Development and Simulation of Voltage Regulation System of A.C. Transmission lines using Static Synchronous Compensator (STATCOM)

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Abstract - ***A Due to the fast technological development, the utilization of electric energy increases always however various system of transmission are not extensive to the similar level because building of new lines is difficult for environmental as well as financial reasons that's why the systems are driven nearer to their limits resulting in congestions and dangerous situations endangering the system protection.***

Flexible AC Transmission Systems (FACTS) are a Power Flow Control device which offers the opportunity to influence power flows and voltages and therefore to improve system safety measures. From the last few years static synchronous compensator plays an essential function in regulation of voltage within AC Transmission Systems. An investigation voltage irregulation problem often occurs in the three phase A.C. transmission lines and its solution by taking forward, development of a voltage regulation system using a FACTS device static synchronous compensator (STATCOM) have been discussed. After the successful simulation of the STATCOM in MATLAB Simulink the resultant waveform of voltage shows the voltage regulation capability of the STATCOM based three phase A.C. transmission line system.

Key Words: *Voltage profile, Voltage Regulation, transmission lines, FACTS devices, STATCOM.*

1. INTRODUCTION

An inherent characteristic of electric energy transmission and distribution by alternating current (AC) is that real power is generally associated with reactive power. AC transmission and distribution associated with relative power. AC transmission and distribution lines are dominantly reactive networks, characterized by their per-mile series inductance and shunt capacitance. Thus, load and load power factor changes alter the voltage profile along the transmission lines and can cause large amplitude variations in the receiving end voltage. Most of loads are not tolerant to voltage variation.

Under voltage causes degradation in the performance of loads such as induction motors, light bulbs, etc.; overvoltage causes magnetic saturation and resultant harmonic generation, as well as equipment failure due to insulation breakdown. Reactive power also increases transmission losses. Power System Stability is the ability of the system to regain its original operating conditions after a disturbance to the system. Power system transient stability analysis is considered with large disturbances like sudden change in load, generation or transmission system configuration due to fault or switching [1]. Dynamic voltage support and reactive power compensation have been identified as a very significant measure to improve the transient stability of the system.

Flexible AC Transmission Systems (FACTS) devices with a suitable control strategy have the potential to increase the system stability margin [2, 3]. Shunt FACTS devices play an important role in reactive power flow in the power network. In large power systems, low frequency electro-mechanical oscillations often follow the electrical disturbances. Generally, power system stabilizers (PSS) are used in conjunction with Automatic Voltage Regulators (AVR) to damp out the oscillations [3]. However, during some operating conditions this device may not produce adequate damping and other effective alterations are needed in addition to PSS [4, 5].

Another means to achieve damping is to use the shunt FACTS device Static synchronous Compensator (STATCOM) designed with auxiliary controllers [6]. Therefore STATCOM is more effective and if accommodated with supplementary controller, by adjusting the equivalent shunt capacitance, STATCOM will damp out the oscillations and improves the overall system stability [7]. The system operating conditions change considerably during disturbances.

Various approaches are available for designing auxiliary controllers in STATCOM. In [8] a proportional integral derivative (PID) was used in STATCOM. It was found that significant improvements in system damping can be achieved by the PID based STATCOM. Although PID controllers are simple and easy to design, their performances deteriorate when the system operating conditions vary widely and large disturbances occur. PID control approach is an emerging tool for solving complex problems whose system behavior is complex in nature. An attractive feature of PID control is its robustness in system parameters and operating conditions changes [9, 10].

PID controllers are capable of tolerating uncertainty and imprecision to a greater extent [11]. In the paper the designing and simulation of a line conditioning system for three phase line voltage regulation using STATCOM is discussed.

2. STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

The STATCOM is the static counterpart of the rotating synchronous condenser but it generates/absorbs reactive power at a faster rate because no moving parts are involved. In principle, it performs the same voltage regulation functions as the SVC but in robust manner because unlike the SVC, its operation is not impaired by the presence of low voltage. The STATCOM has superior performance during low voltage condition as the reactive current can be maintained constant. (In a SVC, the capacitive reactive current drops linearly with the voltage at the limit of capacitive susceptance). It is even possible to increase the reactive current in a STATCOM under transient conditions if the devices are rated for the transient overload. In 1976, Gyugyi discussed various switching power converters, which generating controllable reactive power directly without the use of ac capacitors or reactors. Functionality, from the standpoint of reactive power generation, their operation is similar to that of an ideal synchronous machine whose reactive power output is varied by excitation control. Like the mechanically powered machine these converters can also exchange real power with the ac system if supplied from a suitable, generally dc energy source. Because of these similarities with a rotating synchronous generator, they are termed Static Synchronous Generator (SSG). When SSG is operated without an energy source and with appropriate controls to function as shunt-connected reactive compensator, it is termed, analogously to the rotating synchronous compensator (condenser) a Static Synchronous Compensator (STATCOM) or Static Synchronous Condenser (STATCON).

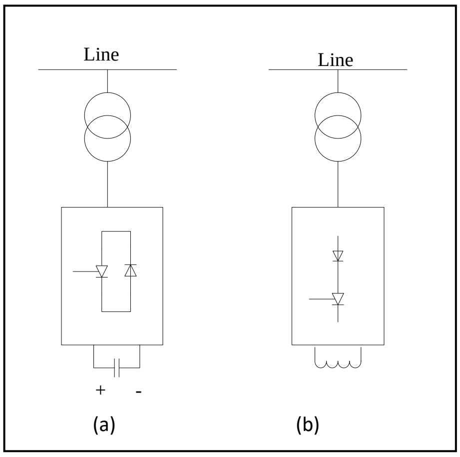

Fig-1: Static Synchronous Compensator (STATCOM) based on (a) Voltage sourced (b) current-sourced converter

2.1 VOLTAGE REGULATION OF AC LINES USING CONVENTIONAL STATIC SYNCHRONOUS COMPENSATOR (STATCOM)

One of the many devices under the FACTS family, a STATCOM is a regulating device which can be used to regulate the flow of reactive power in the system independent of other system parameters. STATCOM has no long term energy support on the dc side and it cannot exchange real power with the ac system. In the transmission systems, STATCOMs primarily handle only fundamental reactive power exchange and provide voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, improve the transient stability margins and to damp out the system oscillations due to these disturbances. Reactive power is generated by (STATCOM capacitive) while it has low system voltage, It absorbs reactive power (STATCOM inductive) When system voltage is high. A STATCOM consists of a three phase inverter (generally a PWM inverter) using SCRs, MOSFETs or IGBTs, a D.C. capacitor which provides the D.C. voltage for the inverter, a link reactor which links the inverter output to the a.c supply side, filter components to filter out the high frequency components due to the PWM inverter. From the D.C. side capacitor, a three phase voltage is generated by the inverter. This is synchronized with the A.C. supply. The link inductor links this voltage to the A.C. supply side. This is the basic principle of operation of STATCOM.

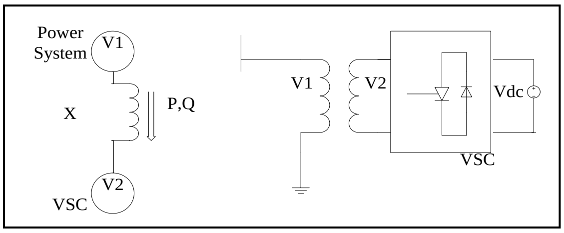

Fig-2: Operation of the STATCOM

Active Power, $P = (V_1 V_2) \sin\delta / X$ ... (1)

Reactive Power, $Q = V_1 (V_1 - V_2 \cos\delta) / X$ ... (2)

Where,

V_1 = source 1 Line to line voltage

V_2 = source 2 Line to line voltage

X = interconnection transformer and filters Reactance

δ = Phase angle of V_1 w.r.t. V_2

For two AC sources which have the identical frequency and are connected through a series inductance, the active power flows from the leading source to the lagging source and the reactive power flows from the higher voltage magnitude source to the lower voltage magnitude source. The phase angle difference between the sources determines the active power flow and the magnitude voltage variation stuck between the starting places determines the flow of reactive power. Thus the reactive power flow in a STATCOM can be regulated by changing the magnitude of the VSC voltage with respect to source bus voltage. The reactive power is given by

$$Q = (V_1 (V_1 - V_2)) / X.$$

A capacitor attached on the DC surface of the VSC acts as a DC voltage source. In order to balance for transformer and VSC losses and to keep the capacitor charged, the steady state the voltage V_2 has to be phase shifted slightly behind V_1. Two VSC technologies are:

- VSC used GTO-based square-wave inverters and special interconnection transformers. For build a 48-step voltage waveform four three-level inverters are used. Special interconnection transformers are used to neutralize harmonics contained in the square waves generated by individual inverters. In this type of VSC, the primary component of voltage V_2 is proportional to the voltage V_{dc}. Therefore V_{dc} has to be varied for calculating the reactive power.

This project work deals with the GTO based static synchronous compensator. A single-line diagram of the STATCOM with a basic block diagram for control system is shown in figure 3.

The control system of STATCOM mainly consists of:

1) The positive-sequence component of the three-phase primary voltage V1 is synchronizes with phase locked loop (PLL). The AC three-phase voltage and currents (V_d, V_q or I_d, I_q on the diagram), output of the PLL (angle $\alpha=\omega t$) are used for the calculation of direct-axis and quadrature-axis mechanism.
2) By the help of measuring component of d and q the DC and AC voltages are to be controlled.

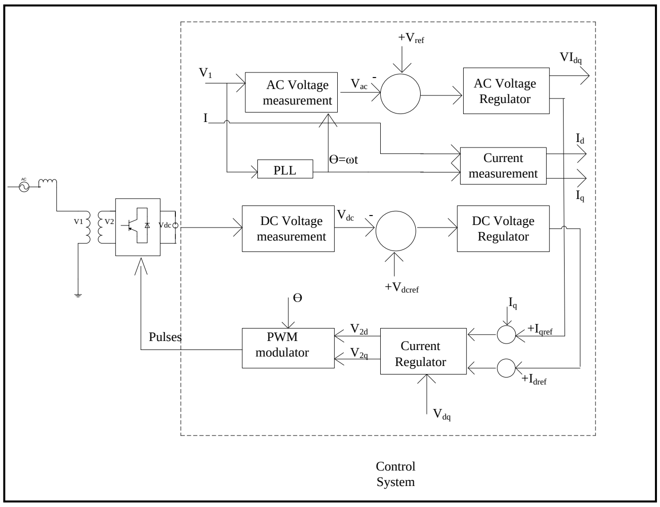

Fig -3: STATCOM with basic block diagram of its control system

3) An AC voltage regulator and a DC voltage regulator are present in outer regulation loop. For the current regulator (I_q = current in quadrature with voltage which controls reactive power flow) the output of the AC voltage regulator is the reference current I_{qref} .The output of the DC voltage regulator is the reference current I_{dref} An internal current regulation loop consisting of a current regulator. It controls the magnitude and phase of the voltage generated by the PWM converter (V_{2d} V_{2q}) from the I_{dref} and I_{qref} reference currents produced respectively by the DC voltage regulator and the AC voltage regulator (in voltage control mode). The current regulator is assisted by a feed forward type regulator which predicts the V_2 voltage output (V_{2d} V_{2q}) from the V1 measurement (V_{1d} V_{1q}) and the transformer leakage reactance.

2.2 STATCOM V-I CHARACTRICS

The Static synchronous compensator can be operated in two different modes:

1) In voltage regulation mode (the voltage is regulated inside limits as explained below)
2) In var control mode (the STATCOM reactive power output is kept stable) when the STATCOM is operated in voltage regulation mode. The following V-I characteristic of STATCOM is shown below:-

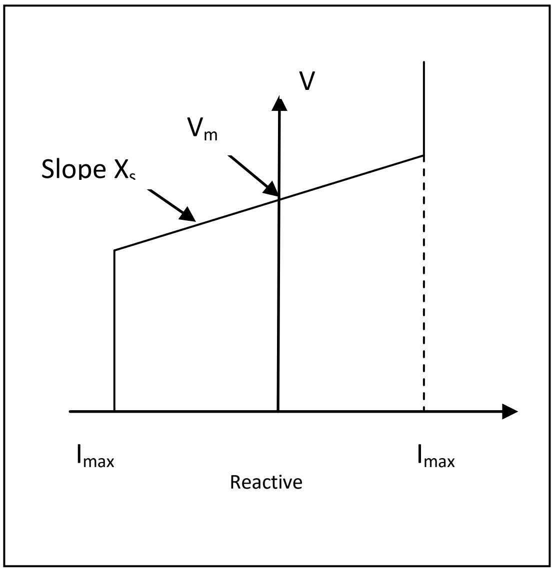

Fig-4: STATCOM V-I Characteristic

As long as the reactive current stays inside the the converter rating, the voltage is regulated at the reference voltage V_{ref}. However, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope indicated in the figure. The V-I characteristic is described by the following equation in the voltage regulation mode:

$$V = V_{ref} + X_s I \qquad (3)$$

where

V = Voltage at Positive sequence (pu)

I = Reactive current (pu/P_{nom}) ($I > 0$ I, is an inductive current)

X_s = Slope or droop reactance (pu/P_{nom})

P_{nom} = Three-phase nominal power of the converter.

3. METHODOLOGY

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 [1]. By the help of STATCOM, Controlling the quantity of reactive power injected into or wrapped up from the power system, which regulates voltage at its terminal. Reactive power is generated by (STATCOM capacitive) while it has low system voltage, It absorbs reactive power (STATCOM inductive), when system voltage is high.

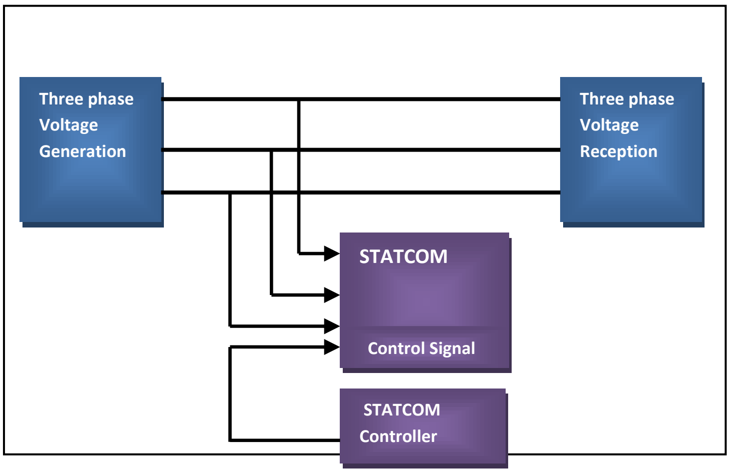

Fig-5: Block diagram Representation of STATCOM Voltage Regulation

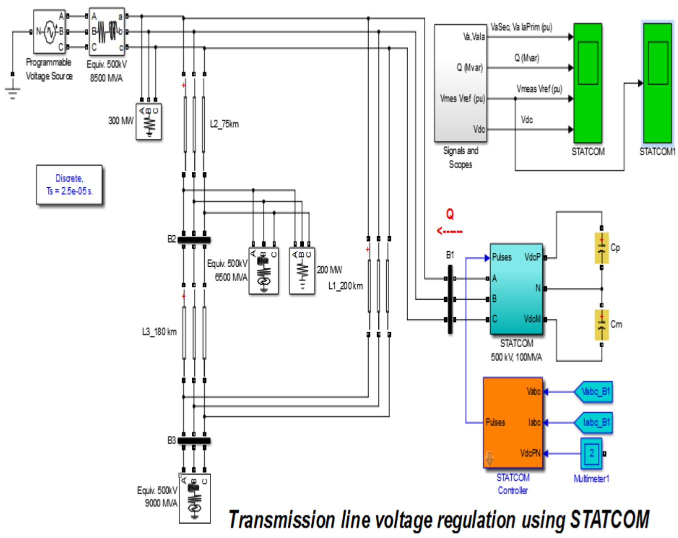

Fig-6: Actual simulation of proposed work

4. RESULT & DISCUSSION

This section presents the results obtained after successful simulation of proposed work in MATLAB Simulink. For the complete analysis of the proposed work a voltage disturbance has been introduced in the transmission line as per following specifications using programmable voltage source.

Table -1: Parameters during simulation

Complete Simulation time	0.4 Sec
Simulation starts at 0 sec	With voltage is 1 pu
First disturbance generated at 0.1 sec	Amplitude reduced to 0.955 pu
Second disturbance generated at 0.2 sec	Amplitude increased to 1.045 pu
Third disturbance generated at 0.3 sec	Amplitude reduced to 1 pu

Power flow control device(STATCOM) such as flexible as transmission system provide the opportunity to influence power flow and voltages and therefore enhanced stability by resolving the congestion & improving the voltage profile. As the graph shown in below there are voltage disturbances has been generated by programmable voltage source at point 0, 0.1, 0.2, 0.3 sec, and then the oscillations at point 0.03 is 1.1 pu. By the help of STATCOM with PID controller this oscillations is to be controlled at different point and improving the voltage profile. The resultant waveform that the output voltage tried to affectively follow the reference voltage. But due to the fault generated during the simulation the output voltage fluctuates (at point 0.33sec fluctuation is 0.35 pu) & tires to settle around the reference voltage, which is shown in figure-7.

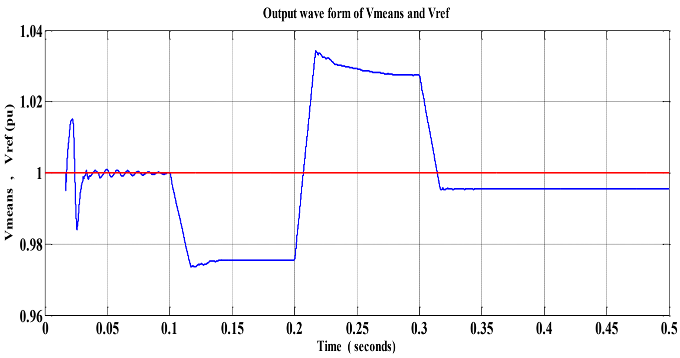

Fig-7: Output wave form of main line voltage and reference voltage

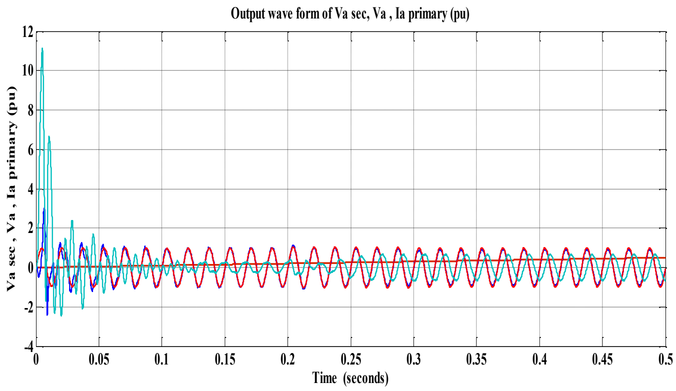

Fig-8: Output wave form of Va Sec, Va, Ia Primary

Figure -8 shows that output wave form of secondary voltage (Va sec), primary voltage (Va) & primary current (Ia) which oscillates 3 volt at point 0 sec to 0.15 sec. After point 0.15 sec it settled down.

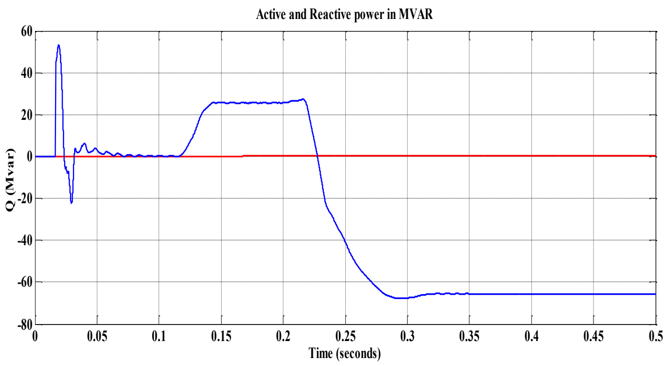

Fig-9: Output wave form of Active and Reactive power Supplied during voltage regulation

Figure-9 shows that Active and reactive power (Q, mvar) of PID based STATCOM. It oscillates 53 mvar at point

0.025 sec. After 0.3 sec, quality factor is constant i.e. -75 mvar.

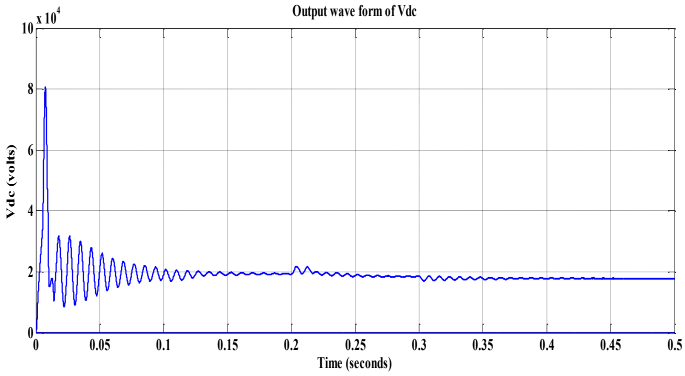

Fig-10: Output wave form of V_{dc}

Figure-10 shows that output wave form of dc voltage, which oscillates (fluctuates) 8 volt at point 0.02 sec and oscillation is to be settled down after 0.015 sec and output will be in constant nature i.e. 1.18 volt at 0.3 sec.

The advancement in the technology like home equipments and plant equipments, demands for precession and highly regulation in the received voltage from energy generator through the lines, because in current scenario the equipments are very much sensitive to supply voltage regulation. Any kind of fluctuation either damage the costly equipment or may harm full for further used equipments. The work deals with the effective and practical solution of the voltage regulation problem in transmission lines using static synchronous compensator (STATCOM). The outcomes of the work presented in this paper are:-

I. As clearly observable from the figure 7 that the means line voltage tries to track reference voltage, because of the utilization of STATCOM and hence It is provide an efficient voltage regulation in the transmission lines.
II. It is also observable that the use of PID logic controller will provide an expert environment for defining and handling imperfections presents in the transmissions lines.

5. CONCLUSIONS

In this paper the voltage regulation problem of three phase transmission line has been successfully investigated using STATCOM and simulation model is also developed using MATLAB Simulink 2012b. It is observable from the resultant waveform that the output voltage obtained after using STATCOM tried to affectively follow the reference voltage. But due to the voltage fluctuations generated during the simulation the output voltage fluctuates & tires to settle around the reference voltage.

In addition to this after simulation of the developed work, it is also observed, through the output voltage tires to follow reference voltage but oscillates during the transient period, more ever the steady state output voltage is regulated.

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