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Modelling and Simulation of STATCOM for Reactive Power and Voltage Control.

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***Abstract*—The continuous demand in electric power system network has caused the system to be heavily loaded leading to voltage instability. However, Flexible Alternating Current Transmission System (FACTS) devices provide the necessary features to avoid technical problems in the power systems. They also increase the transmission line efficiency. Among the FACTS family is Static Synchronous Compensator (STATCOM). It injects the compensating current in phase quadrature with line voltage, it can emulate as inductive or capacitive reactance so as to produce capacitive power for the AC grid or draws inductive power from the ac grid to control power flow in the line. This paper describes the approach of a shunt connected FACTS device (STATCOM), in which the device is modelled and used to provide controllable bus voltage and reactive power compensation. Simulation results obtained using MATLAB/SIMULNK for selected 3-bus- 3-machine 500 kV interconnected power system. The findings reveal that the performance and behaviour of the STATCOM in controlling bus voltage and reactive power on 500 kV transmission network was effective. The simulated results show the advantages of using STATCOM.**

Keywords—Flexible AC Transmission System (FACTS); Static Synchronous Compensator (STATCOM); Reactive Power Compensator; Bus Voltage

I. INTRODUCTION

In interconnected power systems, which today are very complex, there is great need to improve utilization while still maintaining reliability and security. While some transmission lines are charged up to the limit load, the others may have been overloaded, which have an effect on the values of voltage and reduces system stability and security. Transmission networks of present power systems are becoming progressively more stressed because of increasing demand and limitations on building new lines. One of the consequences of such a stressed system is the risk of losing stability following a disturbance. For this reason, it is very important to control the power flows along transmissions lines to meet transfer of power needs. Summarizing the current development, it must be noticed that both planning and operation of electric networks are undergoing fundamental and radical changes in order to cope with the increased complexity of funding economic and reliable network solutions. The necessity to design power system networks that provide the maximal transmission capacity and at the same time resulting in minimal cost is a great engineering challenge. Despite that the reactive power problem have been successfully employed in some sample power system [1] and [2]. Still much need to be done to ensure effective and efficient distribution of reactive power and voltage control in an electric network. In an attempt to circumvent the deficiencies of the conventional methods, FACTS technology which was developed by [3] offers considerable advantage over the conventional one's in terms of space reduction and performance [4]. FACTS are a result of the development in the power electronic area and aim to rapidly control electrical signal [5].

This paper deals with modeling and simulation of Static Synchronous Compensators, (STATCOM), a shunt compensation device from the family of Flexible Alternating Current Transmission System, FACTS. A STATCOM or Static Synchronous Compensator is used for voltage compensation at the receiver end of a transmission lines, thus replacing banks of shunt capacitors. When used for this purpose, STATCOMs offer a number of advantages over banks of shunt capacitors, such as much tighter control of the voltage compensation at the receiver end of the ac transmission line and increased line stability during load variations [6]. It is build based on power electronics Voltage Source Converter and can act as either a source or sink of reactive AC power which is tied to a transmission line. The STATCOM regulates the voltage magnitude at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the STATCOM generates reactive power (STATCOM capacitive). When system voltage is high, it absorbs reactive power (STATCOM inductive). So the shunt controller is therefore a good way to control voltage in and around the point of connection through injection of reactive current (leading or lagging) alone or a combination of active and reactive current for a more effective voltage control and damping of voltage dynamics [7]. The real power (P) and reactive power (Q) are given by:

$$P = \frac{E.V}{X} \sin \delta \qquad (1)$$

$$Q = \frac{E^2}{X} - \frac{E.V}{X}\cos\delta \qquad (2)$$

Where E is the line voltage of transmission line
V Is the generated voltage of the Voltage Source Converter.
X Is the equivalent reactance of interconnection transformer δ Is the phase angle of E with respect to V.

The basic element is the Source Voltage Converter (SVC) which converts an input DC voltage to an AC voltage at the fundamental frequency with a given magnitude and a controllable phase. The AC output voltage is dynamically controlled in order to provide the required reactive power to the network [8].

A. *Operational Principle of STATCOM*

The fig. 1 shows the STATCOM tie on to a transmission line.

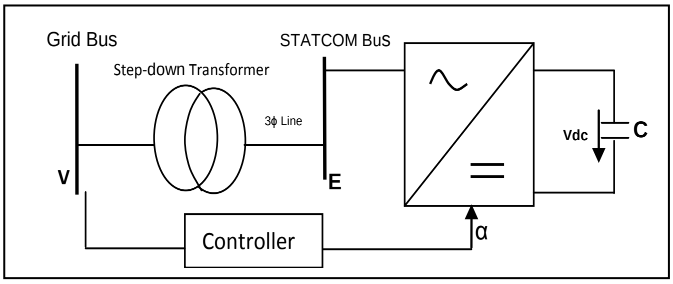

Fig.1. *STATCOM connected to the power system via coupling transformer.*

The STATCOM consist of a coupling transformer,converter/inverter circuit, and a DC capacitor, which is shown in fig.1 above. For such an arrangement, the ideal steady state analysis assumed that the active power exchange between the AC system and the STATCOM can be neglected, and only the reactive power can be exchanged between them.

When the amplitude of the output voltage is raised over the system voltage, then the current flows via reactance from the inverter to the AC system and the inverter produces capacitive power for the AC grid. On the other hand, if the output voltage amplitude is decreased under that of the AC grid, then the reactive current flows from the AC system to the inverter and the inverter draws inductive power. In addition, when the output voltage amplitude is balanced to the AC grid voltage, the reactive power flows become zero.

The output of reactive current strongly depends on the thyristor firing angle *α* that is given by the phase shift between the STATCOM-voltage *E* and the bus voltage *V*. Depending on this firing angle *α*, the charging state of the dc- capacitor is changed and therefore the amplitude of the STATCOM bus voltage *E* changes. The amplitude difference of the STATCOM bus voltage and the grid voltage together with the transformer leakage reactance $X_T$determines the amplitude of reactive current that is injected into the power system given in equation (3).

$$I = \frac{V - E}{X_T} \qquad (3)$$

In the same way, there is exchange between the reactive power of the inverter and the AC system, which can be controlled by varying the magnitude of the output voltage [7, 8].

B. *Multi Control Function of STATCOM*

In the practical application of a STATCOM, it may be used for controlling one of the following Parameters.

1. Voltage magnitude of the local bus to which the STATCOM is connected.
2. Reactive power injection to the local bus, to which the STATCOM is connected.
3. Impedance of the STATCOM.
4. Voltage Injection.
5. Voltage magnitude at a remote bus.
6. Power flow.
7. Apparent power or current control of a local or remote transmission line.

Among these control options, control of the voltage of the local bus which the STATCOM is connected to, is the most recognized control function. The other control possibilities have not fully been investigated in power flow analysis [9, 10, 11].

II. METHODOLOGY

A. *STATCOM Model*

Based on the operating principle of the STATCOM, the equivalent circuit can be derived, which is given in fig. 2. In the derivation, it is assumed that,1.Harmonic generated by the STATCOM is neglected 2. The system as well as the STATCOM is assumed three phase balanced

The STATCOM can be equivalently represented by a controllable fundamental frequency positive sequence voltage source V_{sh}. In principle, the STATCOM output voltage can be regulated such that the reactive power of the STATCOM can be changed.

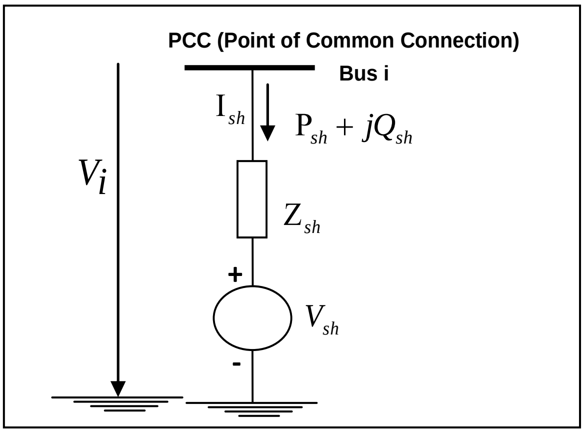

Fig. 2. *STATCOM Equivalent Circuit.*

Based on the equivalent circui, it can be established, V_i is the voltage at bus i, I_{sh} is the current through the STATCOM shunt converter. P_{sh} and $Q_{sh}$are the shunt converter branch active and reactive power flows respectively. The power flow direction of P_{sh} and Q_{sh} is leaving bus i. Z_{sh} is the equivalent STATCOM shunt coupling transformer impedance.

From the equivalent circuit,suppose [9] $\mathbf{V}_{sh} = V_{sh} \angle\theta_{sh}$ and $\mathbf{V}_i = V_i \angle\theta_i$ then the power flow constraints of the STATCOM are:

$$P_{sh} = Vi^2 g_{sh} - V_i V_{sh}(g_{sh}\cos(\theta_i - \theta_{sh}) + b_{sh}\sin(\theta_i - \theta_{sh})) \quad (4)$$

$$Q_{sh} = -Vi^2 b_{sh} - V_i V_{sh}(g_{sh}\sin(\theta_i - \theta_{sh}) - b_{sh}\cos(\theta_i - \theta_{sh})) \quad (5)$$

Where $g_{sh} + jb_{sh} = 1/Z_{sh}$

The operating constraint of the STATCOM is the active power exchange (PE) via the DC link as described by:

$$PE = \Re_e(V_{sh} I^*{}_{sh}) =$$

$$\Re_e(V_{sh} I^*{}_{sh}) = Vi^2 g_{sh} - V_i V_{sh}(g_{sh}\cos(\theta_i - \theta_{sh}) - b_{sh}\sin(\theta_i - \theta_{sh})) \quad (6)$$

The principle of operation of VSC based STATCOMdepends on the control strategy for regulating the interchange of power between the converter/inverter circuit and the grid and it depends also on the output AC voltage of the converter/inverter circuit. If the magnitude of the voltage of the converter is equal to the voltage of the grid $V_{sh} = V_i$, the interchange of reactive power between the STATCOM and the grid is equal to zero. In contrast, if the voltage of the converter is less than the grid voltage at point of common connection (PCC), $V_{sh} \angle V_i$ the STATCOM absorbs reactive power (draws lagging current).

However, if the STATCOM controlled happens to be in such a way that the output voltage of the converter is higher than the grid voltage at PCC, $V_{sh} > V_i$, reactive power is injected into the grid. Also, note that the capacity for injecting reactive power into the grid is limited by the maximumvoltage and the maximum current allowed by the semiconductors [9].

In practice, it is also necessary to control the active power exchange of the STATCOM by regulating the phase angle $\theta_{sh} = \theta_i - \theta_{sh}$ between the voltage at the VSC $(V_{sh} = V_{sh}\angle\theta_{sh})$ and the voltage at the PCCis $(V_i = V_i\angle\theta_i)$ so that the VSC absorbs active power from the grid to maintain a constant voltage for the DC link [9, 11].

B. Restriction of Operation

1. In a STATCOM, the maximum reactive power that can be supplied to the grid depends on the maximum voltage and current permitted by the power semi-conductor, so it s necessary to include the following restriction.

The VSC output voltage must fall within the allowed limits of operation:

$$V_{sh}^{\min} \le V_{sh} \le V_{sh}^{\max}, \qquad -\pi \le \theta_{sh} \le \pi$$

Where $V_{sh}^{\max}$ is the voltage rating of the STATCOM,

While $V_{sh}^{\min}$ is the minimal voltage limit of the STATCOM.

2.The current flowing through a STATCOM I_{sh} , must be less than the current rating: that is $\mathbf{I}_{sh} \le \mathbf{I}_{sh}^{\max}$ Where $I_{sh}^{\max}$ is the current rating of the STATCOM converter while I_{sh} is the magnitude of current through the STATCOM and given by $I_{sh} = \dfrac{Vi - V_{sh}}{Z_{sh}}$

In contrast, it is necessary to include external restriction of the grid voltage at the PCC. According to the specific regulation of the grid operator, the grid voltage at the PCC must be within certain allowed limits. $Vi^{\min} \angle V_i \angle Vi^{\max}$ [9].

C. Modelling and Simulation of 500 kV System Case Study.

To study a system, it is sometimes possible to experiment with the system itself. The goal of the system simulation is to predict how a system performs when it is build. So, it is not feasible to experiment with a system when it is already put into use. It is very costly, dangerous and often impossible to make experiment with real systems. Provided that models are adequate descriptions of reality (they are valid), experimenting withthem can save money, suffering and time.The block building principle employed in modeling help organize system description by isolating subsystem and identifying their input and output.Fig. 3 shows the single line diagram of system case study model which is used to analyse the impact of STATCOM on the 500 kV power network.

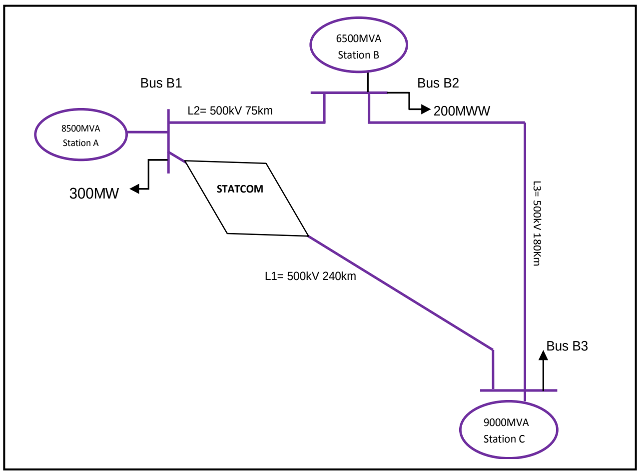

Fig. 3. *Single line diagram of the proposed interconnected power system with STATCOM installed as system study.*

The STATCOM is used to control the power flow along planned 500 kV interconnected line. The STATCOM is installed at the Bus B1of the 240km line 1 planned transmission line between 500 kV Bus B1 (Section A) and Bus B3 (Section C). The STATCOM is employed to regulate B1 Bus voltage at (Section A), and reactive power flow through B1. It consists of 100-MVA, three-level, 48-pulse GTO-based converter; it's connected in shunt at bus B1. The MATLAB / SIMULINK model of the case study system is shown in Fig. 4.

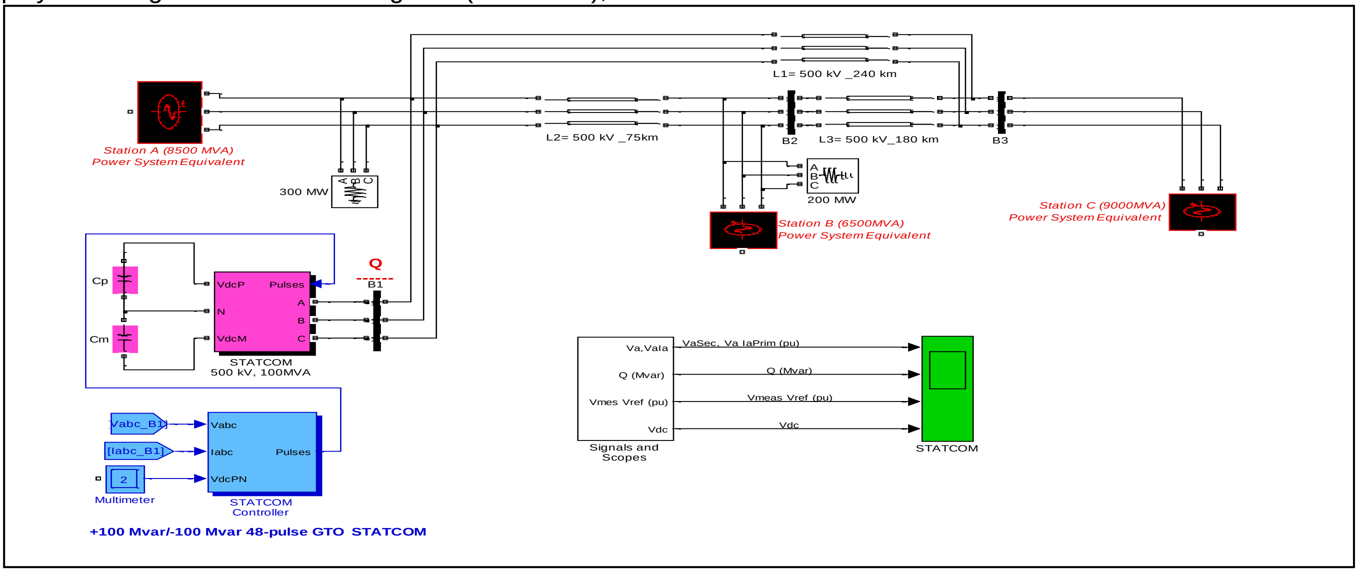

Fig. 4. *MATLAB/SIMULINK Study System Model using STATCOM [13]*

The Typical Overhead Transmission Line parameters of the 500 kV Transmission line system was taken from [12].

III. Results and Discussion

The simulation was prepared using MATLAB/SIMULINK package available in MATLAB 9.1. The STATCOM characteristic is simulated for bus voltage and reactive power flow control.

From fig. 5, STATCOM is in the voltage control mode and its reference voltage is set to Vref = 1.0 P.U. The voltage drop of the regulator is 0.03pu/100VA. Therefore when the STATCOM operating point changes from fully capacitive (+100 Mvar) to fully inductive (-100 Mvar) the STATCOM voltage varies between 1.0 – 0.03 = 0.97pu and 1.0 + 0.03 = 1.03pu.

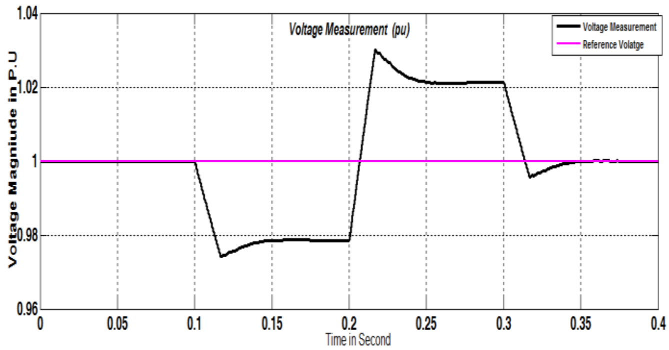

Fig. 5. *STATCOM Voltage Magnitude Measurement (V p.u)*

Result in fig. 5 shows the STATCOM voltage source 1.0p.u at time t= 0 second, while fig. 6 reveals reactive power at 0-Mvar at time t= 0 sec respectively. At t = 0.1 second, the voltage source of fig. 5 suddenly decrease to 0.955pu. As a result, Fig. 6 display STATCOM reaction by generating reactive power of Q=+70Mvar (capacitive mode) in order to keep the bus voltage of fig. 5 at 0.979pu.

A 100-Mvar STATCOM regulates voltage on the bus B3 of a 500 kV interconnected power system. Result in fig. 5 reveals that, when the bus voltage B3 is 1.0pu, the STATCOM is out of service. Thus, if the reference voltage Vref is set to 1.0pu, the STATCOM doesn't exhibit current interchange (zero current).

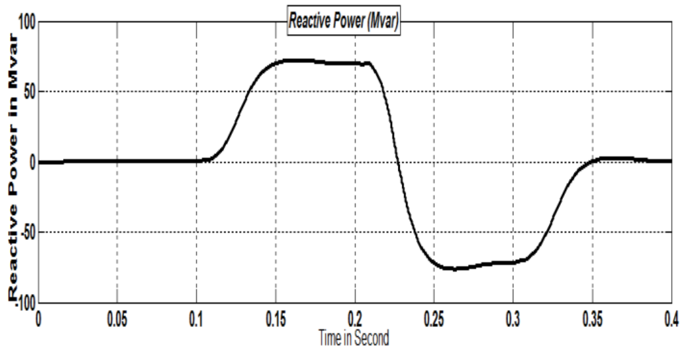

Fig. 6. *Change in Reactive Power (Mvar)*

At time t= 0.2 second, fig. 5 reveals a rapid increase of source voltage from 0.979p.u to 1.03p.u. As a result, fig. 6 displays STATCOM reaction by changing its operating point from capacitive mode (+70Mvar) to inductive mode (-75Mvar) to keep voltage at 1.021pu. At this point the STATCOM absorbs -75Mvar as shown in fig. 6.

At time t=0.3second, fig. 5 and 6 also displayed how the voltage source is set back to its nominal value, and that of STATCOM operating point comesup to 0 Mvar respectively.

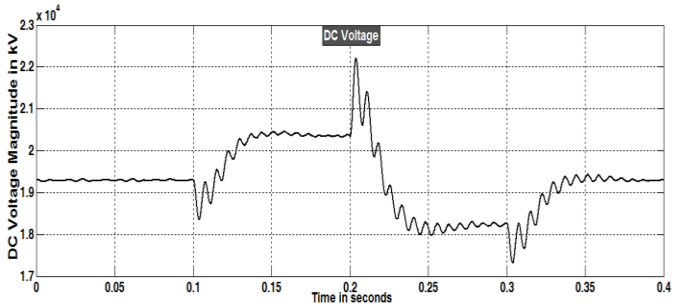

Fig. 7.*Behaviour of the DC bus voltage (kV)*

Finally, result in fig. 7 shows the behaviour of DC bus voltage. At time t= 0.1 second of fig. 5 when a sharp drop in source voltage is noticed, the fig. 7 reveals DC voltage response by raising from 19.3 kV to 20.4 kV to keep the voltage within the operating range. On the other hand, at t=0.2 sec of fig. 5, when a sudden increase in voltage is observed, the DC voltage has lowered to 18.2 kV. At this point, the STATCOM absorbs reactive power.

IV. CONCLUSSION

The STATCOM is a shunt device used in improving the bus voltage profile. It is commonly used to maintain a constant voltage across ac transmission lines and also serve as automatic reactive power control. The MATLAB/SIMULINK environment was used to simulate a model of power system with STATCOM connected to an interconnected power system. The control and performance of STATCOM intended for installation on a transmission line for power quality improvement is presented.

The STATCOM dynamic response is very fast (in millisecond) and able to pass from capacitive mode of operation to an inductive one in a few cycles. When the source voltage decreases, the STATCOM reacts by generating reactive power, so the DC voltage increases; this is the capacitive mode. On the other hand, when the AC voltage increases, the STATCOM reacts by absorbing the reactive power, so the DC voltage decreased. This is the inductive mode.

Simulation results show the effectiveness of STATCOM for regulating bus voltage and control reactive power flow through the line.

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