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Simulation of Reactive Power Compensation Using STATCOM

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Abstract: - Power quality in distribution systems has been attracting an increasing interest during recent years. Research studies include the quality of voltage supply with connected to the same point of common coupling (PCC). Utility distribution networks, sensitive industrial loads and critical commercial operations suffer from various types of outages and service interruptions which can cost significant financial losses. With the restructuring of power systems and with shifting trend towards distributed and dispersed generation, the issue of power quality is going to take newer dimensions. [1]In developing countries like India, where the variation of voltage and many such other determinants of power quality are themselves a serious question, it is very vital to take positive steps in this direction .The present work is to identify the prominent concerns in this area and hence the measures that can enhance the quality of the power are recommended The rapid development of power electronics technology provides opportunities to develop new power equipment to improve the performance of the actual power systems. During the last decade, a number of control devices called “Flexible AC Transmission Systems” (FACTS)[1] technology have been proposed and implemented.

FACTS devices STATCOM are the mostly used device in the power systems. In this research, principle of operation and modeling of a STATCOM (Static Synchronous Compensator) used for reactive power compensation on a Distribution network have been carried out. The [2] STATCOM consists of a DC storage capacitor, a VSC (Voltage Source Converter) and a small reactance in series with VSC. The simulation of STATCOM model is done using MATLAB/SIMULINK. The IGBT/Diode switches are used for the VSC. The pulses to these switches are generated using [3] SPWM (Sinusoidal Pulse Width Modulation) technique. Reactive power compensation is achieved by applying the direct output voltage control technique. Steady state and dynamic performance of a ±3 MVAR STATCOM on a 25 KV Distribution network is evaluated. Both Inductive and Capacitive operating modes of STATCOM have been studied and presented.

Key words- *Power quality; FACTS control devices; STATCOM ; MATLAB Simulation..*

I. INTRODUCTION

In recent years, voltage stability and control are increasingly becoming a limiting factor in the planning and operation of some power systems, mainly in longitudinal ones. However, a variety of considerations constrains the construction of new transmission lines. This has been reflected in the necessity to maximize the use of existing transmission facilities. On steady state, bus voltages must be controlled on a specified range. A suitable voltage and reactive power control allows to obtain important benefits in the power systems operation such as the reduction of voltage gradients, the efficient transmission capacities utilization and the increase of stability margins. A Power quality problem is an occurrence manifested as anon standard voltage, current or frequency that results in a failure or a mis-operation of end user equipments. Some of the most common types of power quality disturbances in the distribution systems are listed as

A. *Voltage Sag, Voltage Swell and Voltage Flickring*

A simple understanding of the causes will allow for effective solutions to mitigating these disturbances in most applications. This chapter will explain the power quality problems in the distribution system.

B. *Power Quality Problems*

1) *Voltage Sag (or) DIP*

A voltage dip is a short time (10 ms to 1 minute) event during which a reduction in RMS 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 a 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-grounded 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 transformer energizing.

2) *Voltage Swell*

Swells, originally referred to as surges, and were similar to sags, except that the voltage exceeded a user defined high limit. Swell - an increase to between 1.1 pu and 1.8 pu in RMS voltage or current at the Power frequency durations from 0.5 to 1 minute. Sag is differentiated from an outage or interruption by the amplitude being greater than or equal to 0.1 per unit (of nominal voltage).

3) *Volatge Flickering*

Voltage flicker, a phenomenon of annoying light intensity fluctuation, caused by large rapid industrial load changes, has been a major concern for both power companies and customers in the area of power quality. This flicker is objectionable only when the magnitude and frequency of occurrence of the voltage drop exceed certain thresholds. The threshold of objection is shown on a Voltage-Flicker curve. If the magnitude of the voltage drop and the frequency of occurrence lie below the threshold of perception, people generally do not notice any flicker. Voltage flicker occurs when large industrial loads, such as electric arc furnaces, rolling mills, and pumps operate periodically in a weak power distribution system. Large industrial loads i.e. electric arc furnaces, used for melting, for example scrap with electric energy, and cause voltage distortion like harmonics and voltage fluctuation in the feeding AC system. 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 the reactive control to be fast enough to maintain the desired voltage levels and the system stability. Flexible AC Transmission Systems (FACTS), besides the underlying concept of 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.

II. VOLTAGE SOURCE CONVERTER

A voltage-source converter is a power electronic device, which can generate a sinusoidal voltage of desired magnitude, frequency and phase angle. VSC is the main building block of the STATCOM. Voltage source converters are widely used in adjustable-speed drives, but can also be used to mitigate power quality problems. The VSC is used to either completely replace the voltage or to inject the 'missing voltage'.

The 'missing voltage' is the difference between the nominal voltage and the actual. The converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage. The solid-state electronics in the converter is then switched to get the desired output voltage. Normally the VSC is not only used for voltage dip mitigation, but also for other power quality issues, i.e. flicker and harmonics. The power converter employed in the [3]STATCOM can be either a Voltage Source Converter (VSC)or a Current-Source Converter (CSC). In practice, however, the VSC is preferred because of -blocking capability required by the power semiconductor devices used in CSC. The VSC can operate with higher efficiency than the CSCs do in high-power applications. [4]The VSC is analyzed as a linear network with a topology that changes depending on the state of the six (ideal) switching devices. The analysis exploits the fact that the system is piecewise linear; consequently, over each interval during which the switches do not change their state, the circuit equations may be solved using standard linear techniques. Simple voltage Source Converter (two level-poles)The voltage-source converter (VSC) is presently considered the best candidate for the implementation of a high power STATCOM and other FACTS devices based on VSC such as the UPFC and the SSSC, and all existing and planned new installations know based on this approach. A two- level pole is the simplest switching arrangement capable of producing AC output from a DC source in the form of a simple square wave switches the direct voltage source on and off, as illustrated. Voltage source converter may be six pulses or 12 pulses or may be multi level inverter. In this chapter we go for the six pulse converter.

III. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The Static Synchronous Compensator (STATCOM) is a shunt device of the Flexible AC Transmission Systems (FACTS) family using power electronics to control power flow and improve transient stability on power grids. The STATCOM regulates voltage at its terminal by controlling the amount of reactive power injected into or absorbed from the power system. The STATCOM mainly consists of a VSC(Voltage Source Converter)connected to AC system through a coupling transformer. The DC link voltage is provided by a capacitor C which is charged with power taken from the network. The VSC uses forced-commutated power electronic devices (GTOs, IGBTs or IGCTs) to synthesize an AC voltage from the DC voltage of capacitor. When system voltage is lower than the VSC output voltage, the STATCOM generates reactive power (capacitive operating mode). When system voltage is higher than the VSC output voltage, it absorbs reactive power (inductive operating mode). The STATCOM [3]is a Shunt connected FACTS device It is a Voltage source converter operated from a DC source or an energy storage capacitor and has the capability to inject the Controllable Current into the AC system. [4]The STATCOM regulates the voltage at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. The STATCOM capacitive or inductive output currents can be controlled independently from its terminal AC bus voltage. Because of the fast-switching characteristic of power converters, [5]STATCOM provides much faster response as compared to the SVC. In addition, in the event of a rapid change in system voltage, the capacitor voltage does not change instantaneously; therefore, STATCOM effectively reacts for the desired responses. For example, if the system voltage drops for any reason, there is a tendency for STATCOM to inject capacitive power to support the dipped voltages. [6]TATCOM is capable of high dynamic performance and its compensation does not depend on the common coupling voltage. Therefore, STATCOM is very effective during the power system disturbances. Moreover, much research confirms several advantages of STATCOM. These advantages compared to other shunt compensators include:

- Size, weight, and cost reduction
- Equality of lagging and leading output
- Precise and continuous reactive power control with fast response
- Possible active harmonic filter capability.

IV. SIMULINK MODEL OF STATCOM

A ±3 MVAR STATCOM is used for reactive power compensation on a 25Kv distribution network has been modeled and simulated using [3]MATLAB/SIMULINK. Direct output voltage control strategy has been used in which both the magnitude and phase angle of VSC output voltage can be controlled. Good transient response and good voltage regulation in the event of voltage sag / voltage swell can be effectively achieved with this control strategy.

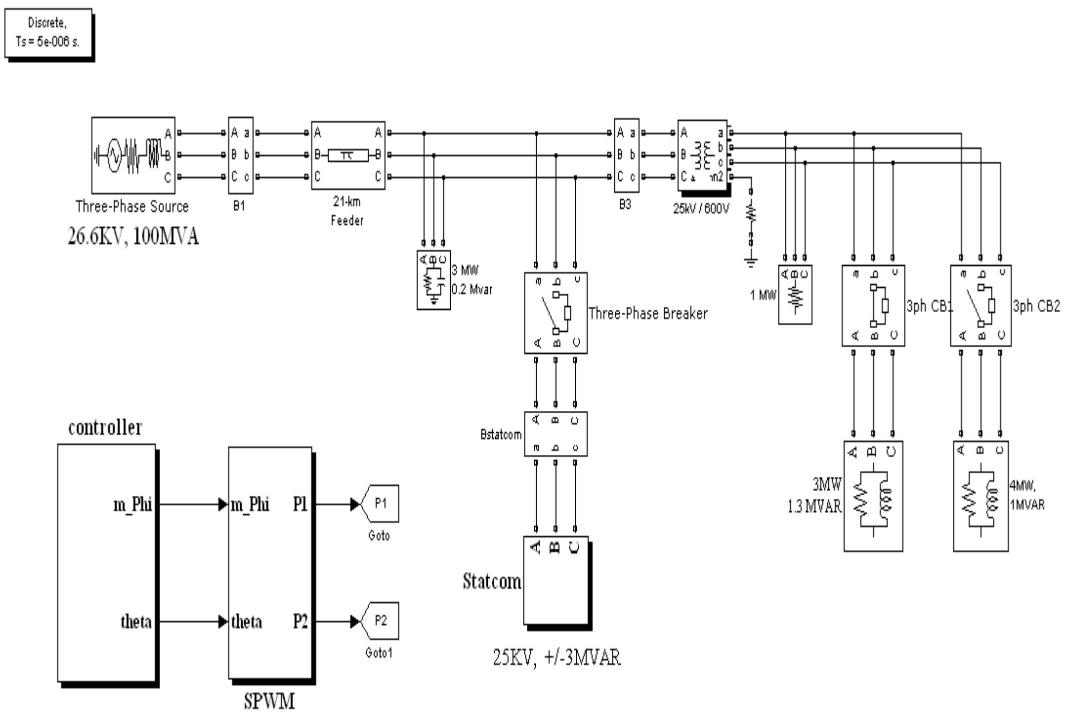

Fig.1 MATLAB/SIMULINK model of STATCOM

The distribution network consists of a 25KV, 100MVA source followed by a 21Km feeder which is modeled by a pi-equivalent circuit connected to bus B3. At this bus a 3 MW, 0.2MVAR load, a 25KV/600V transformer, a 1 MW load and two transient loads of 3MW, 0.8MVAR and 4 MW, 1 MVAR respectively are connected.

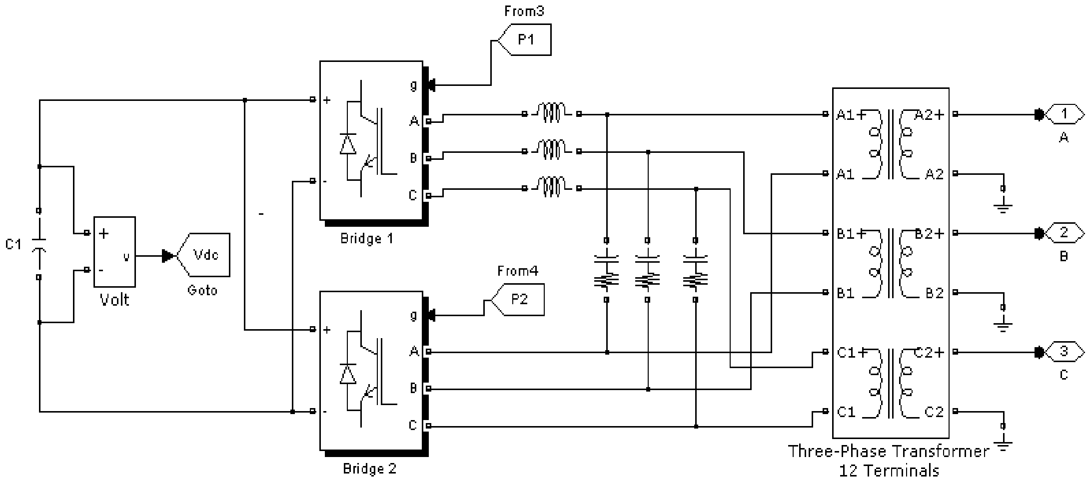

Fig.2 STATCOM internal circuit

A ±3 MVAR STATCOM is connected to a 25KV distribution network in shunt through a filter and 1.25/25KV Δ - Y coupling transformer. The primary of this transformer is fed by a voltage source PWM inverter consisting of two IGBT bridges. A filter circuit is used at the inverter output side to reduce the harmonics. A 8000μf capacitor is used as dc voltage source for the inverter. The sinusoidal pulse width modulation technique is used for generating the gate pulses to both IGBT bridges and carrier frequency used for pulse generation is 2 KHz

V. SIMULATION RESULTS

This chapter presents the results obtained from the simulation of STATCOM model shown in Fig.1. Simulations are carried out using MATLAB/SIMULINK. The static and dynamic performance of STATCOM [2]under both steady state and transient conditions has been studied and the results are verified. In the present model the Distribution network have two transient loads Load-1 (3 MW, 0.8 MVAR) and Lod-2 (4 MW, 1 MVAR) respectively.

The loads on the distribution network during time t =0 to 0.5 sec is shown in table Table 5.1.

Time(Sec)	Load-I 3MW, 0.8MVAR	Load-II 4MW, 1MVAR
0 to 0.1	Connected	Disconnected
0.1 to 0.2	Connected	Connected
0.2 to 0.3	Connected	Disconnected
0.3 to 0.4	Disconnected	Disconnected
0.4 to 0.5	Connected	Disconnected

Table 5.1.

A. *Without Statcom*

The voltages at buses B1 and B3 without STATCOM are shown in Fig 3. From time t = 0 to 0.1sec only load-I is connected to the system and the voltage at bus 3 VB1 is 1 pu. From time t =0.1 to 0.2 sec the second load is connected to the system then the current drawn from the distribution system increases, the Voltage VB3 fall down to 0.955 pu. From time t= 0.2 to 0.3sec load-2 is disconnected from the system and voltage VB3 is 1 pu. During time t = 0.3 to 0.4sec both the loads are disconnected from the distribution system, then the Voltage VB3 raised to

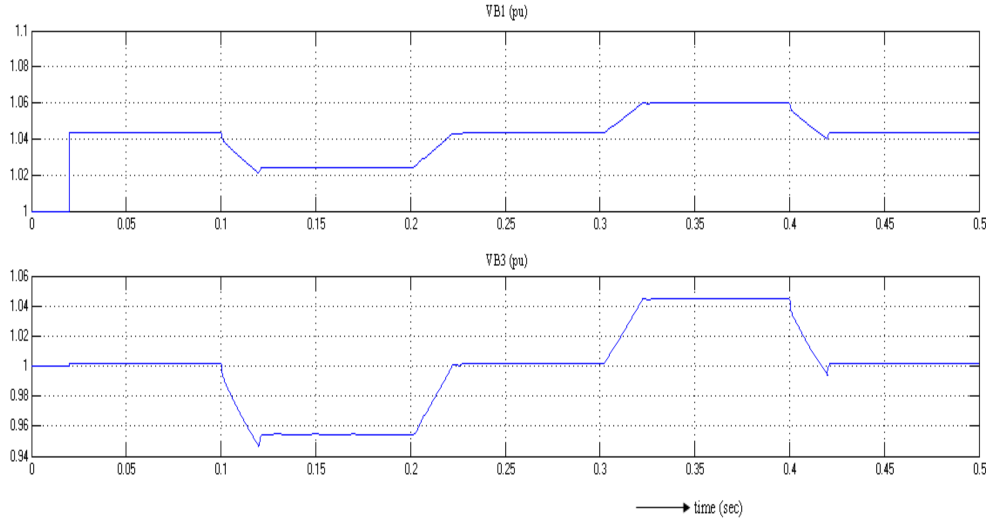

Fig.3 *Voltage at buses B1 and B3 without STATCOM*

1.045 pu. From time t = 0.4 to 0.5 sec load-I is connected to the system, then the voltage VB3becomes 1 pu.

B. *With Statcom*

With STATCOM connected to the distribution network the output voltage and output current of STATCOM are shown in Fig 4. When there is an increase of load from time t = 0.1 to 0.2 sec the STATCOM output current is leading with respect to the Voltage i.e. the [5]STATCOM is generating and supplying reactive power to distribution network. And from time t = 0.3 to 0.4sec both the loads are disconnected the STATCOM output current is lagging to the Voltage i.e. the STATCOM is absorbing the reactive power from the distribution system

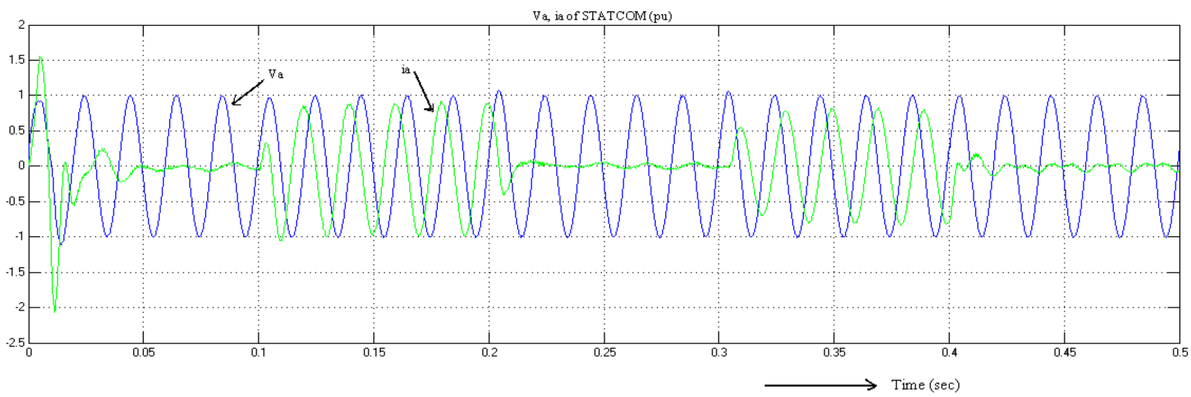

Fig.4 Output Voltage and Currents of STTCOM

The waveforms of reactive reference current (iqref), real reference current (idref), the direct and quadrature axis components of STATCOM output current are shown in Fig 5.

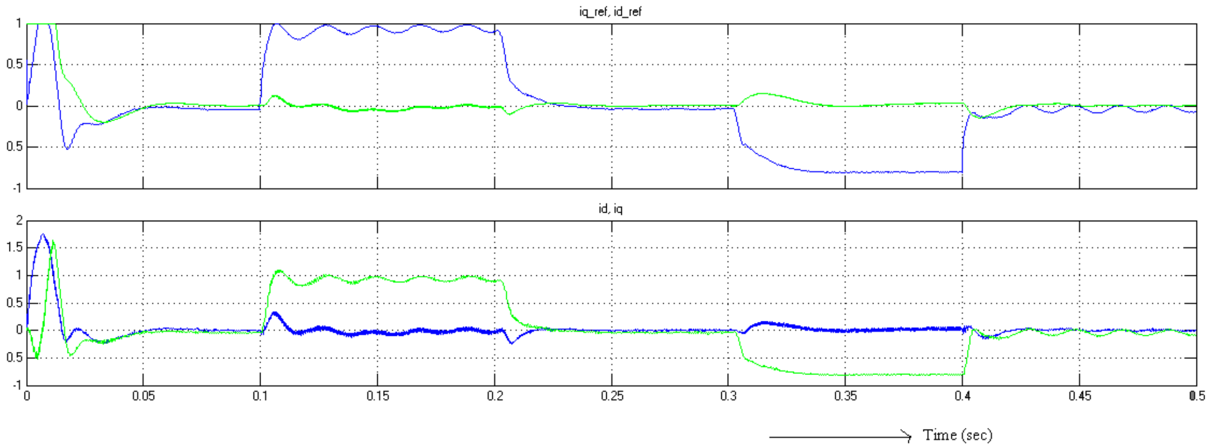

Fig.5 iqref, idref, id and iq waveforms

During time t = 0.1 to 0.2 sec the reactive current (iq) is nearly +0.9pu, STATCOM supplying the current and during t = 0.3 to 0.4 sec the reactive current (iq) is nearly -0.75pu, STATCOM drawing current from [6]distribution system. Fig 6. Modulation index and Phase angle the waveforms of Modulation index (mi) and Phase angle (phi) are shown in figure 6. Initially it is constant when there is load increase mi is increased and when there is load decrease mi is decreased.

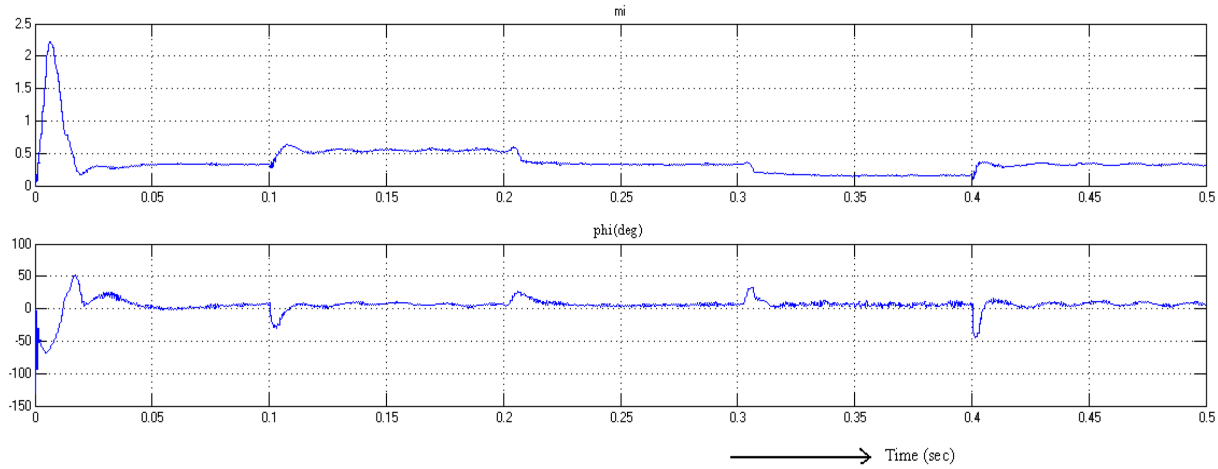

Fig.6a. Load on the system

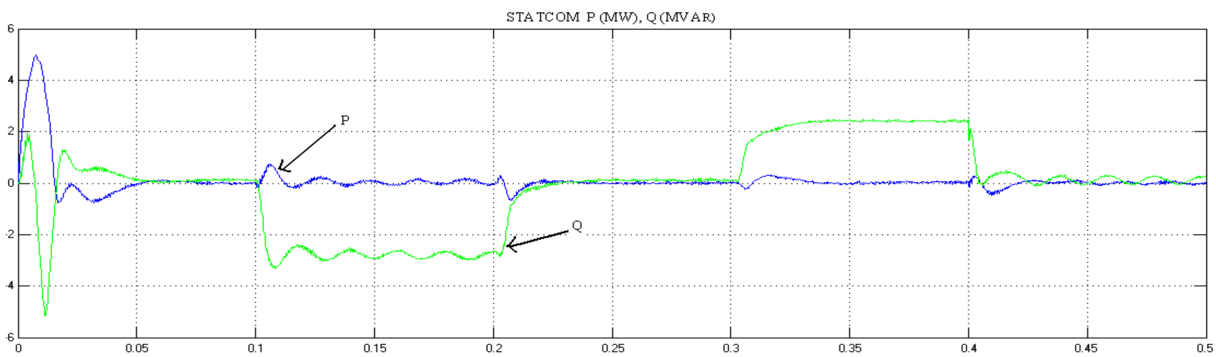

Fig.6b. Real and Reactive power of STATCOM

The load on the distribution system and real and reactive power of STATCOM are shown in Fig 6a and fig 6b.
The waveforms of voltage at buses B1 and B3 with STATCOM are shown in Fig 7.

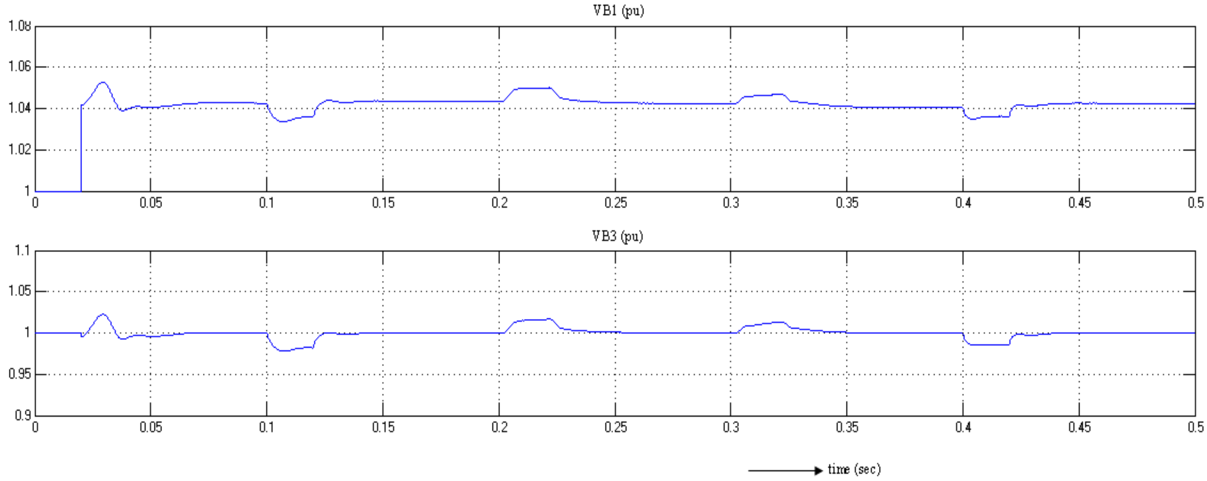

Fig.7. *Voltages at Bus1 and Bus3 with STATCOM*

With STATCOM connected to network at starting the voltage at bus B3 is constant at 1.0pu. So the STATCOM neither generate nor absorb the reactive power from the network. At t =0.1sec load1 is connected to the network. The STATCOM supplies reactive power o2.8Table 5.2 Real and Reactive powers of STATCOM and load MVAR

Time (sec)	Load at Bus3		STATCOM	
	P (MW)	Q (MVAR)	P (MW)	Q (MVAR)
0 to 0.1	3.9	1.4	0	0
0.1 to 0.2	7.6	2.7	0	-2.8
0.2 to 0.3	3.9	1.4	0	0
0.3 to 0.4	1	0	0	+2.4
0.4 to 0.5	3.9	1.4	0	0

Table 5.2

MVAR to the network to maintain the voltage at bus B3 constant. At t = 0.2 sec this load is disconnected from the network. The STATCOM does not supply reactive power to the network. At t = 0.3 sec both load1 and load-II are disconnected from the network.
The STATCOM absorbs reactive power of +2.4 MVAR from the system to maintain voltage at bus B3 constant.

C. System Parameters Taken For The Simulation

Fundamental frequency: 50 Hz
Three phase source: 100 MVA,26.6 KV,
Rs = 0.625Ω,
LS = 16.58mH.
Load Transformer rating: 3 MVA25 KV /1250 V
Inverter rating: +/- 3 MVAR
25 KV On secondary side of Transformer

DC capacitor capacitance: 8000 μF
Filter circuit parameters: Rf = 78.54 Mω
Lf =800 μH
Cf =100 μF
Inverter switching frequency: fc = 2 KHz
DC link voltage: Vdc = 3000 V
Sampling time: Ts =5 μs
Load 1: P1 = 3 MW, Q1 =1.2 MVAR
Load 2: P2 = 4 MW, Q2 =1 MVAR

This research discussed the simulation results of proposed STATCOM model. The results showed the reactive power compensation, voltage regulation can be effectively achieved using STATCOM with good transient response. The next chapter focuses on the conclusion and scope for further work.

VI. CONCLUSION AND SCOPE FOR FURTHER WORK

Power quality problems are the one of the major concern in the distribution systems. The major power quality problems are voltage dip, voltage swell and voltage flickering. There are so many effects associated with these problems like deteriorates the performance of electric drives ,leads to malfunction of protective relays and leads to the reduction in the life span of most equipment. Voltage dips are caused by transient overloads, Voltage swells are caused by transient under loads, and Voltage flickering is caused when large industrial loads such as electric arc furnaces, rolling mills, and pumps operate periodically in a weak power distribution system. All these power quality problems can be mitigated by supplying the reactive power. There are many FACTS devices which will supply the reactive power. Among those devices STATCOM is the most effective FACTS controller for reactive power compensation and voltage regulation. ASTATCOM which employs direct output voltage control strategy has been modeled and simulated using MATLAB/SIMULINK. The simulation results showed that good transient response and good voltage regulation in the event of voltage sag / voltage swell can be effectively achieved by the proposed STATCOM.

In this thesis the STATCOM using Six-Pulse inverter based VSC is simulated using MATLAB/SIMULINK. But the simulation of STATCOM with Multilevel inverter based VSC was not carried out and the hardware implementation of STATCOM with Six-Pulse inverter based VSC also not carried out here. Further work includes the simulation of STATCOM with multilevel inverter based VSC and the hardware implementation.

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