diodes, the PWM signal generator and the dc capacitor are explicitly represented. Considering the DSTATCOM as a voltage controller, the detailed model is shown in Fig. 5.3. Such a model consists of a six- pulse voltage-source converter using IGBTs/diodes, a 10000-µF dc capacitor, a PWM signal generator with switching frequency equal to 3 kHz, a passive filter to eliminate harmonic components, and a voltage controller as that shown in Fig4.4.1. The dc voltage (V_{dc}) is measured and sent to the controller as well as the three-phase terminal voltages (V_{ABC}) and the injected three-phase currents (I_{abc}). V_a, V_b and V_c are voltages at the converter output.

Test System

Figure 5.1 shows the test system used to carry out the various D-STATCOM simulations presented in this section. Figure 4.3 shows the test system implemented in MATLAB SIMULINK. The test system comprises a 230kV, 60Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3- winding transformer connected in Yg/Yg/Yg, 230/11/11 kV.

A varying load is connected to the 11 kV, secondary side of the transformer. To show the effectiveness of this controller in providing continuous voltage regulation, simulations were carried out with and with no D-STATCOM connected to the system.

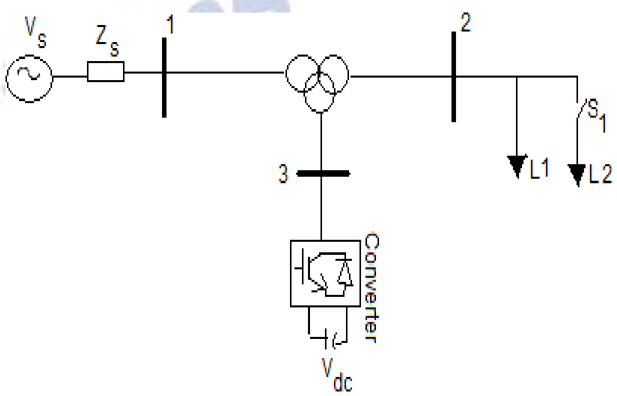

Fig.Single line diagram for D-STATCOM

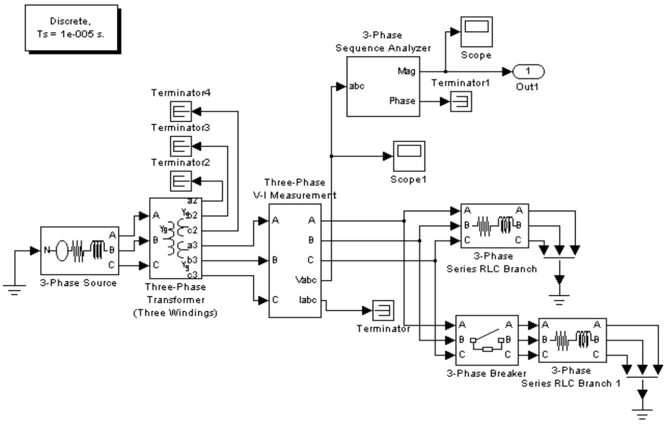

Fig.Circuit diagram for test system without D-STATCOM

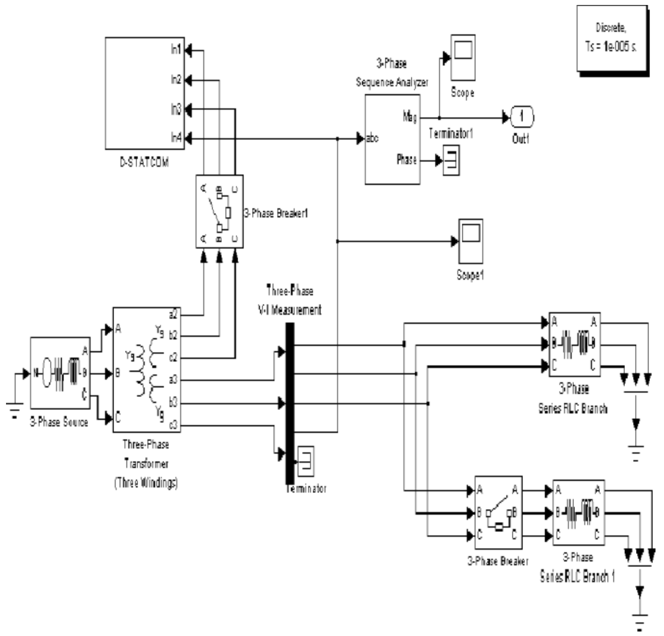

Fig circuit diagram for test system with DSTATCOM

To verify the working of a DSTATCOM employed to avoid voltage sags during short- circuit, an additional load is switched on for 100msec.Using facilities available in MATLAB/SIMULINK the DSTSATCOM is simulated to be in operation only for the duration of the fault as it is expected to be the case in practical situation. Power System Bock set for the use with Matlab simulink is based on state-variable analysis and employs either variable or fixed integration-step algorithms. Fig.6.3. shows the simulink model of the test system for

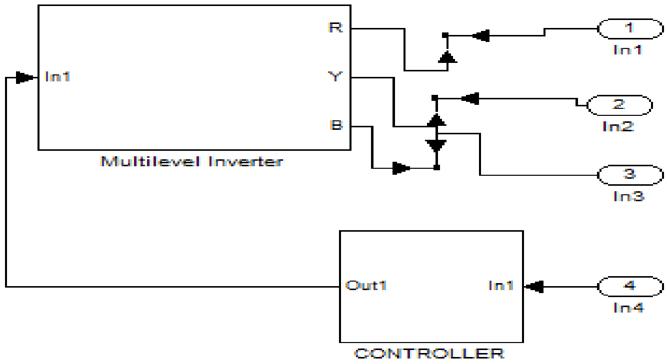

Fig PWM based model of VSC implementation in Sim Power Systems.

Fig.6.4. shows the subsystem of DSTATCOM. The reference control signals are generated considering the phase angle jump δ for five and seven-level MLI. The phase shifted pulse width modulation or single phase for five level and seven level as shown in Fig.5.8, 5.9.

In this control technique Sinusoidal PWM technique is used which is simple and gives a good response. The error signal obtained by comparing the measured system rms voltage and the reference voltage, is fed to a PI controller which generates the angle which decides the necessary phase shift between the output voltage of the VSC and the AC terminal voltage. This angle is summed with the phase angle of the balanced supply voltages, assumed to be equally spaced at 120 degrees, to produce the desired synchronizing signal required to operate the PWM generator. In this algorithm the D.C. voltage is maintained constant using a separate dc source. The pulse generators for Five and Seven levels as shown in Fig.5.6. & 5.7.

Voltage Controller of DSTATCOM

In this the supply phase angle is measured and is summed with and the difference in phase angle from the voltages obtained given to a PI controller which is given to the VSC based DSTATCOM.

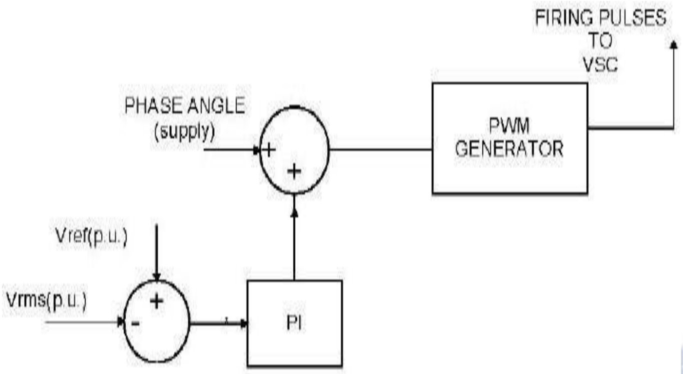

Fig Voltage controller block diagram

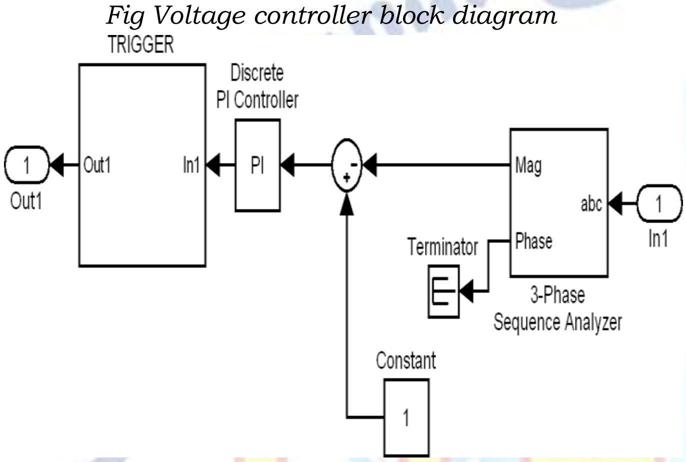

Fig Phase Shift Control implementation in Sim Power Systems.

The first simulation contains no DSTATCOM and a single line to ground fault is applied at point A in Fig.6.2.via a fault resistance of 0.2Ω, during the period 500-900ms. The voltage sag at the load point is 30% with respect to the reference voltage. The second simulation is carried out using the same scenario as above but now with the DSTATCOM in operation. The total simulation period is 1400ms. When the DSTATCOM is in operation the voltage sag is mitigated almost completely, and rms voltage at the sensitive load point is maintained at 98% as shown in Fig.6.8. The total harmonic distortion is maintained at 0.58% at the load end for five level MLI as shown in Fig.6.9.

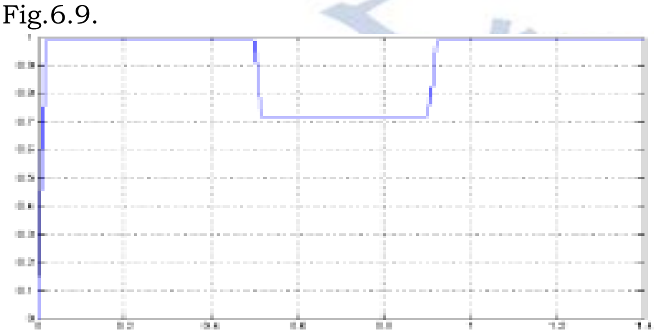

Fig.Load voltage without DSTATCOM

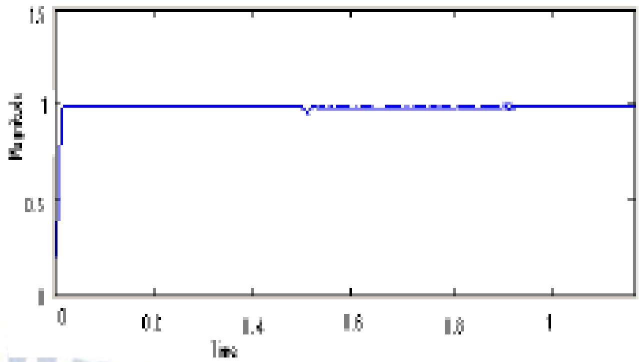

Fig.Load voltage 5-level DSATCOM with isolated dc voltage of 5.87KV

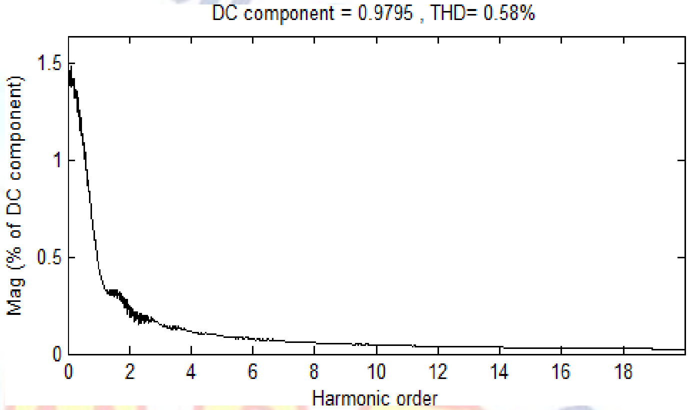

Fig.Total harmonic distortion of LOAD

VOLTAGE for 5-level

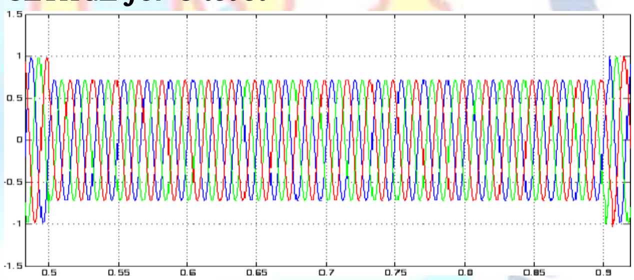

Fig.Three phase sourse voltage without DSTATCOM

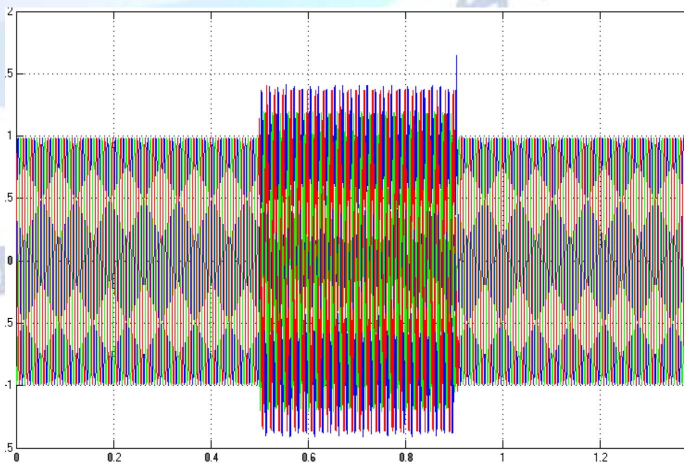

Fig.Three phase load voltage with DSTATCOM for five level

When the 7-level (cascaded H-bridge inverter) DSTATCOM is in operation the voltage sag is mitigated almost completely, and rms voltage at the sensitive load point is maintained at 98% as shown in Fig.9. The total harmonic distortion is maintained at 0.57% at the load end.

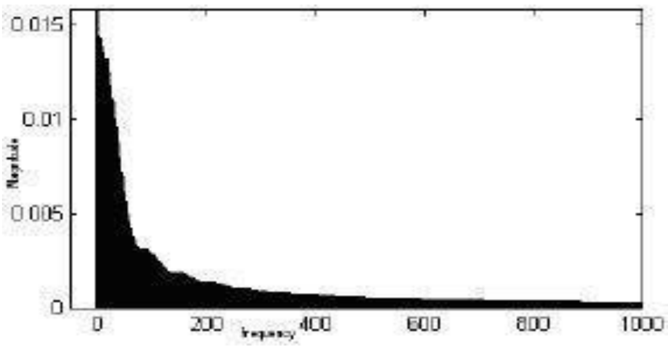

Fig.Total harmonic distortion of LOAD VOLTAGE for 7-level

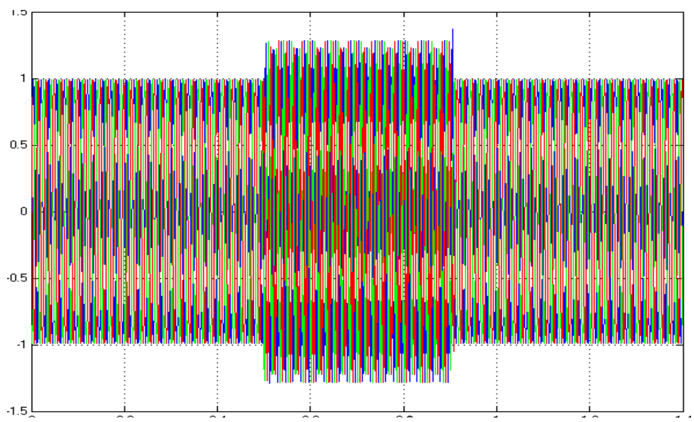

Fig.Three phase load voltage with DSTATCOM for seven level

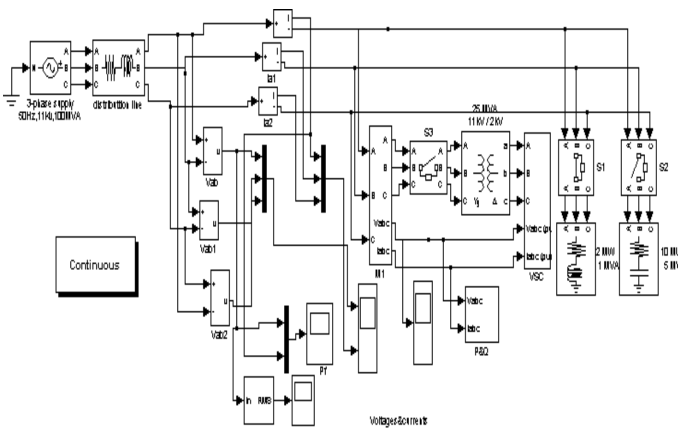

Fig DSTATCOM connected to 25kV distribution system

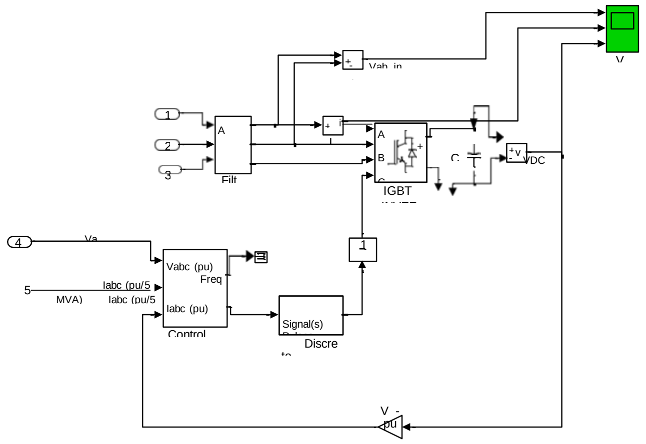

Fig.PWM based model of VSC implementation in SimPowerSystems.

Voltage Controller of DSTATCOM

This section describes the PWM-based control scheme for the DSTATCOM. The aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances.

The voltage controller analyzed in this work is exhibited in Fig. 6.15. and its simpower systems implementation is presented in Fig.6.16.Which employs the dq0 rotating reference frames because it offers higher accuracy than stationary frame based techniques. In this Figure, VABC are the three-phase terminal voltages, Iabc are the three-phase currents injected by the devices into the network, Vrms is the rms terminal voltage, Vdc is the dc voltage measured in the capacitor and the superscripts * indicate reference values. Such controller employs a PLL (Phase Locked Loop) to synchronize the three-phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. Therefore, the PLL provides the angle φ to the abc-to-dq0 (and dq0-to-abc) transformation. There are also four PI regulators. The first one is responsible for controlling the terminal voltage through the reactive power exchange with the ac network

This PI regulator provides the reactive current reference Iq*, which is limited between +1 pu capacitive and -1 pu inductive. This regulator has one droop characteristic, usually ±5%, which allows the terminal voltage to suffer only small variations. Another PI regulator is responsible for keeping constant the dc voltage through a small active power exchange with the ac network, compensating the active power losses in the transformer and inverter. This PI regulator provides the active current reference Id*.

The other two PI regulators determine voltage reference Vd* and Vq*, which are sent to the PWM signal generator of the converter, after a dq0-to-abc transformation. Finally, Vabc* are the three-phase voltages desired at the converter output.

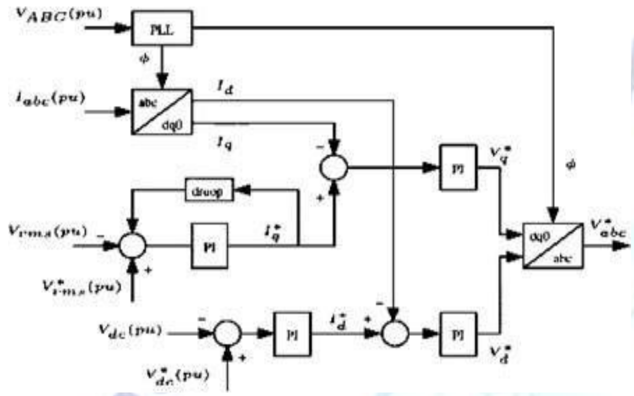

Fig Voltage controller of DSTATCOM

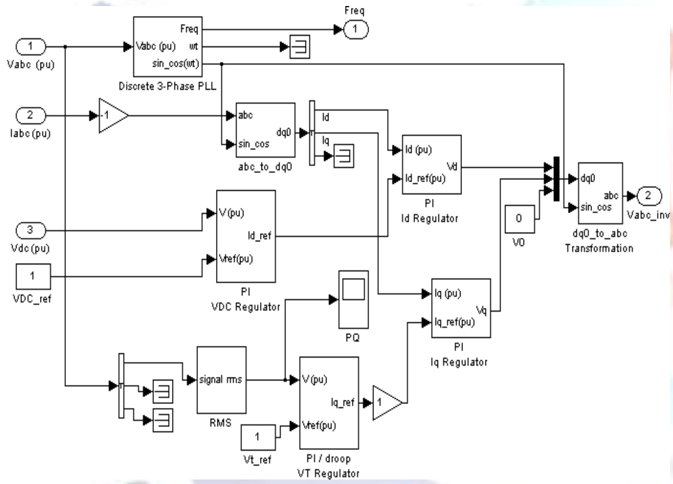

Fig Voltage controller implementation in SimPowerSystems.

Without DSTATCOM compensation

Case: 1 (an inductive load is applied .1seconds after the start of the simulation)

Initially there is a fixed inductive load is connected to the line. After .1 second the circuit breaker .is closed and the terminal voltage is decreased to.8pu. The top window shows the change in the three phase voltage waveforms, the second window shows the changes in the currents when the inductive load is applied after .1seconds and the bottom window shows the magnitude of the voltage.

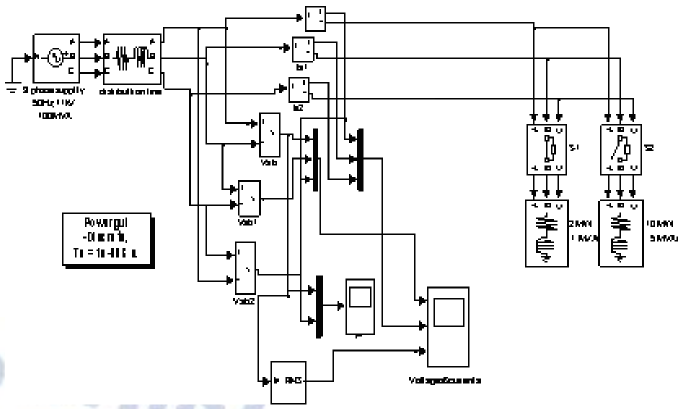

Fig simulink model of uncompensated lines with inductive load

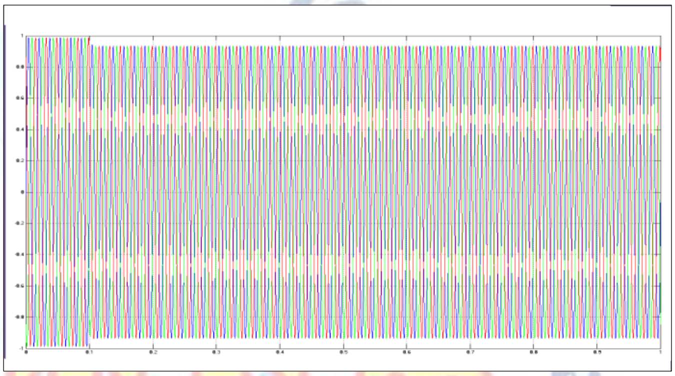

Fig Load voltage with Inductive load in the uncompensated line

Case: 2 (A capacitive load is applied at 0.1seconds after the start of the simulation)

Initially there is a fixed inductive load is connected to the line. After 0.1seconds start of the simulation the circuit breaker is closed and a capacitive load is applied and the scope shows the magnitude of the voltage in pu.

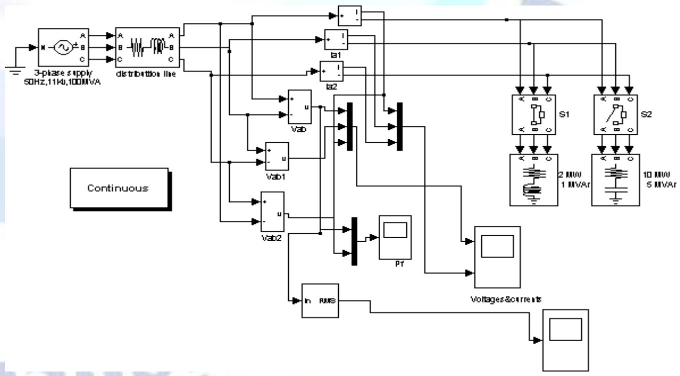

Fig simulink model of uncompensated lines with capacitive load

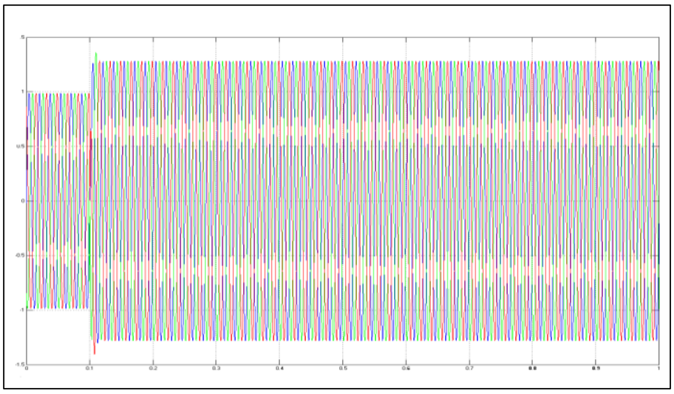

Fig Load voltage in pu with Capacitive load in the uncompensated line

(i) Compensation Using Decoupled Current Control or instantaneous p-q theory Control

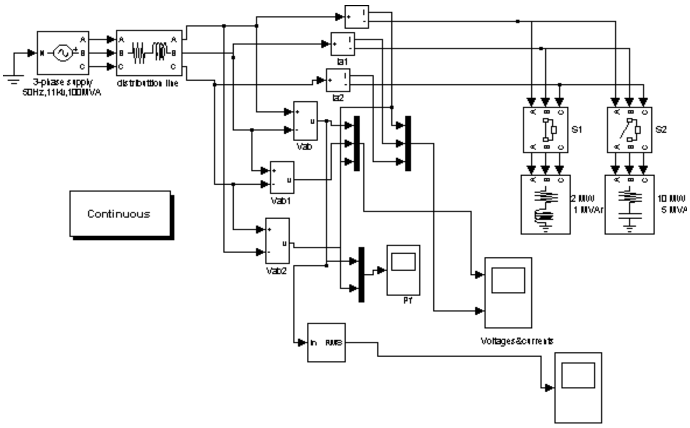

Fig Simulink model of compensated line

Case: 1 (an inductive load is applied 0.1 seconds after the start of the simulation)

Considering that the DSTATCOM is connected in shunt with the line. Initially there is a fixed inductive load is connected to the line. After 0.1 seconds the circuit breaker is closed an inductive load is applied, and the DSTATCOM is applied at 0.3 seconds. We observe that there is no drop in the terminal voltage due to the injection of reactive power by the DSTATCOM .Therefore the load is maintained at unity power factor.

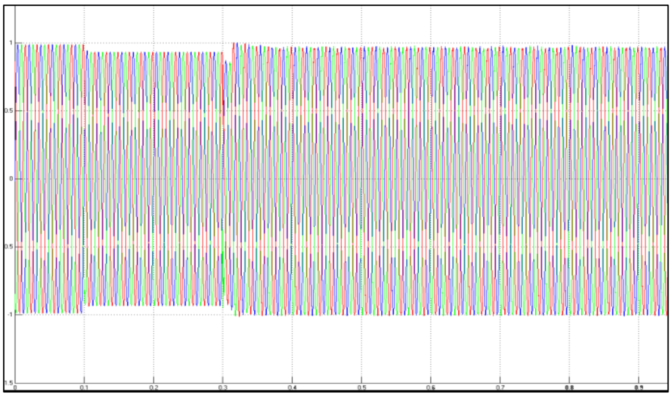

Fig Load voltage in pu with Inductive load in the compensated line

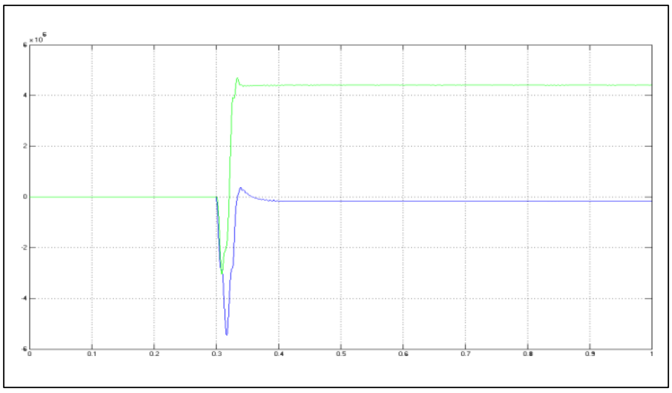

Fig.Reactive power of compensated lines with inductive load

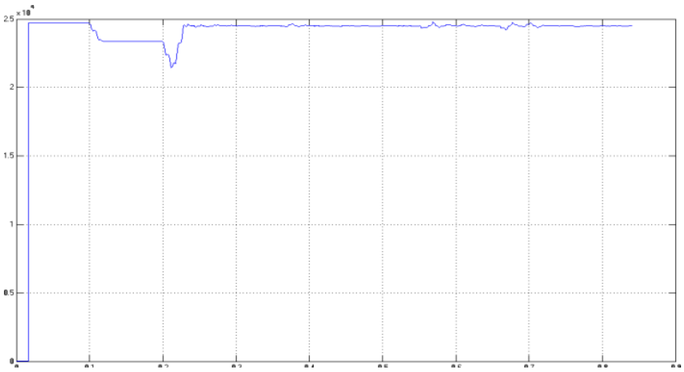

Fig.Load voltage with inductive load

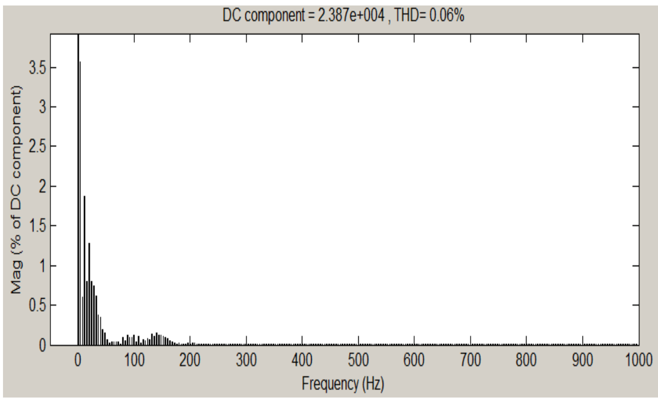

Fig.Total Harmonic Distortion(THD) for inductive load

Case:2 (an capacitive load is applied at 0.1 seconds after the start of the simulation)

Considering that the DSTATCOM is connected in shunt with the line. Initially there is a fixed inductive load is connected to the line. After 0.1 seconds the circuit breaker is closed a capacitive load is applied and the DSTATCOM is applied at 0.2 seconds then we observe that voltage is maintained at 1 pu due to the absorption of reactive power by the DSTATCOM.
Therefore the load is maintained at unity power factor.

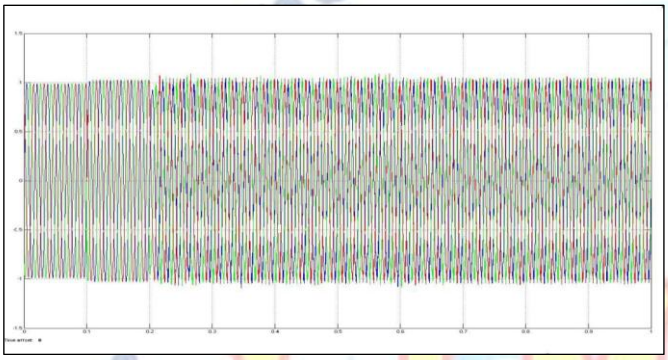

Fig .Load voltage in per unit with capacitive load in the compensated line

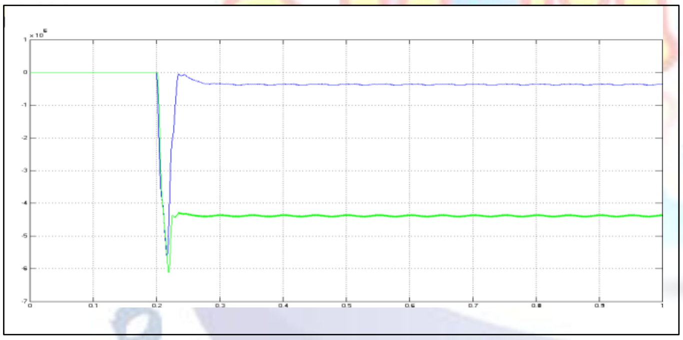

Fig .Reactive power of compensated lines with capacitive load

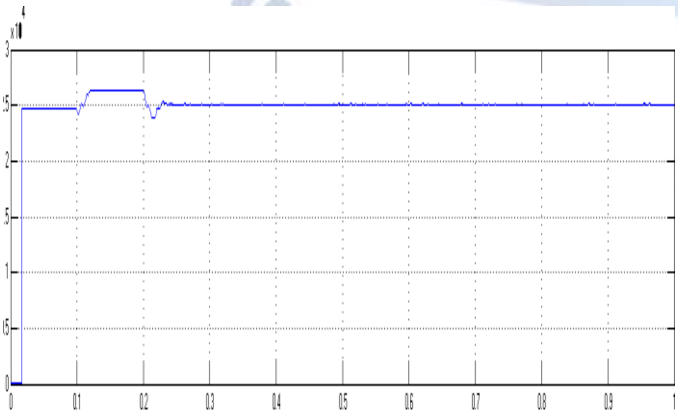

Fig.Load voltage with capacitive load

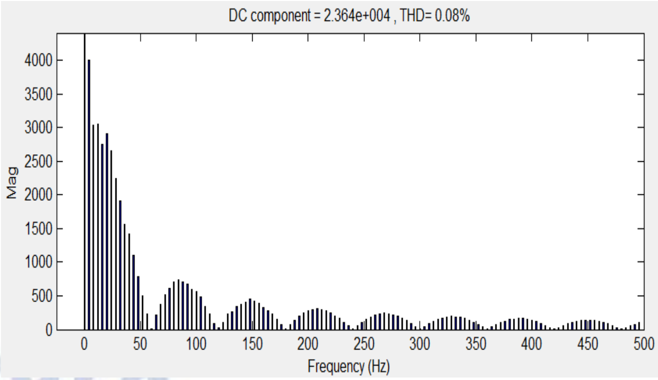

Fig.Total Harmonic Distortion (THD) for capacitive load

IV. Conclusion

1. Cascaded five and seven level multilevel inverter is simulated in matlab simulink.
2. Phase shifted pulse width modulation is employed for cascaded h-bridge multilevel inverter.
3. DC storage requirement reduced to 50% compared to conversion VSI.

This paper presents the detailed modeling of one of the custom power products, DSTATCOM is presented using instantaneous P-Q theory, used for the control of DSTATCOM are discussed. These control algorithms are described with the help of simulation results under linear loads. The control scheme maintains the power balance at the PCC to regulate the dc capacitor voltages. PWM control scheme only requires voltage measurements. This characteristic makes it ideally suitable for low-voltage custom power applications. The control scheme was tested under a wide range of operating conditions, and it was observed to be very robust in every case. It is concluded that a DSTATCOM though is conceptually similar to a STATCOM at the transmission level; its control scheme should be such that in addition to complete reactive power compensation, power factor correction and voltage regulation the harmonics are also checked, and for achieving improved power quality levels at the distribution end.

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