Reactive Power Correction using Distributed Static Synchronous Compensator

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ABSTRACT

The distributed synchronous compensation is a shunt connected FACTS device which supplies reactive power to the load to improve the voltage stability of the load buses. In this system the voltage regulation can be improved by reducing the losses. This work deals with comparison of Push Pull and Voltage Inverter based D-STATCOM for multi bus system. Eight bus system is modeled using the elements of SIMULATION. The models are developed for eight bus system with and without D-STATCOM. The two D-STATCOM systems are compared with respect to total harmonic distortion and reactive power comparison. The D-STATCOM is studied with respect to the voltage stability improvement at the load buses. The results of VSI based D-STATCOM system are compared with those of Push pull inverter based D-STATCOM system.

Introduction

This paper deals with how the voltage stability is improved by using distributed static synchronous compensator. The most common problem in power quality is power sag. Developing of new approaches to Power System Operation and Control are required for overload relief, and efficient and reliable operation. Supporting dynamic disturbances such as transmission lines switching, loss of generation, short-circuits and load rejection, needs there active control to be fast enough to maintain the desired voltage levels and the system stability [1].Flexible AC Transmission Systems (FACTS), besides the underlying concept of independent control of active and reactive power flows, are an efficient solution to the reactive power control problem and voltage in transmission and distribution systems, offering an attractive alternative for achieving such objectives. Originally, equipment based on thyristor, like TCR (Thyristor Controlled Reactor), TSC (Thyristor Switched Capacitor), and SVC (Static VAR Compensator), have been employed involving these problems, but now equipment based on controlled switches such as GTO, IGBT and IGCT is common. The Static Synchronous Compensator (Stat Com), and Static VAR Compensator (SVC) are two types of shunt controllers for injection of reactive current, their primary function is the dynamic voltage control. Related to the SVC, the current is a function of the line voltage and hence its reactive power is function of square of the line voltage. Thus, when the dynamic voltage is say 90%, the injected reactive power is reduced to 75%, just when more is needed. For similar performance, Stat Com size would be much smaller and should be the more cost effective of both. The Stat Com is one of the most used FACTS devices [2] for many applications. In relation to the SVC, the Stat Com differs in that it can synthesize the reactive power from small values of storing elements, and, when operating in the linear region, it exhibits a similar behaviour to the SVC. However, it is seen by the system as a source of synchronous voltage, while the SVC is seen as a variable admittance [3][4]. From the reactive power point of view, the Stat Com provides operating characteristics similar to

a rotating synchronous compensator without the mechanical inertia, and it provides rapid controllability on the three-phase voltages both in magnitude and phase angle. It has received great attention due to its diverse possibilities of construction and operation. The improvements and benefits that can be gained when using a Stat Com include the following:

• Provides smooth voltage control over a wide range of operating conditions.
• Use of encapsulated electronic converters, which minimizes environmental impact on the equipment..
• Power oscillation damping in power transmission systems.
• Transient stability improvement.
• Rapid response to system disturbances.
• Ability to control not only reactive power but, if needed, also active power (with a DC energy source available)
• A small footprint, due to the replacing of passive banks by compact electronic converters.
• Modular, factory built equipment, reducing site works and commissioning time.
• Dynamic voltage control in transmission and distribution systems.

Analysis of STATCOM

This paper analyzes the key issues in the power quality problems, as one of the prominent power quality problems, the origin, consequences and mitigation techniques of voltage sag problem has been discussed in detail. The STATCOM is applied to regulate transmission voltage to allow greater power flow in a voltage limited transmission network, in the same manner as a static VAR compensator (SVC), the STATCOM has further potential by giving an inherently faster response and greater output to a system with depressed voltage and offers improved quality of supply. The FACTS controllers are used to regulate the system voltage. The main applications of the STATCOM are; Distribution STATCOM (D-STATCOM) exhibits high speed control of reactive power to provide voltage stabilization and other type of system control. The DSTATCOM protects the utility transmission or distribution system from voltage sag and

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/or flicker caused by rapidly varying reactive current demand. During the transient conditions the D-STATCOM provides leading or lagging reactive power to active system stability, power factor correction and load balancing and /or harmonic compensation of a particular load [6, 7].

Principle and Operation of D-Statcom

The power electronic based three phase reactive power compensation equipment is the D-STATCOM, which generates and /or absorbs the reactive power whose output can be varied so as to maintain control of specific parameters of the electric power system. The D-STATCOM basically consists of a coupling transformer with a leakage reactance, a three phase GTO/IGBT voltage source inverter (VSI), and a DC capacitor. The Basic Arrangement of D-STATCOM is as shown in fig.1a. The AC voltage difference across the leakage reactance power exchange between the D-STATCOM and the Power system, such that the AC voltages at the bus bar can be regulated to improve the voltage profile of the power system, which is primary duty of the D -STATCOM. However a secondary damping function can be added in to the D-STATCOM for enhancing power system oscillation stability. The D-STATCOM provides operating characteristics similar to a rotating Synchronous compensator without the mechanical inertia. The D-STATCOM employs solid state power switching devices and provides rapid controllability of the three phase voltages, both in magnitude and phase angle. The D- STATCOM employs an inverter to convert the DC link voltage V_{dc} on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the D-STATCOM can be treated as a voltage controlled source. The D-STATCOM can also be seen as a current controlled source.

The objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage. The operation of the D-STATCOM is as follows: The voltage is compared with the AC bus voltage system (Vs). When the AC bus voltage magnitude is above that of the VSI magnitude (V_{dc}); the AC system sees the D-STATCOM as inductance connected to its terminals. Otherwise if the VSI voltage magnitude is above that of the AC bus voltage magnitude, the AC system sees the D-STATCOM as capacitance to its terminals. If the voltage magnitudes are equal, the reactive power exchange is zero. If the D-STATCOM has a DC source or energy storage device on its DC side, it can supply real power to the power system. This can be achieved by adjusting the phase angle of the D-STATCOM terminals and the phase angle of the AC power system. When phase angle of the AC power system leads the VSI phase angle, the DSTATCOM absorbs the real power from the AC system, if the phase angle of the AC power system lags the VSI phase angle, the D-STATCOM supplies real power to AC system.

The main function is to regulate key bus voltage magnitude by dynamically absorbing or generating reactive power to the ac grid network, like a thyristor static compensator. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary transformer voltage in phase with the primary voltage (network side). The VI characteristics of the stat com is as shown in Fig.2.

The following equations shows the real and reactive powers in Compensator and is given by

Real Power $P_{12} = (V_1 V_2 / X_{12}) * \text{Sin}(\delta_1 - \delta_2)$

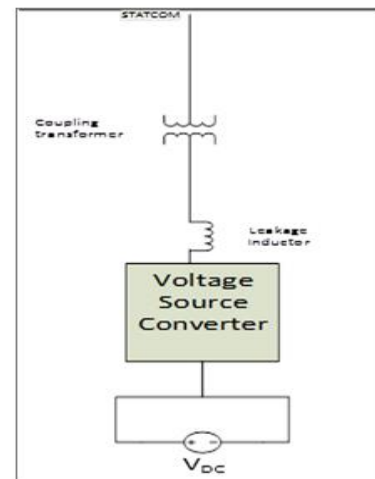Reactive Power $Q_{12} = (V_2 / X_{12}) * (V_1 - V_2)$
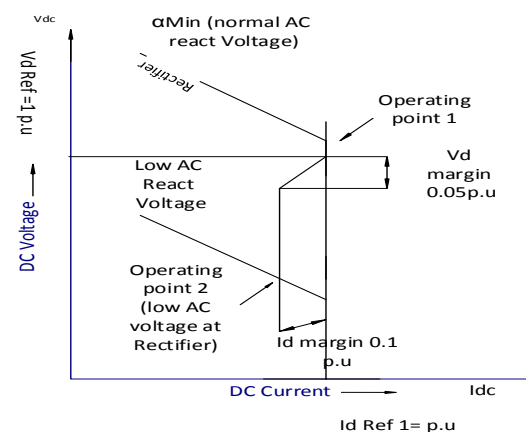
System Bus VAC

Fig.1 Basic Arrangement of D-STATCOM

Fig 2. Natural V-I characteristic of a D-STATCOM

D-STATCOM with VSI:

The basic principle is to use a voltage source inverter that generates a controllable AC voltage source behind a leakage reactance. The voltage difference across the transformer reactance produces active and reactive power flows with the network. The exchange of reactive power with the network is obtained by controlling the magnitude V and the exchange of active power results from a control of the phase shift w. The exchange of active power is only used to control the DC voltage [8]. Under steady state conditions and ignoring the losses the exchange of active power and thus the DC current are zero. A complete STATCOM generally combines several converters. Alternative inverter structures are being designed, for example using single-phase bridges in series. The most common methods used for controlling the AC voltage generated by the inverter are: DC variable voltage with a full wave inverter, sometimes called Pulse Amplitude Modulation (PAM). Constant DC voltage with a pulse-width modulated inverter (PWM).

The Voltage Source Inverter (VSI) is the building block of a D-STATCOM and other FACTS devices. A very simple inverter produces a square voltage waveform as it switches the direct voltage source on and off. The basic objective of a VSI is to produce a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage.

The STATCOM generates a balanced 3-phase voltage whose magnitude and phase can be adjusted rapidly by using semiconductor switches. The STATCOM is composed of a voltage-source inverter with a DC capacitor, coupling transformer, and signal generation and control circuit. The voltage source inverter for the transmission STATCOM operates in multi-bridge mode to reduce the harmonic level of the output

current [9]. Fig.4 shows a single-phase equivalent circuit in which the STATCOM is controlled by changing the phase angle between the inverter output voltage and the bus voltage at the common point connection point. The inverter voltage Vi is assumed to be in phase with the AC terminal voltage Vt [10].
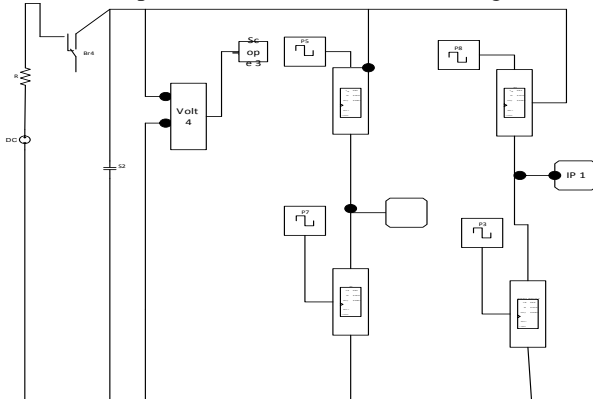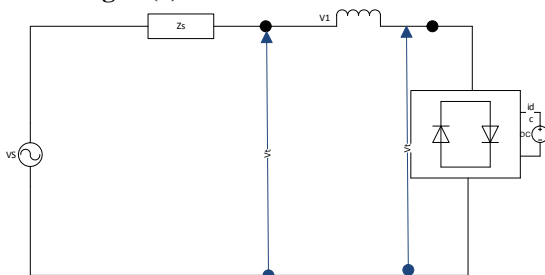

Fig 3. (a) VSI based D-STATCOM

Fig 3. (b) Operating Principle

The STATCOM supplies reactive powers to the AC system if the magnitude of Vi is greater than that of Vt. It draws Reactive power from the AC system if the magnitude of Vt > Vi.

D-STATCOM with Push Pull Inverter

The push-pull inverter circuit comprising a transformer with a power output end coupled to a load and two power input ends is as shown in fig.4. A power driver unit is connected between the two power output ends. A power supply unit, and the power driver unit receives a power signal and outputs two sets of drive signals having same frequency. Circuit diagram of Push-Pull inverter is shown in Fig 4.This circuit is also called parallel inverter since the capacitor appears in parallel with the transformer. T_1 and T_2 conduct alternatively to produce the AC output.
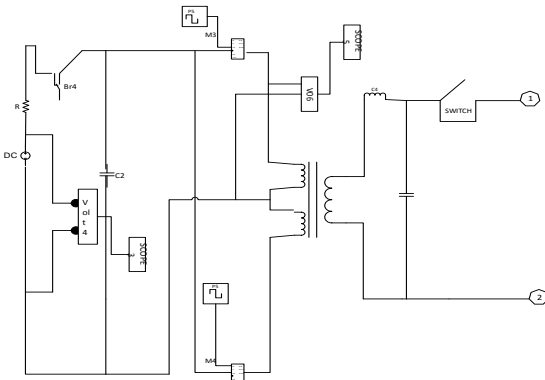

Fig 4. PUSH PULL based D-STATCOM

Simulation Results

For simulation studies, the eight bus system is considered. The circuit model of eight bus system is shown in Fig 4a. Each line is represented by series impedance model. The shunt capacitance of the line is neglected. By closing the breaker in series with the loadanadditionalloadisaddedinparallelwithload-1. Scopes are connected to display the voltages across the two

loads .At t= 0.2 sec, additional load is connected. Voltage across the load-1decreases.This fall in voltage is due to the increased voltage drop. The voltage across bus 4 is as shown in Fig.4b.The active and reactive power across bus4 are as shown in Fig4c.

VSI based system:

The VSI based D-STATCOM added with an eight bus system is as showninFig.5a.TheD-STATCOM is Connected in the line between buses 4 and 8.TheD- STATCOM Model is shown in Fig5b. The active and reactive power in theload-1, voltages across bus-4is as shown in Fig.5c.Itcan be seen that the voltage cross load-1decreases and resumes to the rated value due to the injection of voltage by the D-STATCOM. The RMS voltage across bus-4 is as shown in Fig.5d. The real and reactive power s across bus-4 are as shown in Fig.5e. Bus number Vs Reactive power (Q) is as shown in Fig.5f. The FFT analysis for voltage is as shown in Fig.5g.

Push Pull Based System

The Push Pull Inverter based D-STATCOM added with an eight bus system is showninFig.6a.TheD-STATCOM is connected in the line between buses 4 and 8.The PUSH PULL based D- STATCOMModelisshowninFig.6b. The active and reactive power in theload-1, voltages across D- STATCOM are shown in Fig.6c.It can be seen that thevoltageacrossload-1decreases and resumes to the rated value due to the injection of voltage by the D-STATCOM. The RMS voltage across bus-4 is as shown in fig.6d. The real and reactive power across bus-4 is as shown in Fig.6e. Bus number Vs Reactive Power Q) is as shown in Fig.6f. FFT analysis for voltage is as shown in Fig.6g.
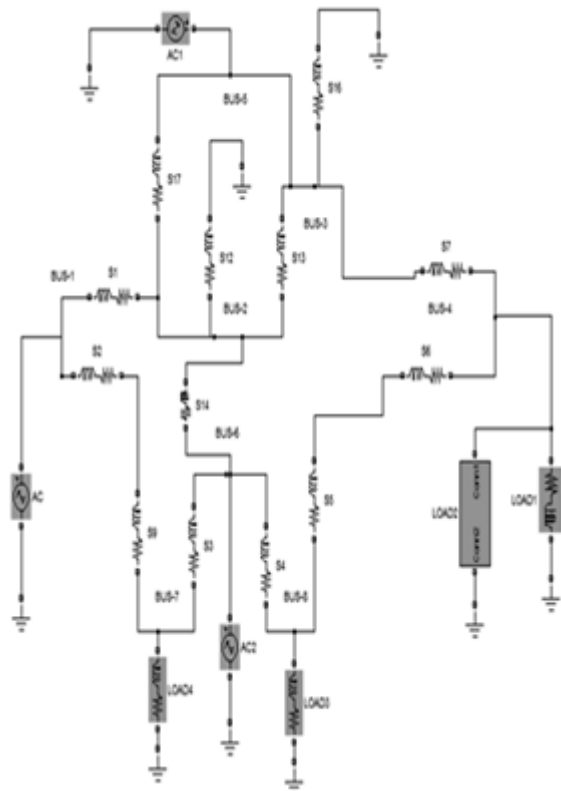

Fig. 4(a). Eight Bus System

Thus the D-STATCOM is able to mitigate the voltages are produced by the additional load. Power quality is improved since the voltage reaches normal value. Summary of real and reactive powers with and without VSI based D-STATCOM are given in Table1. The reactive power increases by the addition of D-STATCOM. This is due to the increase in the bus voltage. Summary of real and reactive powers with and without PUSH PULL based D-STATCOM is given in the Table2. The reactive

power increases when the D-STATCOM is added. Comparison of VSI and PUSH PULL based D-STSTCOM systems is given in Table3. THD in Push Pull inverter system is less by 1.7% than VSI based D-STATCOM system.
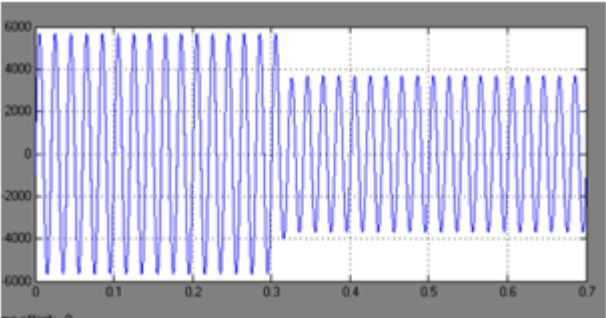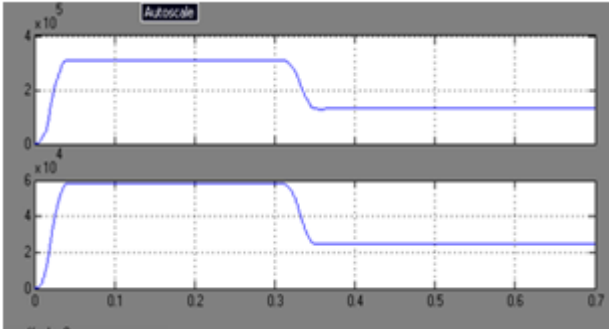

Fig 4(b) Voltage across bus-4
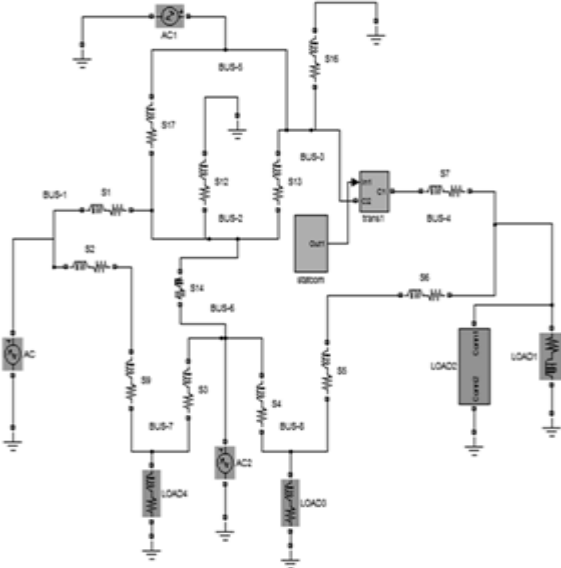

Fig 4(c) Real and Reactive Power across Bus -4
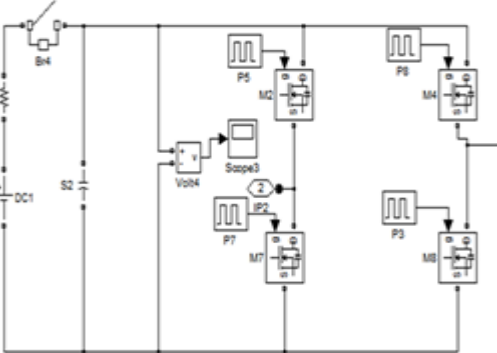

Fig.5(a) Eight Bus System with VSI based D-STSTCOM

Fig. 5(b) VSI based DSTATCOM

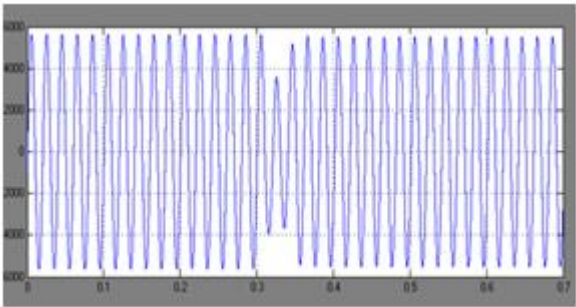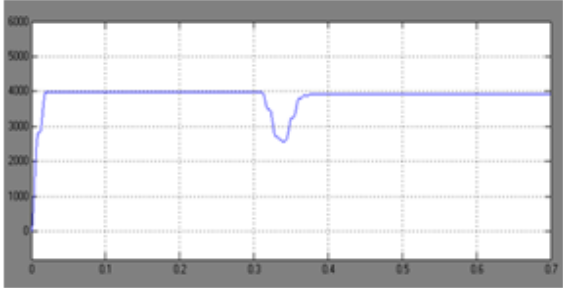**Fig. 5(c) Voltage across bus-4**
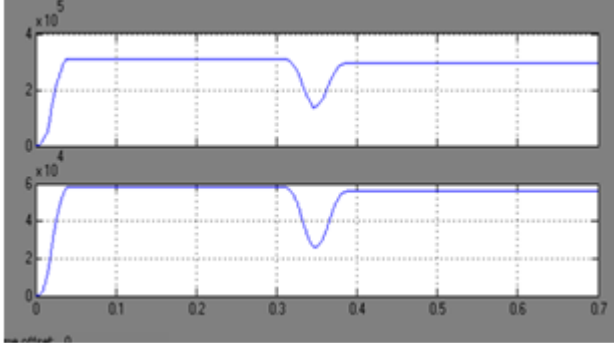

Fig. 5(d) RMS Voltage

Fig.5 (e) real and reactive power across bus-4

Table 1. Summary of Real and Reactive powers with and without VSI based D-STATCOM

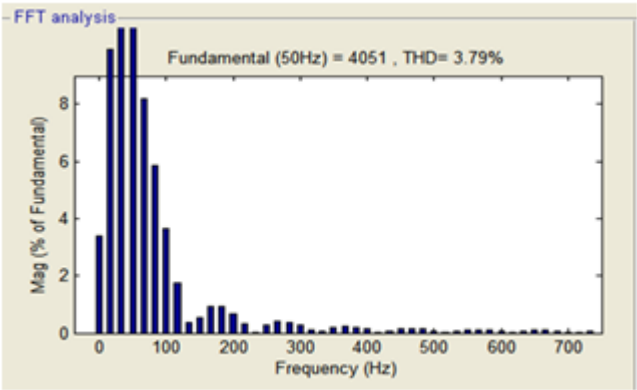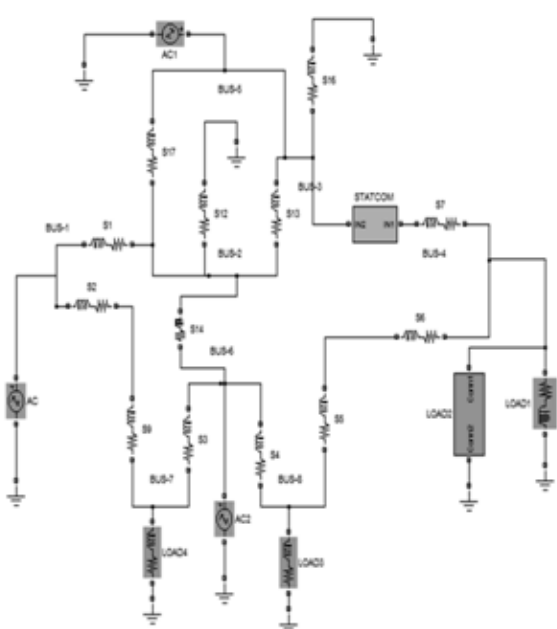| BUS NO	REAL POWER WITHOUT D-STATCOM (MW)	REAL POWER WITH D-STACOM (MW)	REACTIVE POWER WITHOUT D-STATCOM (MVAR)	REACTIVE POWER WITH D- STATCOM (MVAR)
BUS-4	0.130	0.296	0.245	0.56
BUS-7	0.60	0.604	0.38	0.39
BUS-8	0.27	0.326	0.26	0.31

Fig. 5(f) FFT analysis for voltage

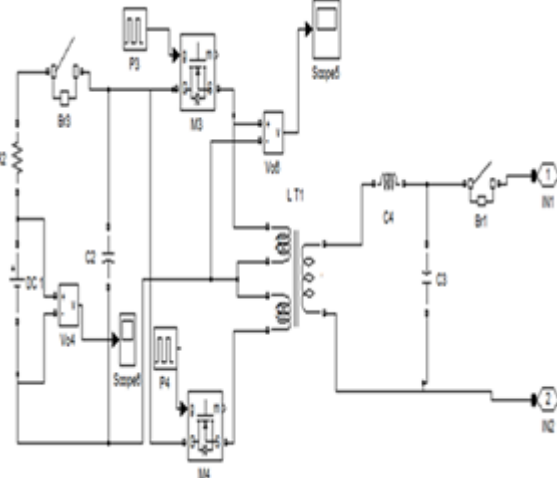**Fig. 6(a) Eight Bus System with PUSHPULL based D-STATCOM**

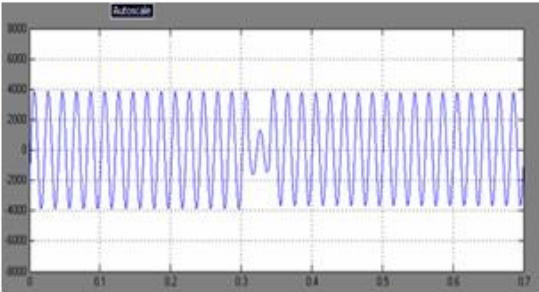**Fig. 6(b) PUSH PULL based D-STATCOM**

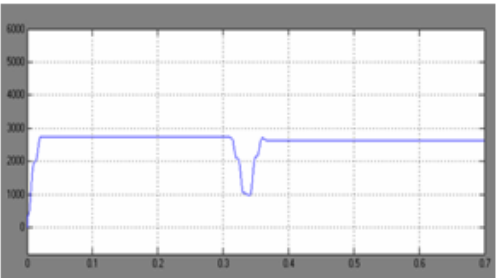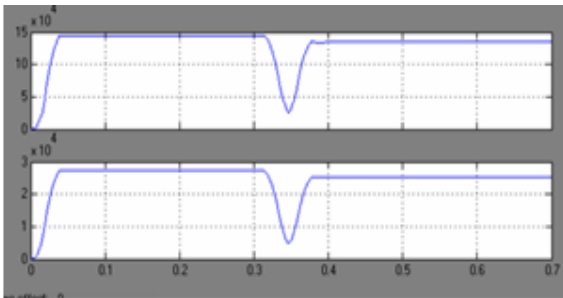Fig. 6(c) Voltage across bus-4

Fig. 6(d) RMS Voltage

Fig. 6(e) Real and Reactive Power across bus-4

Table 2.Summary of Real and Reactive powers with and without Push Pull based D- STATCOM

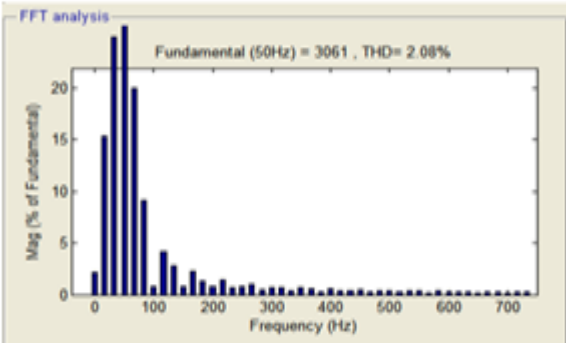| BUS NO	REAL POWER WITHOUT STATCOM (MW)	REAL POWER WITH STATCOM (MW)	REACTIVE POWER WITHOUT STATCOM (MVAR)	REACTIVE POWER WITH STATCOM (MVAR)
BUS-4	0.130	0.134	0.245	0.254
BUS-7	0.60	0.604	0.38	0.382
BUS-8	0.27	0.275	0.26	0.259

Fig. 6(f) FFT Analysis for Voltage

Table 3. Comparison between VSI and Push Pull Inverter based D_STATCOM

INVERTER TYPE	RMS VOLTAGE(V)	SAG TIME (SEC)	REACTIVE POWER	COMPENSATION TIME (SEC)	THD %
VSI	3919	0.31	0.55	0.4	3.79
PUSH PULL INVERTER	2640	0.31	0.254	0.38	2.08

Model of distribution system with dstatcom:

Fig. 7 shows the Simulink model of distribution system with DSTATCOM. Fig.7 (a) shows the internal view of DSTATCOM. In this the simulation is carried out in two cases. In case 1 we have considered load disturbance means sudden change of reactive load without DSTATCOM and with DSTATCOM. In case 2 we have considered line disturbance like single line to ground fault (SLG), without DSTATCOM and with DSTATCOM. A complicated circuit diagram is shown below, a 3-Φ source is applied to 3-Φ V-I measurement which is linked with a sequence analyser and is transferred to inductive load. A series RLC branches can be seen from the distributed system. Internal view of D-STATCOM is shown in fig 7.(a).
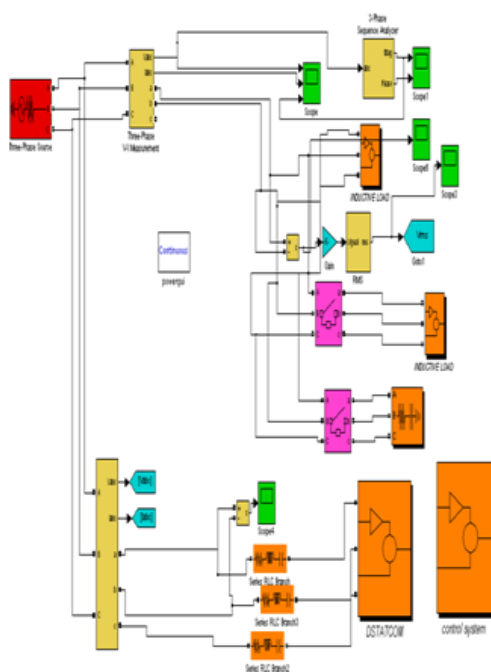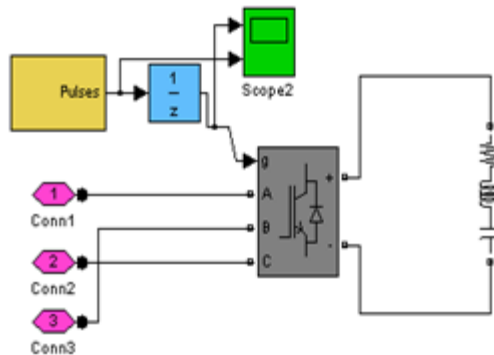
Figure 7. Simulink Model of DSTATCOM

Figure. 7(a) DSTATCOM Internal view

Case 1: Fig. 7(b) shows the three phase voltage and three phase currents and RMS value of one line voltage. Here at t=0.2 sec a inductive load is switched ON the line voltage fall from1 P.U to 0.8 P.U.
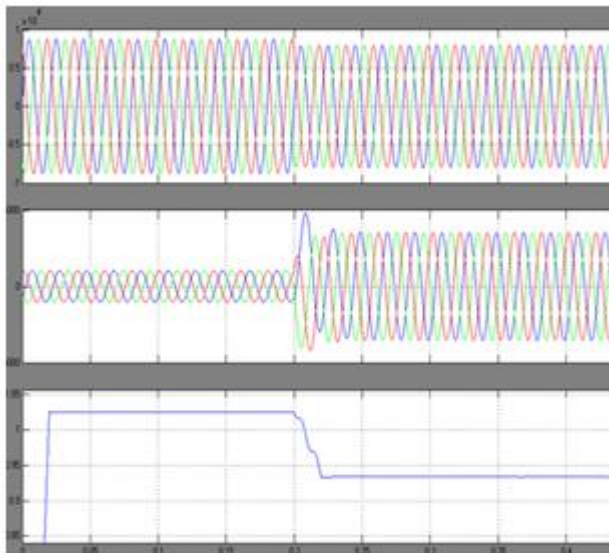

Figure. 7.(b) Simulation results without DSTATCOM

Fig. 7.(c) shows the RMS value of one line voltage with DSTATCOM. Here at t=0.2 sec a inductive load is switched ON the line voltage fall from1 P.U to 0.98 P.U.
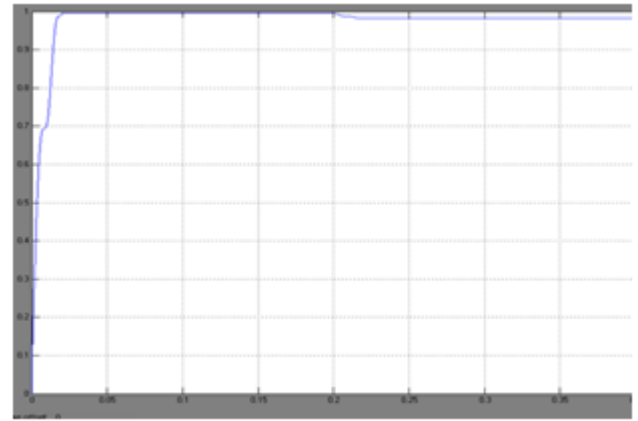

Figure. 7. (c) Simulation results with DSTATCOM

Case 2 : Fig. 7.(d) shows RMS value of line voltage. Here at t=0.2 sec a SLG fault is created the line voltage fall from1 P.U to 0.78 P.U.
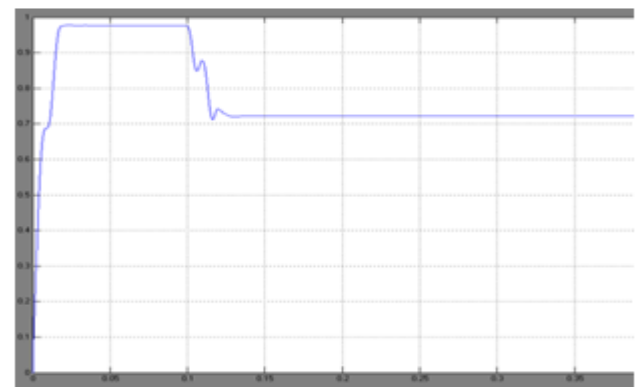

Figure. 7. (d) Simulation results without DSTATCOM

Fig. 7. (e) Shows the RMS value of line voltage with DSTATCOM. Here at t=0.2 sec a SLG fault is created the line voltage fall from1 P.U to 0.98 P.U.
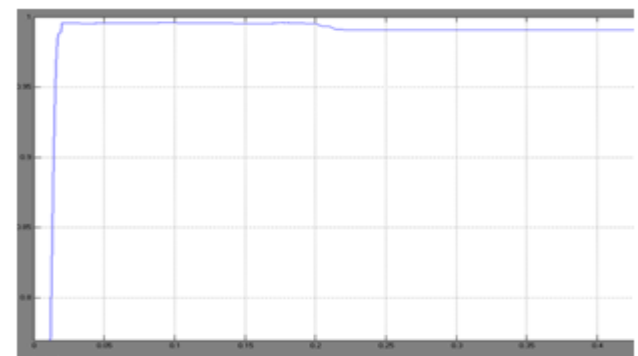
Figure. 7.(e) Simulation results with DSTATCOM

Discussion

This paper deals with how the voltage stability is improved by using D-STATCOM, this is not a new technique but it is optimistic one compared to the other researches. It can be seen from the references that different techniques are used to improve the voltage stability by :

• Supporting dynamic disturbances such as transmission lines switching, loss of generation, short-circuits and load rejection, needs there active control to be fast enough to maintain the desired voltage levels and the system stability [1].

• The Stat Com is one of the most used FACTS devices [2] for many applications.

• It is seen by the system as a source of synchronous voltage, while the SVC is seen as a variable admittance [3][4].

• During the transient conditions the D-STATCOM provides leading or lagging reactive power to active system stability,

power factor correction and load balancing and /or harmonic compensation of a particular load [6,7].

• The exchange of active power is only used to control the DC voltage [8].

• The voltage source inverter for the transmission STATCOM operates in multi-bridge mode to reduce the harmonic level of the output current [9].

• STATCOM (static synchronous compensator) is proposed with constant dc link voltage to achieve this objective, two sets of three-level 12-pulse VSCs are used which are operated at the fundamental frequency switching. The reactive power is controlled by the phase angle difference between the two sets of three-level 12-pulse VSCs. The converter utilization in the proposed configuration of STATCOM is improved as it is working at a constant dc link voltage. The proposed model of the STATCOM is connected to a 33 kV, 50 Hz system and simulation results are presented for demonstrating its steady state and dynamic performance.[16],[17],[18].

• The other one is Variable speed wind turbine with full scale converter or so-called type-D wind turbine generator worldwide installation has been significantly increased in the last few years. Voltage Swell in the grid side may cause the wind turbine to be disconnected from the grid. In this paper, STATCOM is applied to improve the high voltage ride through capability of type-D wind turbine during voltage swell in the grid side. Simulation is carried out using MATLAB/Simulink software. Results show that STATCOM can significantly improve the high voltage ride through (HVRT) capability of type-D wind turbine and prevents it from being disconnected from the grid during certain level of voltage swell in the grid side [19].

Conclusion

Eight bus system is modelled and simulated using SIMULINK. The simulation results of eight bus system with and without VSI based D-STATCOM are presented. Also, simulation of eight bus system with and without Push Pull inverter based D-STATCOM is done. VSI and Push Pull inverter based D-STATCOM systems are compared. Voltage stability is improved by using both types of D-STATCOM. This system has improved reliability and power quality. Push Pull inverter system is found to be superior to VSI based system. The simulation results are in line with predictions. The scope of present work is the modelling and simulation of eight bus system and compared. This concept can be extended to 64 bus system. Further the Simulink model of distribution system with DSTATCOM is introduced in this paper in fig.7. In this the simulation is carried out. we have considered load disturbance means sudden change of reactive load without DSTATCOM and with DSTATCOM and we have considered line disturbance like single line to ground fault (SLG), without DSTATCOM and with DSTATCOM. These techniques are used to improve the voltage stability.

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