

Simulation of Static Synchronous Compensator (STATCOM) for Voltage Profile Improvement

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Abstract

Voltage profile improvement is a very important aspect of power quality and system stability. Flexible A.C Transmission System (FACTS) devices have been developed to provide system stability thereby enhancing controllability and increasing the power transfer capability. Static Synchronous Compensator (STATCOM) is a member of FACTS devices used for voltage profile improvement as well as power quality improvement of the net system. In this paper, a STATCOM is simulated in Simpower Simulink of MATLAB environment for voltage regulation in a nominal π medium transmission line. The simulation results show that a STATCOM without droop is a perfect voltage regulator and follows exactly the reference voltage. When the results are compared to one with droop regulator, it was found that the sooner performs better than the later. However, the droop extends the linear operating range of the STATCOM.

Keywords—STATCOM, FACTS, power quality, voltage regulation, grid

1. Introduction

Power quality is significant to both utility operators and consumers at all level of usage especially to non-linear loads and sensitive devices placed in both industrial and domestic environment (Krishna & Reddy 2013). Power quality refers to the proper characteristics of supply voltage and also a reliable and effective process for delivering electrical energy to consumers. In other words, it is the power that enables equipment to work properly (Srinivas & Reddy 2011). The measure of power quality depends on the nature and type of equipment. Thus, power quality that is considered good for one equipment may not be good for another equipment. Hence, power quality can be directly related to maintaining a smooth sinusoidal waveform of bus voltages at rated frequency and also to be free from noise and harmonic distortion (Kumba & Sumanthi 2012). Therefore, any deviation of magnitude, frequency or purity from the ideal sinusoidal voltage waveform can be considered as power quality issue (Earnest & Wizelius 2011).

Binding standards and regulations are currently being imposed on suppliers and consumers, the obligations to maintain the required power quality parameters at the point of interconnection, POI (Hiren et al 2010). These obligations become necessary due to the widespread use of power electronics equipments that are sensitive in nature such as computers, converters, programmable logic controllers and energy efficient lightning (Mohod & Aware 2011). These loads are very sensitive, hence, can lead to power quality disturbances such as voltage dip, voltage swell, voltage flicker, voltage transient, and harmonic distortion. Among such disturbances, voltage dip is the most dangerous one because it can leads to equipment failure, industrial shut down and tripping of protection devices (Omar & AbdRahim 2008).

However, when good power quality is required, some kinds of compensation devices are necessary to overcome the power quality disturbances (Kanaujia & Srivastava 2013). Thus, to restore the required power quality, FACTS devices have been introduced (Das & Moharana 2012). Among such devices, STATCOM is the latest development in that regard capable of interfacing between the utility and the consumer with the aim of providing voltage profile improvement by compensating the reactive and harmonic power generated or absorbed by the load (Khadem & Basu 2010). Thus, FACTS controllers provides an avenue for the regulation of transmission of alternating current thereby increasing or diminishing the power flow in specific lines and providing a quick response to stability problems (Mohanty and Barik 2014).

2. Static Synchronous Compensator (STATCOM)

Static synchronous compensator, popularly known as STATCOM is a shunt connected reactive power compensation device used on alternating current electricity transmission network. It is capable of generating and or absorbing reactive power and its output can be varied to control certain power parameters. It is a power electronic based voltage source converter (VSC) that can act as either a source or a sink of reactive power in an a.c power system.

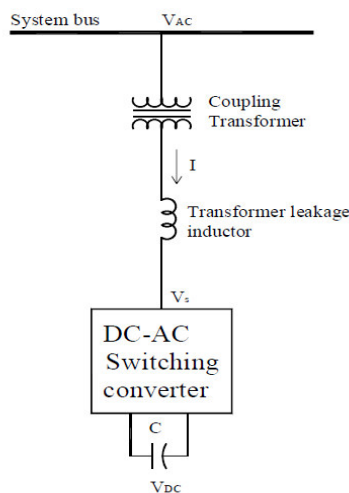


Figure 1. Basic Configuration of a STATCOM

STATCOM is a member of FACTS devices used for voltage profile improvement. It makes use of VSC to inject a compensation current of variable magnitude and frequency into the system at the bus PCC. It is thus a three phase VSC with capacitance on its d.c link. STATCOM is thus a solid-state switching converter capable of generating or absorbing independently controllable real and reactive power at its output when it is fed from an energy source or energy storage device as its input terminal. The d.c voltage can be provided by a battery or an energy-storage capacitor. The output of a STATCOM is a set of three phase voltage, each in phase and coupled to the corresponding a.c system voltage through a small reactance. The reactance can be provided by a leakage inductance of the coupling transformer or by an interface reactor. STATCOM is a very fast acting device that is analogous to an ideal synchronous machine, which generates a balanced set of three sinusoidal voltages at the fundamental frequency, with controllable amplitude and phase angle. It is based on VSC topology that utilizes either Gate-Turn-off Thyristor (GTO), or Insulated Gate Bipolar Transistor (IGBT) devices. Thus, a STATCOM is a VSC that converts a d.c input voltage into an a.c output voltage for active and reactive power compensation (Kamarposhti & Alinezhad 2010).

In general, STATCOM can be operated to perform the following objectives:

- Voltage regulation
- Power factor correction
- Load balancing
- Harmonic compensation

3. Components of a STATCOM

STATCOM is basically comprised of four major components, namely

- Voltage source converter (VSC)
- Coupling transformer
- Controller
- DC energy storage

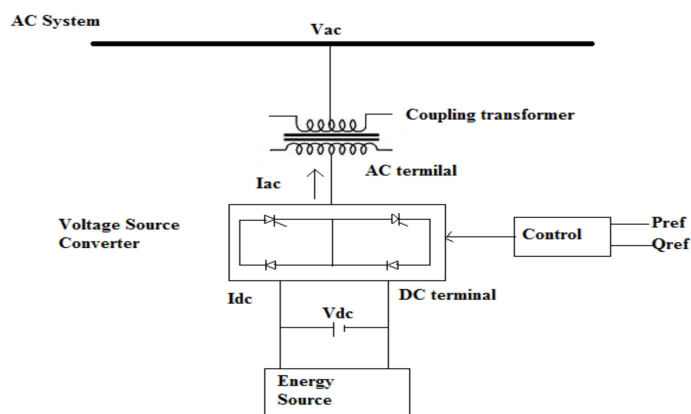


Figure 2. Basic Components of a STATCOM

3.1 Voltage Source Converter (VSC)

VSC is a power electronic device capable of generating a sinusoidal voltage of desired frequency, magnitude and phase angle. It converts the d.c voltage across the storage device into a set of three phase a.c output voltages (Sivakoti et al 2013). The voltages are in phase and coupled with the a.c system through the reactance of the coupling transformer. The function of VSC as an integral part of STATCOM is to contribute in mitigating power quality disturbances either by completely replacing the voltage or by injecting the missing voltage. The missing voltage in this case is the difference between nominal and actual voltage. The VSC is usually based on some kind of energy storage that will supply the d.c voltage. The desired voltage can then be obtained by switching the solid state electronic devices in the converter circuit.

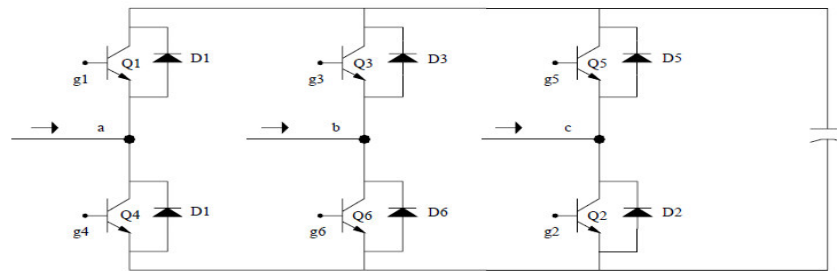


Figure 3. A three phase Voltage Source Converter

3.2 Coupling Transformer

Coupling Transformer is required to step down the system voltage to match that of the utility grid. A coupling reactor is usually incorporated in order to filter out the current harmonic components that are generated by pulsating output voltage of the VSC. The AC voltage difference across the leakage reactance produces reactive power exchange between the STATCOM and the power system, in such a way that the AC voltage at the bus bar can be regulated to improve the voltage profile of the power system, which is the primary duty of the STATCOM. Alternatively, a secondary damping function can be added into the STATCOM to enhance power system oscillation stability.

3.3 Controller

The controller performs feedback control and outputs a set of switching signals to drive the main semiconductor switches of the power converter. It generates switching signal for the STATCOM to enable the STATCOM injects a reactive current into the grid to behave as an over-excited synchronous generator (or capacitor) thereby supporting the grid voltage or absorbs reactive current and behave like an under-excited synchronous generator (or inductor) and tends to decrease the grid voltage. The STATCOM compensator is varied according to the control strategy (Tajavoth et al 2013).

The main function of the controller is to maintain the voltage magnitude constant at the point where sensitive load is connected, under system disturbances. It does this by measuring and comparing the r.m.s voltage at the load point with the reference voltage. The difference between the two values is the error signal which serves as input to the controller. The output is the power angle δ which is provided to the PWM signal generator. Thus, the processed error signal generates the required power angle, δ , that will drive the error to zero, thereby restoring the r.m.s value of the load voltage to the reference voltage value.

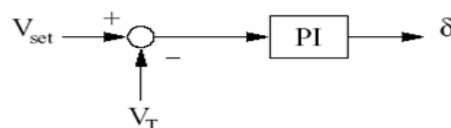


Figure 4. Block Diagram of a STATCOM Controller

3.4 DC Energy Source

The d.c voltage source can be provided by a capacitor connected on the d.c side of the VSC or by a battery energy storage system (BESS). The dc energy source is connected in parallel with the d.c capacitor. It carries the input ripple current of the converter. The capacitor can be charged by the VSC or by BESS. The function of the BESS is to support the real power source under power fluctuating condition. Thus, in order to achieve the required voltage regulation, the BESS is connected in parallel to the d.c capacitor of the STATCOM thereby making it as energy storage element. The BESS will then inject or absorbs the reactive power required to stabilize the grid system while maintaining the d.c capacitor voltage constant. In other words, it charges and discharges to improve the voltage profile. Thus, the d.c energy storage is responsible for supplying and absorbing the real power that is being exchanged by the transmission system at its d.c terminals (Malarvizhi &

Baskaran 2010).

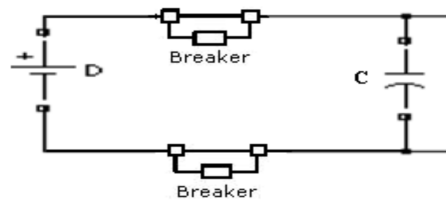


Figure 5. DC Energy Source

4. STATCOM Topology for Voltage Profile Improvement

STATCOM generates a set of balanced three phase sinusoidal voltages at the fundamental frequency, with rapidly controllable amplitude and phase angle (Appala-Naranya et al 2013). In other words, the VSC in the STATCOM generates a controllable AC voltage source behind the leakage reactance. This voltage is compared with the AC bus voltage of the system; if the voltage magnitudes are equal, the reactive power exchange is zero. If the VSC voltage magnitude is higher than that of the AC bus voltage magnitude, the AC system sees the STATCOM as a capacitance connected to its terminals. Conversely if the VSC voltage magnitude is lower than that of the AC bus, the A.C system sees the STATCOM as an inductance connected to its terminals (Usha & Kumar 2013).

Consider the following Figure:

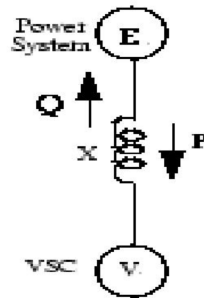


Figure 6. Single line diagram of a STATCOM

Where

E = System voltage (Line voltage of the transmission line)

V = Voltage generated by the VSC

X = Equivalent reactance of the coupling transformer

δ = Phase angle of E with respect to V

P = Active power dissipated in the system

Q = Reactive power generated or absorbed by the STATCOM

The active power, P and reactive power, Q, can be expressed in terms of the system voltage, converter voltage and the reactance of the coupling transformer (Nazrul-Islam & Kazushige 2013):

$$P = \frac{EV}{X} \sin\delta \quad (1)$$

$$Q = \frac{E^2}{X} \cos\delta \quad (2)$$

While the phase angle, δ is given as:

$$\delta = \frac{R}{X} \frac{(V-E)}{E} \quad (3)$$

The STATCOM based current controlled VSC injects compensation current into the grid thereby making the source current harmonic free with a corresponding shift in the phase angle with respect to the source voltage to a desired value. The injected current will then cancel out the reactive and harmonic parts of the load and induction generator current, thereby improving the voltage profile. Thus, the impedance of the shunt controller, which is connected to the line voltage, causes a variable current flow, and hence, represents an injection of current into the line. If the STATCOM has a DC source such as BESS or an energy storage device like capacitor on its DC side, it can supply real power to the power system. This can be achieved by adjusting two parameters, namely; the phase angle of the STATCOM terminals (or VSC) and the phase angle of the AC power system. If the phase angle of the AC power system lags that of the VSC, the STATCOM supplies real power to the AC system. Conversely, if the phase angle of the AC power system leads the VSC phase angle, the STATCOM absorbs real

power from the AC system. The main function of the BESS is to serve as an energy storage element purposely for voltage regulation and to keep the d.c capacitor voltage constant.

The STATCOM can be operated in two modes of operation as under

- In voltage regulation mode (the STATCOM voltage is maintained within specified limits)
- In VAR control mode (the STATCOM reactive power, Q is maintained at a fixed value)

In voltage regulation mode, the STATCOM implements the following V-I characteristic:

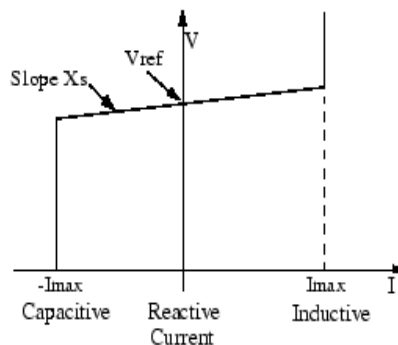


Figure 7: V-I Characteristics of a STATCOM in Voltage Regulation Mode

The voltage is said to be regulated at the reference value, V_{ref} , provided the compensation current, I stays within the minimum and maximum current values ($-I_{max}$, I_{max}) imposed by the converter rating. However, in order to extend the linear operating range of the STATCOM, a voltage droop is normally used (usually between 1% and 4% at maximum reactive power output), and the V-I characteristic has the slope depicted in Figure 10. In the voltage regulation mode, the V-I characteristic is described by the following equation:

$$V = V_{ref} + X_s I \quad (4)$$

Where V = Positive sequence voltage (pu)

I = Compensation current (pu/ P_c)

X_s = Slope or droop reactance

P_c = Three phase power of the converter

STATCOM has no moving parts; hence, it generates or absorbs reactive power at a faster rate than other FACTS devices. It is capable of generating as well as absorbing reactive power thereby regulating the voltage profile of the bus to which it is connected.

5. Simulation Results and Discussion

The entire system is simulated in Simpower Simulink of MATLAB environment. It consists of a 100MVA STATCOM located at the centre of a nominal π medium transmission line. The control parameters of the STATCOM were first set to voltage regulation mode without any droop. The system reference voltage (i.e the p.u voltage used by the regulator) was initially set to 1p.u and decreased to 0.98pu at $t = 0.3s$. It is further increased to 1.02pu at $t = 0.6s$ and finally brought back to 1p.u at $t = 0.9s$.

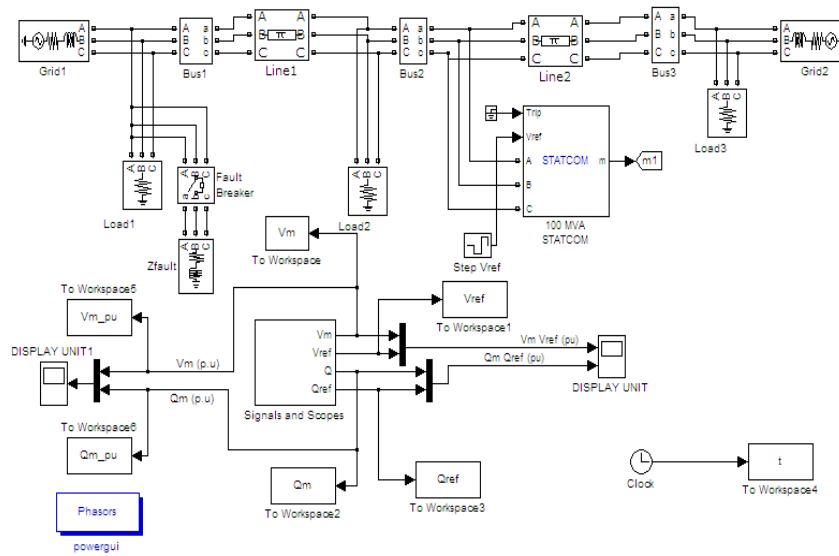


Figure 8: Simulink Diagram of a STATCOM for Voltage Regulation

5.1 Null Droop Condition

It can be seen from Figure 9a that under null droop condition, the STATCOM measured voltage, V_m follows the reference value, V_{ref} . This implies that STATCOM is a very good voltage regulator. Figure 9b shows the reactive power absorbed/generated by the STATCOM, Q_m together with the reference one, Q_{ref} . Positive value of Q_m represents the reactive power absorbed by the STATCOM while negative value indicates the reactive power generated. The two Figures certify that the STATCOM absorbs reactive power when the A.C system voltage rises and generates reactive power when the A.C system voltage falls.

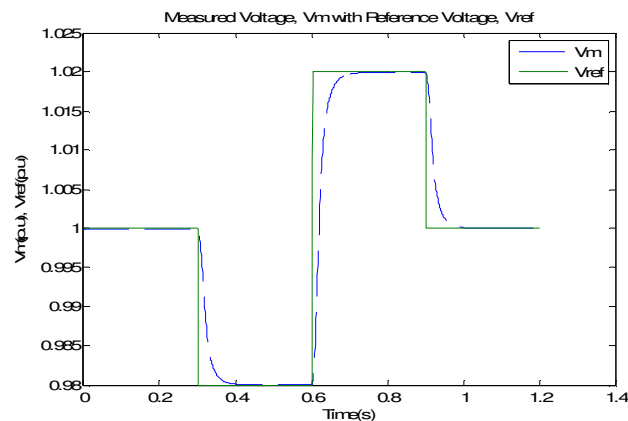


Figure 9a. STATCOM Measured and Reference Voltage under Null Droop Condition

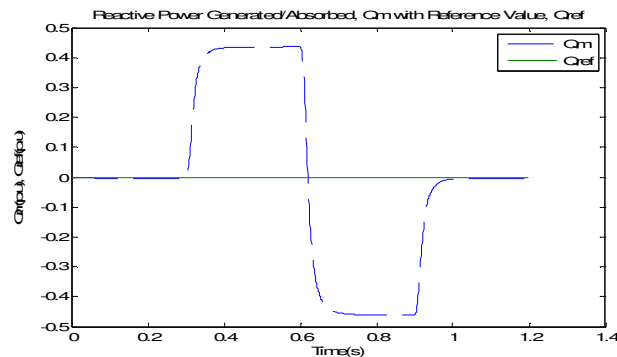


Figure. 9b. Reactive Power Absorbed/Generated by the STATCOM with Reference Value under Null Droop Condition

5.2 Droop Condition

Figure 10a shows the STATCOM measured and reference Q_m voltage (V_m and V_{ref}) under droop condition.

Specifically, a droop of 2% was set. The corresponding reactive power, Q_m absorbed/generated by the STATCOM is shown in Figure 10b. It can be seen from Figure 10a that, because of the droop, the STATCOM measured voltage, V_m does not follow the reference value, V_{ref} perfectly.

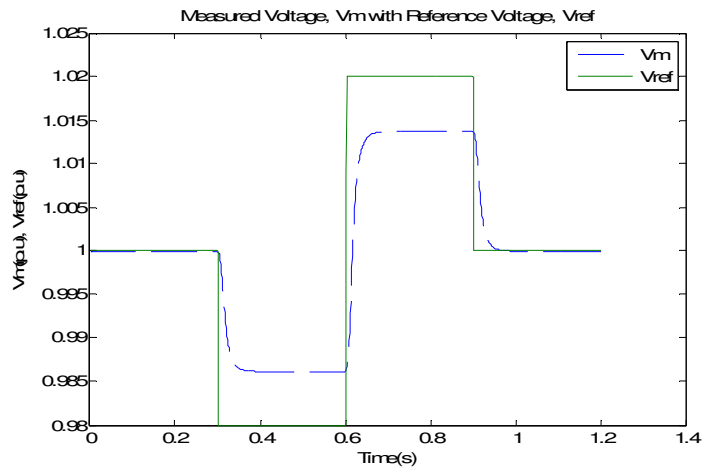


Figure 10a. STATCOM Measured and Reference Voltage under Droop Condition

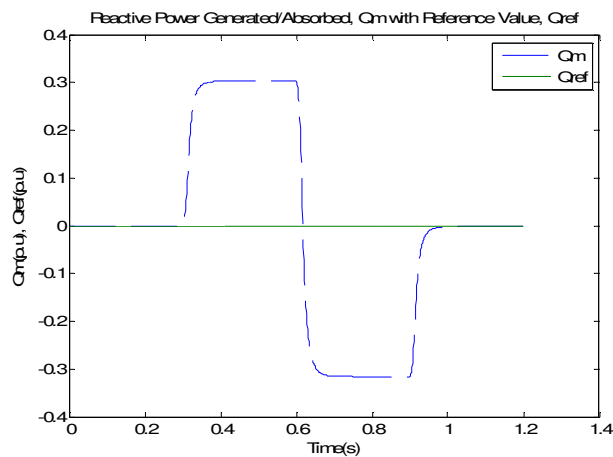


Figure 10b. Reactive Power Absorbed/Generated by the STATCOM with Reference Value under Droop Condition

5.3 During Fault Condition

Figure 11 shows the measured voltage and the reactive power generated by the STATCOM when a remote fault is applied. It can be seen from the Figure that the STATCOM generates reactive power in order to provide voltage support to the system during the fault period.

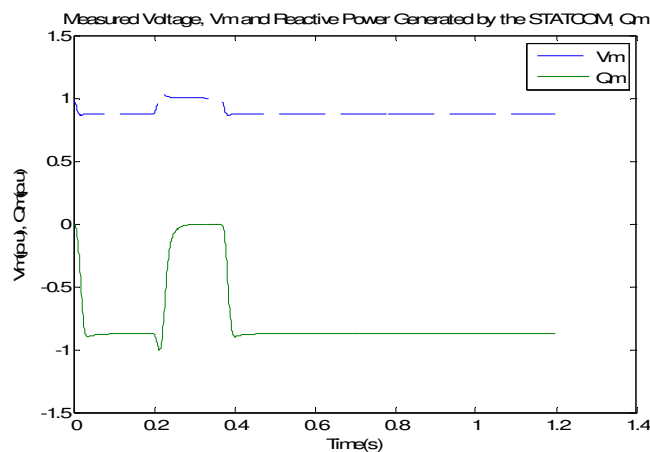


Figure 11. Measured Voltage and Reactive Power Generated by the STATCOM

5. Conclusion

The paper has presented a technological review of STATCOM for voltage profile improvement. Its basic structure, configuration, component parts and topology were also presented. Simulation results reveal that STATCOM is an excellent voltage regulator especially when operated without droop. It can provide both capacitive and inductive compensation. It has the capability of controlling output current over the rated maximum capacitive or inductive range independent of the a.c system voltage and it has increased transient rating in both capacitive and inductive operating regions as well as maintaining full compensating current at depressed line voltage.

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