IMPLEMENTATION OF CUSTOM POWER PRODUCT DSTATCOM IN POWER SECTOR

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Abstract: *FACTS use the latest power electronic devices and methods to control electronically the high-voltage side of the network. Custom Power focuses on low-voltage distribution, and it is a technology born in response to reports of poor power quality and reliability of supply affecting factories, offices and homes. With Custom Power solutions in place, the end-user will see tighter voltage regulation, near-zero power interruptions, low harmonic voltages, and acceptance of rapidly fluctuating and other non-linear loads in the vicinity.*

D-STATCOM (Distribution Static Compensator) is a shunt device which is generally used to solve power quality problems in distribution systems. D-STATCOM is a shunt device used in correcting power factor, maintaining constant distribution voltage and mitigating harmonics in a distribution network. D-STATCOM is used for Grid Connected Power System, for Voltage Fluctuation, for Wind Power Smoothening and Hydrogen Generation etc. The main objective of this paper is to show that using DISTRIBUTION STATIC COMPENSATOR (DSTATCOM) it is possible to reduce the voltage fluctuations like sag and swell conditions in distribution systems. The DSTATCOM which can be used at the PCC for improving power quality is modeled and simulated using proposed control strategy and the performance is compared by applying it to a radial distribution system with and without DSTATCOM. DSTATCOM is applied to a simple Distributed Generation system consisting of AC generators like Induction and Synchronous Generators and the system is analyzed by applying faults at various points. Finally the best generator to be installed with DSTATCOM is chosen.

Keywords: *FACTS, DSTATCOM, Voltage Regulation, power quality, MATLAB, Simulink.*

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1. INTRODUCTION

Custom power is formally defined as the employment of power electronic or static controllers in distribution systems rated up to 33 kV for the purpose of supplying a level of reliability or power quality that is needed by electric power customers who are sensitive to power variations. Custom power devices or controllers, include static switches, inverters, converters, injection transformers, master-control modules and energy-storage modules that have the ability to perform current-interruption and voltage-regulation functions within a distribution system. Each custom power device can be considered to be a type of power-conditioning device. In general, power-conditioning technology includes all devices used to correct end-user problems in response to voltage sags, voltage interruptions, voltage flicker, harmonic distortion and voltage-regulation problems.

A Custom Power specification may include provision for-

1. No power interruption.
2. Tight voltage regulation including short duration sags or swells
3. Low harmonic voltages
4. Acceptance of fluctuating and non linear loads without effect on terminal Voltage

The family of emerging power electronic devices being offered to achieve these Custom power objectives includes: Distribution Static Compensator (DSTATCOM) to protect the distribution System from the effects of a polluting e.g. fluctuating, voltage sags and swells and non-linear loads. Dynamic voltage restorer (DVR) to protect a critical load from disturbances e.g. sags, swells, transients or harmonics, originating on the interconnected Distribution system.

Unified Power Quality Conditioner (UPQC) is the combination of series and Shunt APF, which compensates supply voltage and load current imperfections in the distribution system [1].

1.1 Commonly Used Solutions to Improve Electric Power Quality:

There are three ways that is commonly applied to improve voltage deviation of electrical power system. The most effective solution is reactive power compensation, as SVC - Static Var Compensator (typically, TCR-Thyristor Controlled Reactors and TSC-Thyristor Switched Capacitors), SVG - Static Var Generator and APFCC-Active Power Factor Correction Circuit.

Other solutions include regulation of field current of synchromotor, application of on-load voltage regulation transformer.

A large number of solutions have been selected to solve the problem of fluctuation and flick of voltage and almost all these solutions simultaneously have the function of harmonic suppression. To suppress harmonics in electrical power quality. The most effective solution is to apply filters. The commonly applied filters are passive power filter (usually passive LC filter) and active power filter (APF). APF normally has two types according to the ways it connects to the object that is compensated shunt APF and series APF. Among which, shunt APF is common in practical application[2].

PROBLEM DEFINITION

The main objective of the paper is to show that using DISTRIBUTION STATCOM (DSTATCOM) it is possible to reduce the voltage fluctuations like sag and swell conditions in distribution systems. The DSTATCOM which can be used at the PCC for improving power quality is modeled and simulated using proposed control strategy and the performance is compared by applying it to a radial distribution system with and without DSTATCOM. DSTATCOM is applied to a simple Distributed Generation system consisting of AC generators like Induction and Synchronous Generators and the system is analyzed by applying faults at various points. Finally the best generator to be installed with DSTATCOM is chosen[3].

2. DISTRIBUTION STATCOM

The DSTATCOM is basically one of the custom power devices. It is nothing but a STATCOM but used at the Distribution level. The key component of the DSTATCOM is a power VSC that is based on high power electronics technologies. The Distribution STATCOM is a versatile device for providing reactive Compensation in ac networks. The control of reactive power is achieved via the regulation of a controlled voltage source behind the leakage impedance of a transformer, in much The same way as a conventional synchronous compensator. However, unlike the conventional synchronous compensator, which is essentially a synchronous generator Where the field current is used to adjust the regulated voltage, the DSTATCOM uses an Electronic voltage sourced converter (VSC),to achieve the same regulation task. The fast Control of the VSC permits the STATCOM to have a rapid rate of response.

2.1 Operating Principle of the DSTATCOM

Basically, the DSTATCOM system is comprised of three main parts: a VSC, a set of coupling reactors and a controller. The basic principle of a DSTATCOM installed in a power system is the generation of a controllable ac voltage source by a voltage source inverter (VSI) connected to a dc capacitor (energy storage device). The ac voltage source, in general, appears behind a transformer leakage reactance. The active and reactive power transfer between the power system and the DSTATCOM is caused by the voltage difference across this reactance. The DSTATCOM is connected to the power networks at a PCC, where the voltage-quality problem is a concern. All required voltages and currents are measured and are fed into the controller to be compared with the commands. The controller then performs feedback control and outputs a set of switching signals to drive the main semiconductor switches (IGBT's, which are used at the distribution level) of the power converter accordingly. The basic diagram of the DSTATCOM is illustrated in Figure (1).

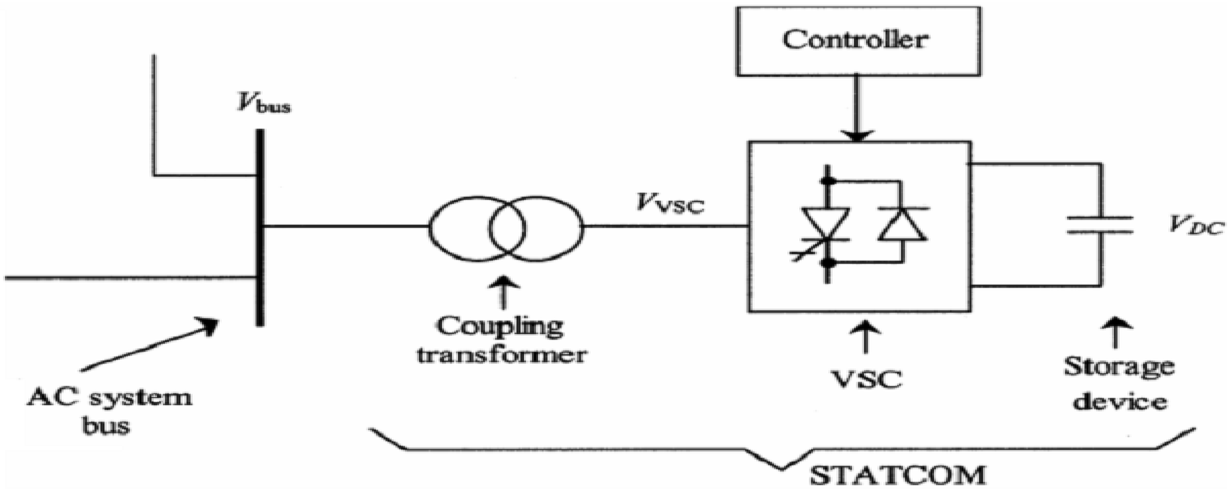

Figure (1) Basic diagram of the DSTATCOM

The ac voltage control is achieved by firing angle control. Ideally the output voltage of the VSI is in phase with the bus (where the DSTATCOM is connected) voltage. In steady state, the dc side capacitance is maintained at a fixed voltage and there is no real power exchange, except for losses. There are two control objectives implemented in the DSTATCOM. One is the ac voltage regulation of the power system at the bus where the DSTATCOM is connected and the other is dc voltage control across the capacitor inside the DSTATCOM [4]. In conventional control scheme, there are two voltage regulators designed for these purposes: ac voltage regulator for bus voltage control and dc voltage regulator for capacitor voltage control. In the simplest strategy, both the regulators are proportional integral (PI) type controllers. Thus, the shunt current is split into d-axis and q-axis components. The reference values for these currents are obtained by separate PI regulators from dc voltage and ac-bus voltage errors, respectively. Then subsequently, these reference currents are regulated by another set of PI regulators whose outputs are the d-axis and q-axis control voltages for the DSTATCOM [5].

2.2 Principle of Voltage Regulation

2.2.1 Voltage Regulation without Compensator

Consider a simple circuit as shown in Figure (2). It consists of a source Voltage E, V is the voltage at a PCC and a load drawing the current Il. Without a voltage compensator, the PCC voltage drop caused by the load current Il, shown in Figure as ΔV,

$$\Delta V = I_s R_s + jI_s X_s$$
$$(R_s + jX_s)\left(\frac{P_l - jQ_l}{V}\right)$$
$$= \frac{(R_s P_l - X_s Q_l)}{V} + j\frac{(X_s P_l + R_s Q_l)}{V}$$
$$= \Delta V_r + \Delta V_x$$

The voltage change has a component ΔVr in phase with V and component ΔVx, which are illustrated in Figure (2). It is clear that both magnitude and the phase of V, relative to the supply voltage E, are functions of the magnitude and phase of the load current namely the voltage drop depends on both the real and reactive power of the load. The component ΔV is rewritten as

$$\Delta V = I_s R_s + jI_s X_s$$

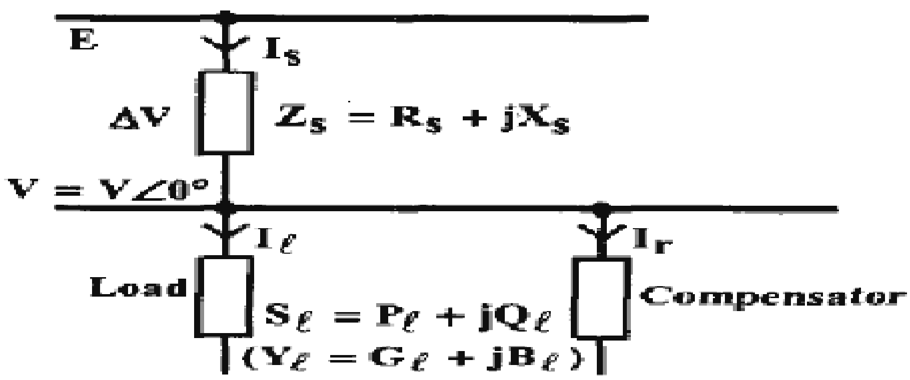

Figure (2) A Simple Circuit for demonstrating the voltage regulation principle

2.2.2 Voltage regulation with DSTATCOM

Now consider a compensator connected to the system. It is as shown in Figureure3 and Figureure4 shows vector diagram with voltage uncompensation and compensation. By adding a compensator in parallel with the load, it is possible to make IEI=IVI by controlling the current of the compensator.

$$I_s = I_r + I_l$$

Where I_r is the compensating current.

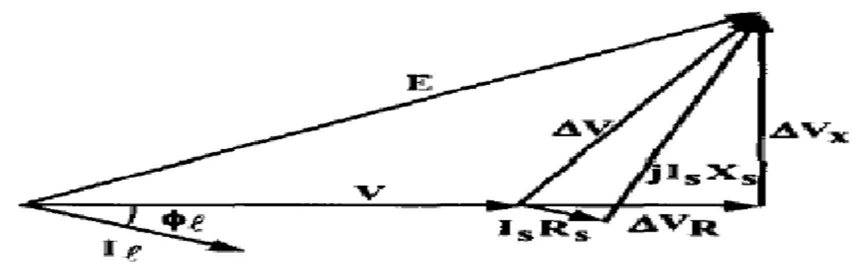

Figure (3) Phasor diagram for uncompensated

3. MODELING OF DSTATCOM

The Figure (5) shows the basic structure of a six-pulse DSTATCOM to a load bus in a power system where Rp represents the 'ON' state resistance of the switches including transformer leakage resistance, Lp is transformer leakage inductance and the switching losses are taken into account by a shunt dc-side resistance Rdc. A VSI resides at the core of the DSTATCOM. It generates a balanced and controlled three-phase voltage Vp. The voltage control is achieved by firing angle control of the VSI. Under steady state, the dc-side capacitor possesses fixed voltage Vdc, and there is no real power transfer, except for losses. Thus, the ac-bus voltage remains in phase with the fundamental component of Vp.

However, the reactive power supplied by DSTATCOM is either inductive or capacitive depending upon the relative magnitude of fundamental component of Vp with respect to Vt. If $|Vt| > |Vp|$ the VSI draws reactive power from the ac-bus whereas if $|Vt| < |Vp|$, it supplies reactive power to the ac-system. This is the basic principle of DSTATCOM [4].

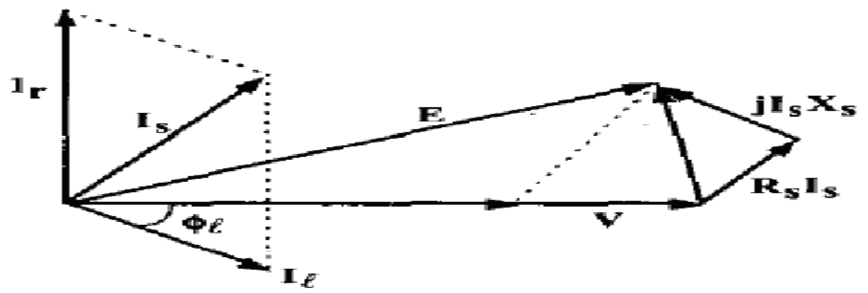

Figure (4) Phasor diagram for voltage regulation with compensation

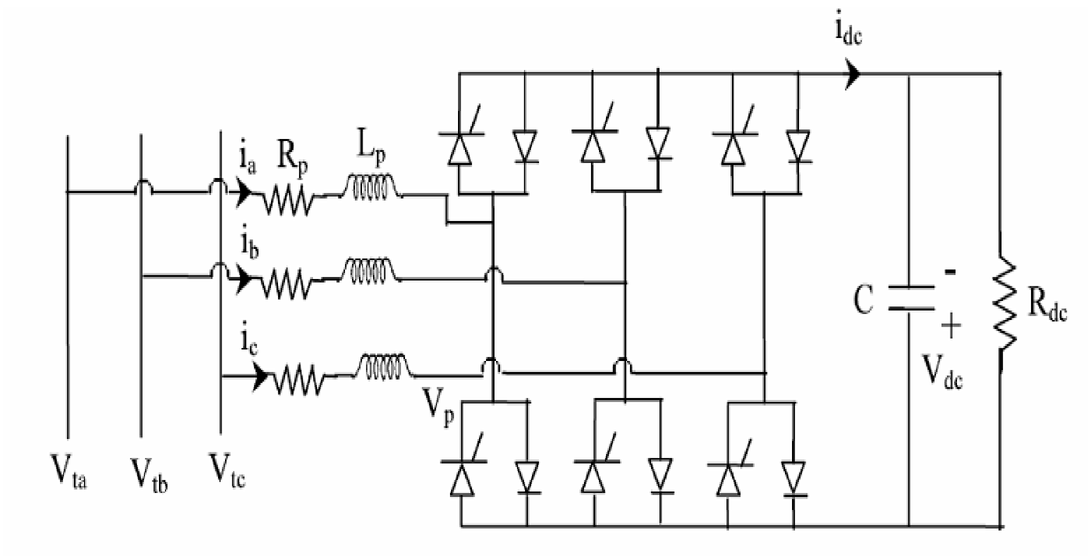

Figure (5) Basic DSTATCOM connected to a load in a distribution system

The sending end source is assumed to be a strong system with high short circuit ratio and low impedance. Thus, the source voltage is treated as a constant source irrespective of variations in load current. The equivalent circuit of the above system is shown is Figure below:

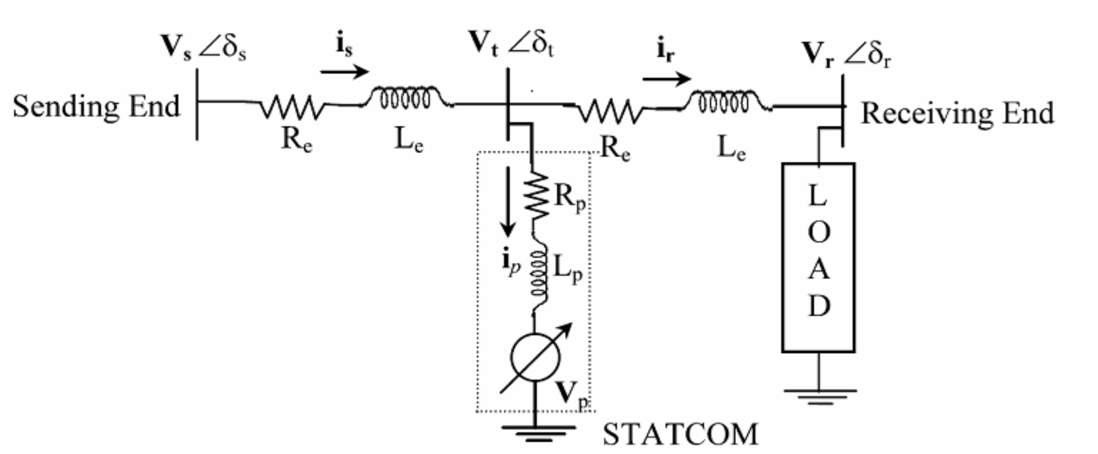

Figure (6) Equivalent circuit of the above system with DSTATCOM

4. DSTATCOM VOLTAGE REGULATION TECHNIQUE

The DSTATCOM improves the voltage sags and swell conditions and the ac output voltage at the customer points is improved, thus improving the quality of power at the distribution side In this paper the voltage controller technique (also called as decouple technique) is used as the control technique for DSTATCOM. . This control strategy uses the dq0 rotating reference frame because it offers higher accuracy than stationary frame-based techniques [2]. In this VABC are the three-phase terminal voltages, I_{abc} are the three-phase currents injected by the DSTATCOM into the network, Vrms is the root-mean-square (rms) terminal voltage, V_{dc} is the dc voltage measured in the capacitor, and the superscripts indicate reference values. Such a controller employs a phase-locked loop (PLL) to synchronize the three phase voltages at the converter output with the zero crossings of the fundamental component of the phase-A terminal voltage. The block diagram of a proposed control technique is shown in Figure (7). Therefore, the PLL provides the angle ϕ to the abc-to-dq0 (and dq0-to-abc) transformation. There are also four proportional-integral (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 I_q^*, which is limited between +1pu capacitive and -1pu inductive. Another PI regulator is responsible for keeping the dc voltage constant 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 I_d^*. The other two PI regulators determine voltage reference V_d^*, and V_q^*, which are sent to the PWM signal generator of the converter, after a dq0-to-abc transformation. Finally, $V_{abc}^*$are the three-phase voltages desired at the converter output.

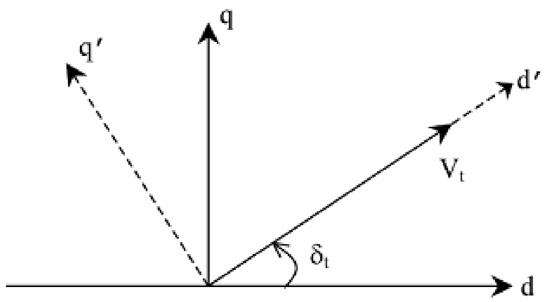

Figure (7) Proposed control technique

5. RESULTS AND DISCUSSIONS

Basically, DSTATCOM consists of PWM voltage source inverter circuit and a DC capacitor connected at one end.. In the distribution voltage level, the switching element is usually the integrated gate bipolar transistor (IGBT), due to its lower switching losses and reduced size. Moreover, the power rating of custom power devices is relatively low. Consequently, the output voltage control may be executed through the pulse width-modulation (PWM) switching method. IGBT based PWM inverter is implemented using Universal bridge block from Power Electronics subset of Sim Power Systems. RC snubber circuits are connected in parallel with each IGBT for protection. Such a model consists of a six-pulse voltage-source converter using IGBTs/diodes, a 3000Vdc capacitor, a PWM signal generator with switching frequency equal to 3 kHz, After modeling of DSTATCOM, It is applied to a simple radial distribution line consisting of different loads. The single line diagram of the radial distribution system to be tested is

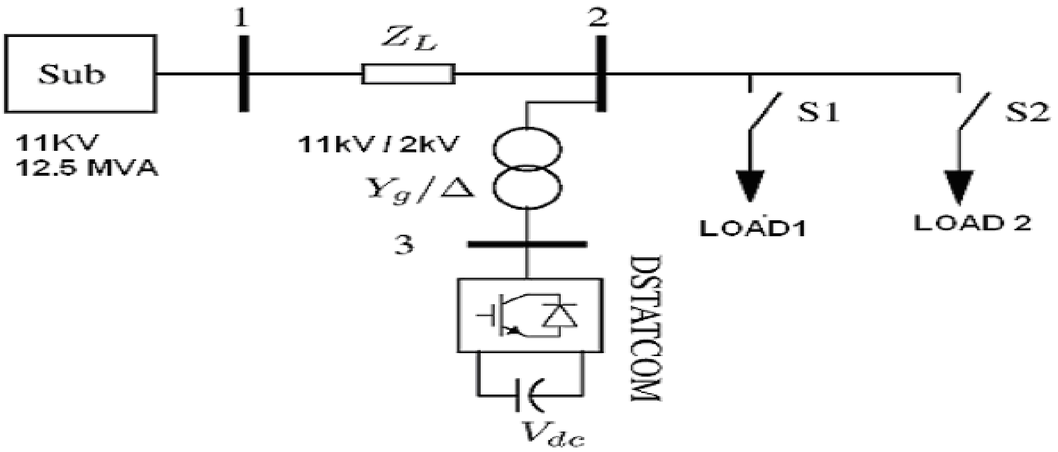

Figure (8) Single Line Diagram of the system used

Table1. The System Details of Single Line Diagram Used

Input Voltage	11kv, 50Hz.
Source Impendence	0.968Ω, 0.03H
Line impedance	0.4 Ω, 0.003H
DC Voltage	3000V.
Capacitor	2000μF.
Load1	0.5MW, 0.2MVAr
Load2	0.10MW, 0.05MVAr

6. TESTING THE DSTATCOM

To verify the performance of the DSTATCOM, a variable load is connected at bus 2 and the substation voltage is also changed during the simulation. The sequence of events simulated is explained as follows. Initially, there is no load connected at bus 2. At t=200ms, the switch S1 is closed so that load1 is applied and at t=500ms, the switch S2 is closed i.e load2 is applied too; both switches remain closed until the end of the simulation. During these events, the terminal voltage of bus 2 decreases showing the effect of sags and, at t=800ms, the substation voltage is increased to the terminal voltage of bus 2 also rises, showing the swell condition.

7. SIMULATION RESULTS

The DSTATCOM along with the Distribution System is simulated in MATLAB /SIMULINK Software of Version 7.0.1. and the diagram is shown in Figure below.

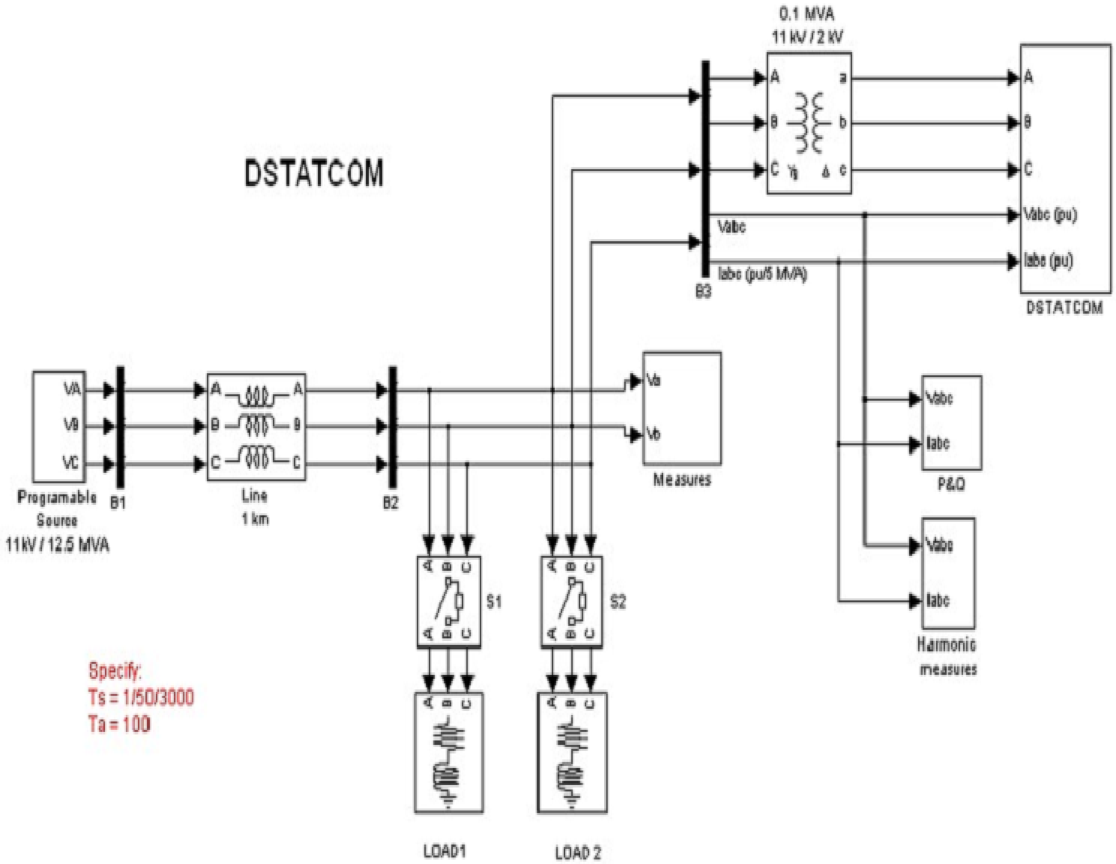

Figure (9) The Single line diagram implemented in MATLAB

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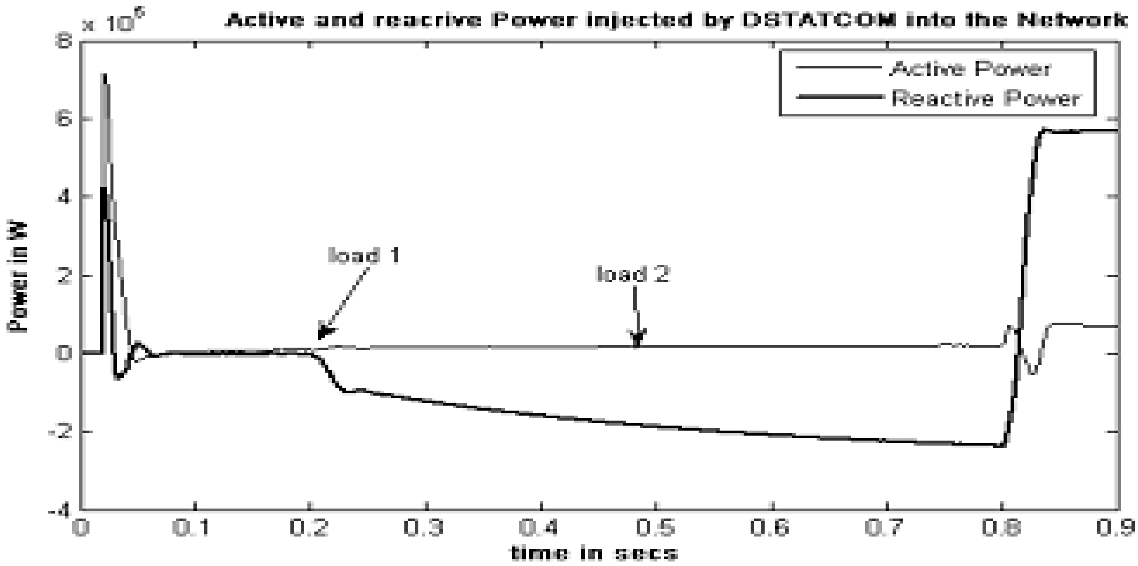

Figure (10) Active and Reactive powers injected by DSTATCOM

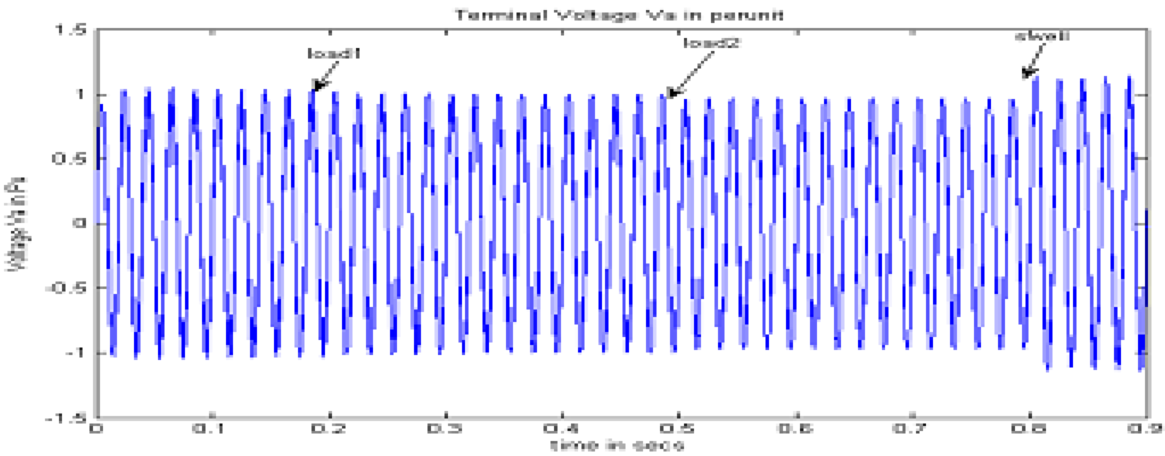

Figure (11) Terminal voltage of bus2 in p.u. injected by DSTATCOM

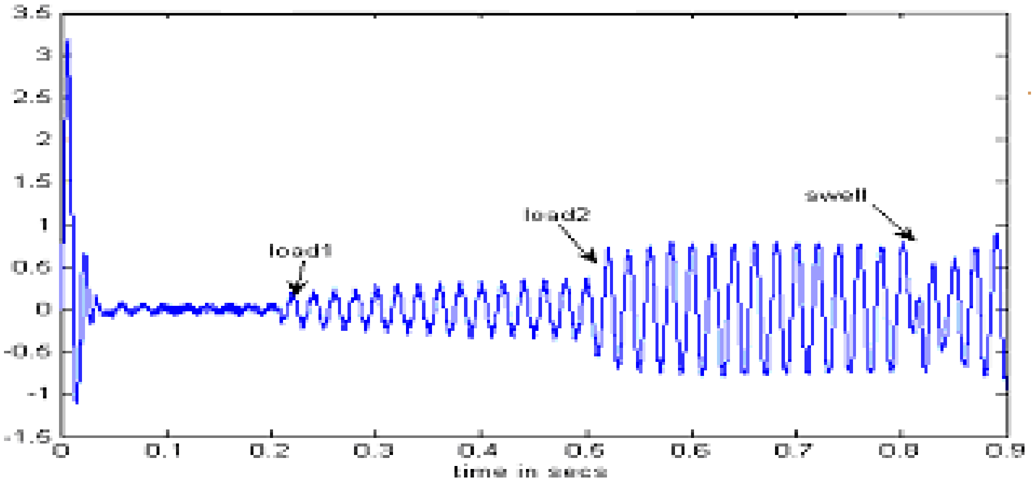

Figure (12) Current in p.u. injected by DSTATCOM in network

Clearly we can observe from the Figure (12) that the voltage sag and swell conditions are compensated with DSTATCOM.

8. CONCLUSION

Voltage sag and swells has emerged as a major concern in the area of power quality. The voltage sag and swell problems in a 11 kV distribution system is investigated in this topic. The DSTATCOM voltage controller can significantly improve the voltage stability performance of induction generators without increasing the short-circuit currents provided by them. A DSTATCOM voltage controller does not introduce significant improvements in the transient stability of synchronous generators.

In fact, the AVR system of these machines can provide voltage control. In a distribution system suffering from short-circuits level and stability constraints, the installation of an induction generator combined with a DSTATCOM voltage controller may be a good choice for distributed generation expansion since the fault currents are minimized in the case of Induction generators. Hence, in the cases of Wind Generations where the Induction Generators are majorly used, it is a good choice to install a DSTATCOM since it can provide the required reactive support for the system. The analysis and simulation of a DSTATCOM application for the voltage flicker mitigating are presented and discussed. The three-phase rms value of the line voltage of bus2 for the events previously described is shown in Figure6.3. Custom power devices like DVR, D-STATCOM, and UPQC can enhance power quality in the distribution system. Based on the power quality problem at the load or at the distribution system, there is a choice to choose particular custom power device with specific compensation. A simple control technique called as Voltage Regulation Technique is simulated for DSTATCOM control and the same is applied to the radial distribution system. The Simulation results shows that the DSTATCOM can compensate the voltage sag and swell conditions caused due to sudden switching of loads. In the absence of the DSTATCOM, the terminal voltage varies considerably, but such variations are minimized in the presence of the DSTATCOM.

9. SCOPE FOR FUTURE WORK

In this paper work, it is shown that the DSTATCOM can mitigate the voltage sag and swell conditions. The work can be extended to reduce the source voltage and source current harmonics supplied due to the non-linear loads. This paper can also be extended for multilevel inverters to reduce the harmonic current at the supply side due to loads. This paper is done for only single generator and can be extended to multi-connected generators with multi level inverters for DSTATCOM.

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