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Simulation of D-STATCOM for Reactive Power Compensation

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Abstract: *In recent years, Flexible AC Transmission Systems, called FACTS, have become a known technology for better controllability using power electronics in power system. A number of FACTS devices are used for different applications all over the world. The shunt connected FACTS devices are generally used for reactive power compensation and hence, voltage regulation, STATCOM being one among these. It is capable of dealing with the voltage dips and flickers and hence, better as compared to SVC. The advantage of a STATCOM is that the reactive power injected is independent of the line voltage at the point of connection. In this work MATLAB based simulation of D-STATCOM and its related analysis is done.*

Keywords: *FACTS, D-STATCOM, Synchronous PI, Shunt Compensation, Power Quality*

I. Introduction

NOWADAYS, more and more revolutionary power electronics equipments are used in industries for attaining better power controlling ability. Also Power Quality, one of the important issues in power systems has been a problem to both suppliers and customers. Any small time disturbances like voltage dips, voltage swells or any other harmonic disturbances can bring a large amount of financial losses. Moreover power electronics and power quality are irreversibly linked together as with the advancement in both broad areas. Flexible AC Transmission Systems (FACTS) which are based on power electronics offer an opportunity to enhance controllability, stability, and power transfer capability of AC transmission systems.

Increase in the consumption of electric power causes transmission lines to be utilized close to or even beyond their transfer capacity, which results in overloaded lines and congestions. Also some other problems like voltage dip, voltage sag and voltage swell creates a critical problem both technically and economically. As a result of all such problems, Power Quality is affected. Since most of the loads are inductive and consume lagging reactive power, leading reactive power is needed to be supplied by the compensation. As a result Shunt compensation of reactive power is needed. STATCOM is such one of the Shunt FACTS Controllers.

A. Power Quality

In power system, power quality refers to a significantly high grade of electric service. The need of the equipment at the user end decides the quality of power required. Generally, power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency.
As per IEEE 519, it is defined by: "The concept of powering and grounding sensitive equipment in a manner that is suitable to the operation of that equipment."[5] Some of the common power quality issues include: Voltage Dips (Sags), Voltage swell, Interruptions, Transients or Voltage flicker, Voltage unbalancing, Notches and Noise, etc.

B. FACTS and FACTS Controllers[2]

In general, FACTS devices possess the following technological attributes:
1) Provide dynamic reactive power support and voltage control.
2) Reduce the need for construction of new transmission lines, capacitors, reactors, etc. which a. Mitigate environmental and regulatory concerns
a. Improve aesthetics by reducing the need for construction of new facilities such as transmission lines
b. Improve system stability
3) Control real and reactive power flow
4) Mitigate potential Sub-Synchronous resonance problems
5) Improvement in power factor

The benefits due to FACTS controllers are listed below:

1) FACTS reduce the losses in the line and enhance voltage profile to contribute to optimal system operation.
2) Enhancement of Power flow in critical lines; in general, the power carrying capacity of lines can be increased to values up to the thermal limits (imposed by current carrying capacity of the conductors).
3) Transient stability limit is increased thereby improving dynamic security of the system and reducing the incidence of blackouts caused by cascading outages.
4) Steady state or small signal stability region can be increased by providing auxiliary stabilizing controllers to damp low frequency oscillations.
5) FACTS controllers such as TCSC can counter the problem of Sub-synchronous
6) Resonance (SSR) experienced with fixed series capacitors connected in lines evacuating power from thermal power stations (with turbo generators).
7) Problem of voltage fluctuations and in particular, dynamic over-voltages can be overcome by FACTS controllers.

C. Shunt Compensation

The primary objective of using reactive shunt compensation in power system is to increase the power transfer capacity. This ultimately leads to improved steady-state transmission characteristics as well as better system stability. Hence, to accomplish the task, reactive power compensation is done to regulate voltage at the midpoint

(or any intermediate) of the transmission line and at the end of the (radial) line. [4]

D. Static Synchronous Compensator (STATCOM)

STATCOM is one of the many devices under the FACTS family, which acts as a regulating device and which can be used to regulate the flow of reactive power in the system independent of other system parameters. It is a shunt connected static compensator, developed as an advanced static VAR compensator, where a voltage source convertor (VSC) is used instead of the shunt connected controllable reactors and switched capacitors. In the power transmission systems, STATCOM primarily handles only fundamental reactive power exchange. It also provides voltage support to buses by modulating bus voltages during dynamic disturbances in order to provide better transient characteristics, to improve the transient stability margins and to damp out the system oscillations due to these disturbances.

E. Various Control Strategies for Distribution-STATCOM (D-STATCOM)

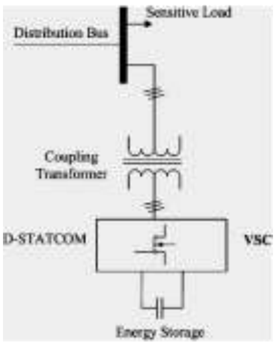

Fig. 1: Configuration of D-STATCOM

Fig. 1 shows a distribution system containing an unbalanced load. A suitable D-STATCOM is connected to the load bus through a step-up transformer. It is assumed that the supply voltage is sinusoidal and positive sequence. However, the voltage at PCC (V_t) becomes unbalanced and contains harmonics due to the system impedance. [2]

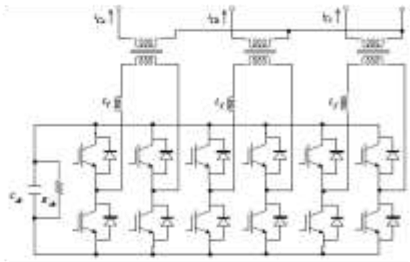

Fig. 2: Configuration of DSTATCOM

The voltage at the point of connection would be sinusoidal and comprise of positive sequence components because the source voltage assumed is sinusoidal and positive sequence. Thus, the D-STATCOM should inject negative, zero sequence fundamental frequency components in addition to harmonic currents of all sequences. As shown in Fig. 2, the DSTATCOM contains three single phase full bridge converters, connected to a common DC bus. The DC link capacitor C_{dc} regulates the DC link voltage. So, a DC bus voltage control loop is required in order to maintain the capacitor voltage near the desired value. Also, with the variation in load over the time period, charging and discharging of capacitor takes place, resulting in ripples in voltage, which are to be minimized. [2]

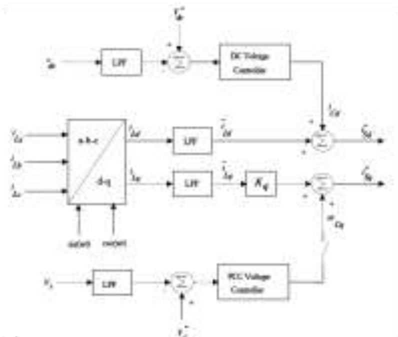

Fig. 3(a): Reference source currents (d and q components)

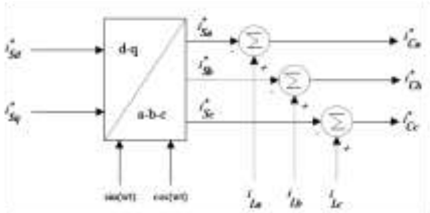

Fig. 3(b): Reference compensator currents

Synchronous Reference Frame (SRF) is used to determine the reference source current vector. First of all, computation for the reference for the source current vector is done. The next step is to obtain the desired compensator currents by taking the difference between load and source (reference) currents. (Fig. 3(a), 3(b)) [2]

F. Synchronous PWM v/s Hysteresis Current Control

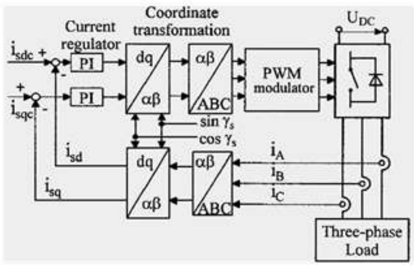

Fig. 4: Synchronous PI

The stationary controller uses three PI error compensators to produce the voltage commands for a three-phase sinusoidal PWM. The control signals for the inverter switches are generated by comparison with the triangular carrier signal. The behaviour of this controller is different from the original PWM Controller, because the output current ripple is fed back and influences the switching times. The main disadvantage of this technique is an inherent tracking (amplitude and phase) error. To achieve compensation, use of additional phase-locked loop (PLL) circuits or feed-forward correction, is also made.

In practical conditions, a minor phase or amplitude error can result in incorrect system operation. This is not at all desirable. To deal with this problem, the scheme as shown in Fig. 4 is used which is based on space vector approach. It uses two PI compensators of current vector components defined in rotating synchronous coordinates
d and q. [9]

G. Filter Design

There are three types of filter designs proposed for the purpose: L-filter, LC-filter and LCL-filter. L-filter is the most popularly used filter but had a low attenuation and requires high inductance value to accomplish the task. The time of response becomes high due to the voltage drop across inductor, resulting in poor system dynamics. A probable solution to this problem is, use of high switching frequency of the inverter to attenuate the harmonics. Also, a shunt element is required to attenuate the switching frequency components. A capacitor is generally preferred as it produces low reactance at switching frequency. This makes an LC-filter. LC-filter is used when the load impedance across capacitor is above switching frequency and comparatively high. The value of capacitance should be high to reduce cost and losses, so that a low inductance can be selected. But, higher the capacitance, higher will be the inrush current, higher is the reactive current, and higher the possibility of resonance at source side.
A better option can be the use of an LCL-filter. It is capable of giving better attenuation ratio even with smaller values of inductance and capacitance. [10], [11]

II. Simulation Circuit

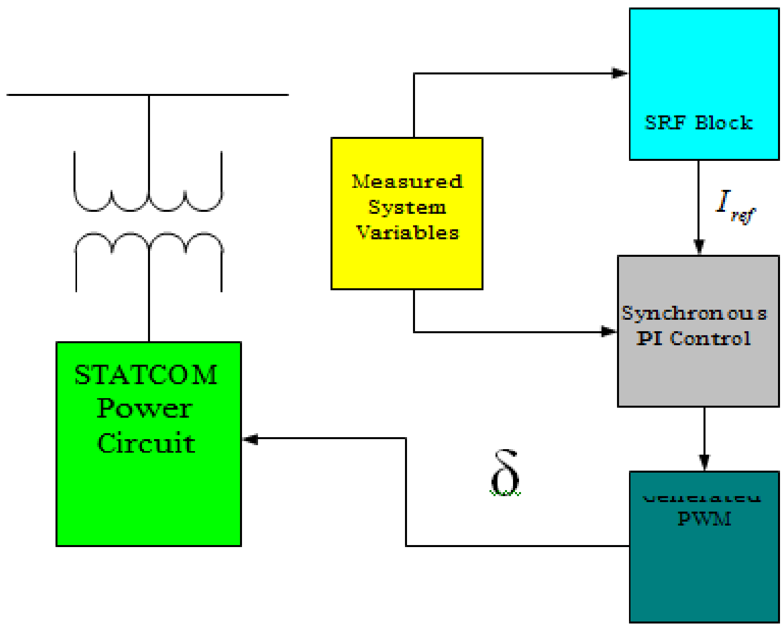

Fig. 5: Block Diagram of STATCOM

Fig. 5 gives the block diagram of the DSTATCOM Circuit to be implemented in MATLAB/Simulink (R2013). Six-switch inverter bridge circuit is implemented as the Voltage Source Converter of STATCOM which is connected in shunt to the line at PCC. The firing pulses are generated using Synchronous PWM. The input to this block is the reference signals of current generated by

'Synchronous Rotating Frame based Extraction of Reference Current' Theory. The input to SRF Block is the line current and angle obtained by Phase-locked Loop (PLL) Block.

The grid and the load data are given below: Grid: V_S = 433 V, 50 Hz

Load: R-L load: Active Power P = 10 kW, Inductive Reactive Power, Q_L = 5 kVAR

R-C load: Active Power P = 10 kW, Capacitive Reactive Power, Q_C = 5 kVAR

III. Results

A. With Compensation

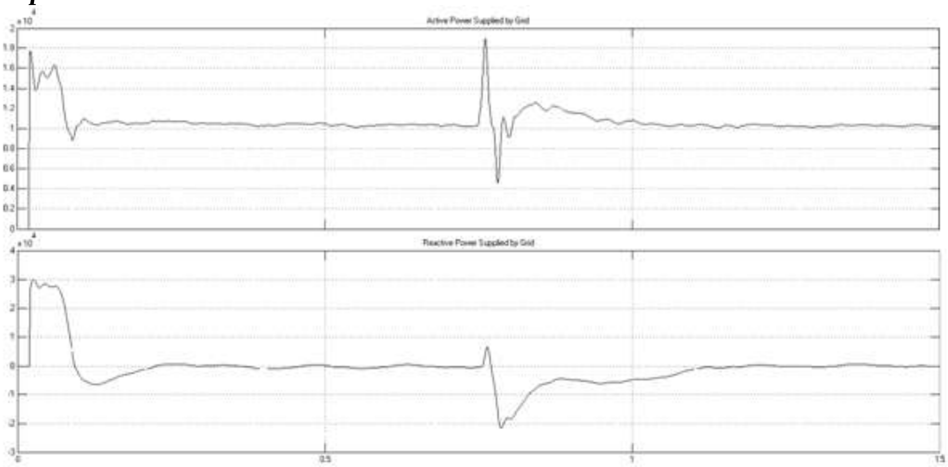

Fig. 6: Active and Reactive power supplied by the Grid

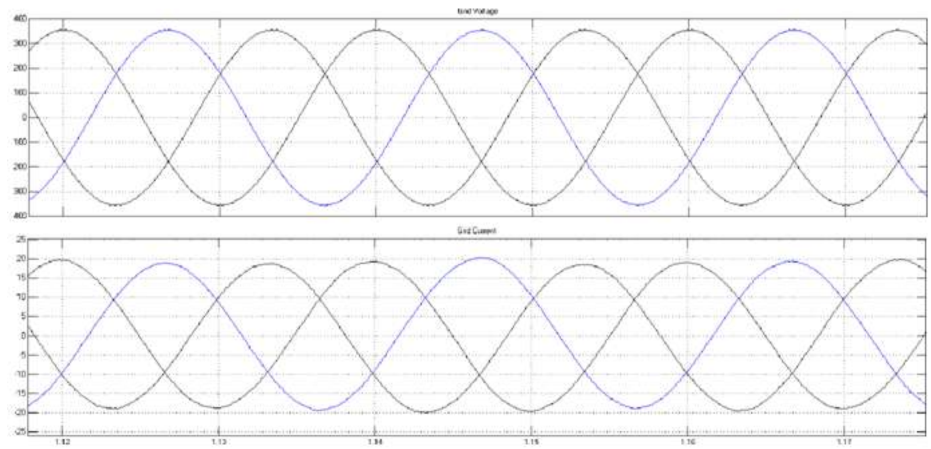

Fig. 7: Grid Voltage and Current: Zoomed in View

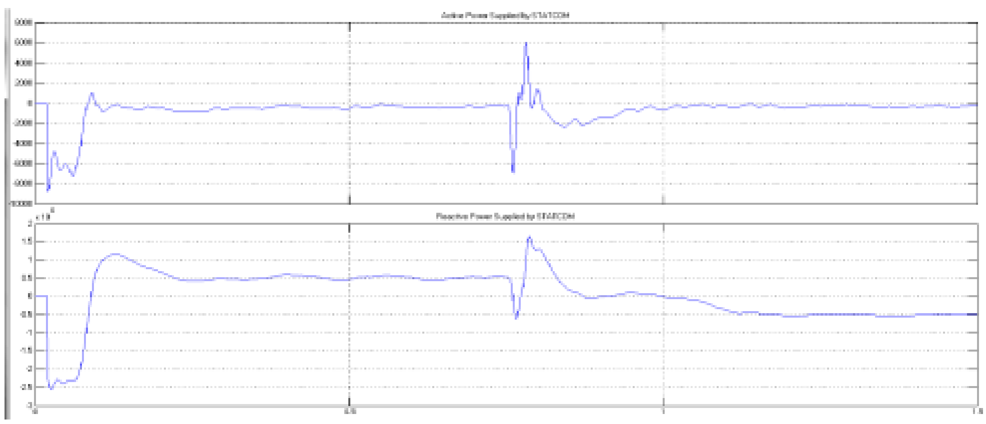

Fig. 8: Active and Reactive Power Injected by STATCOM

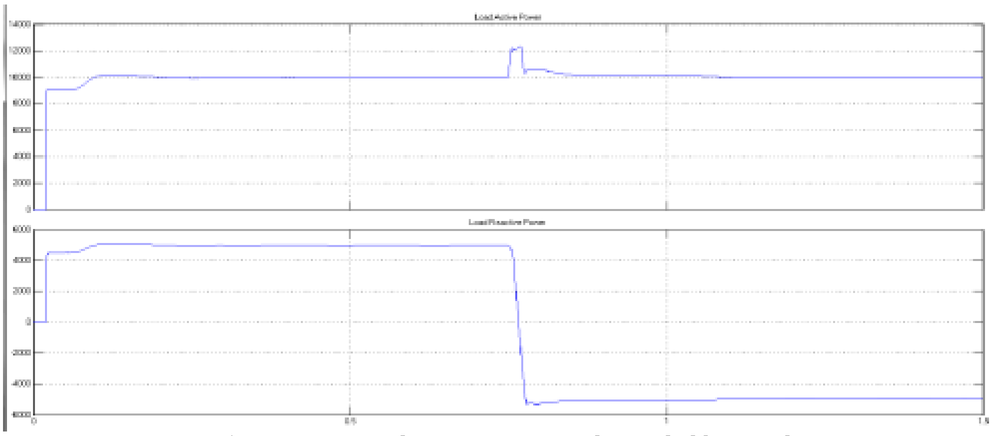

Fig. 9: Active and Reactive Power demanded by Load

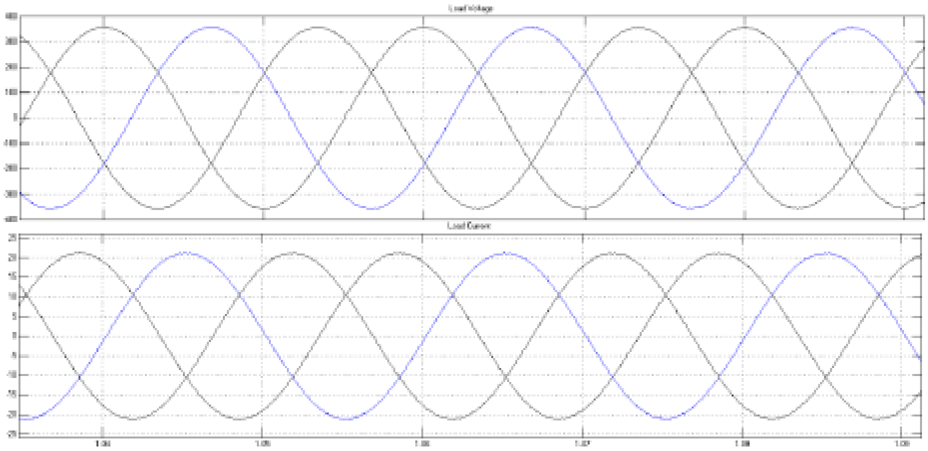

Fig. 10: Load Voltage and Current: Zoomed in View

B. Without Compensation

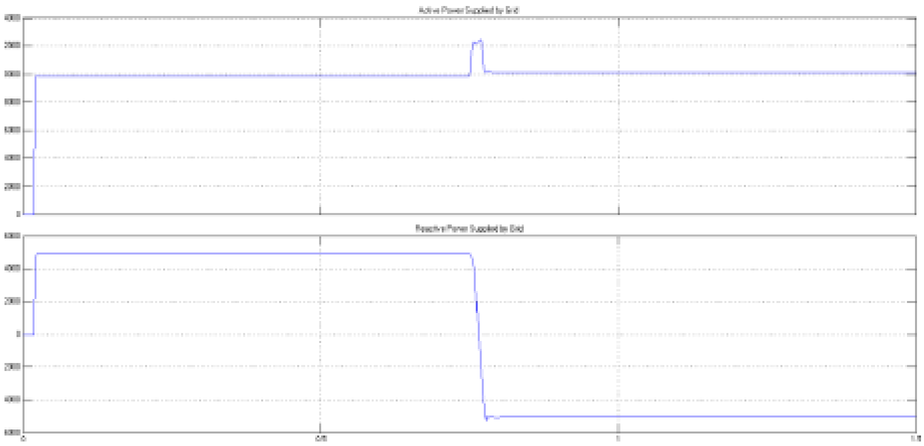

Fig. 11: Active and Reactive Power Supplied by Grid

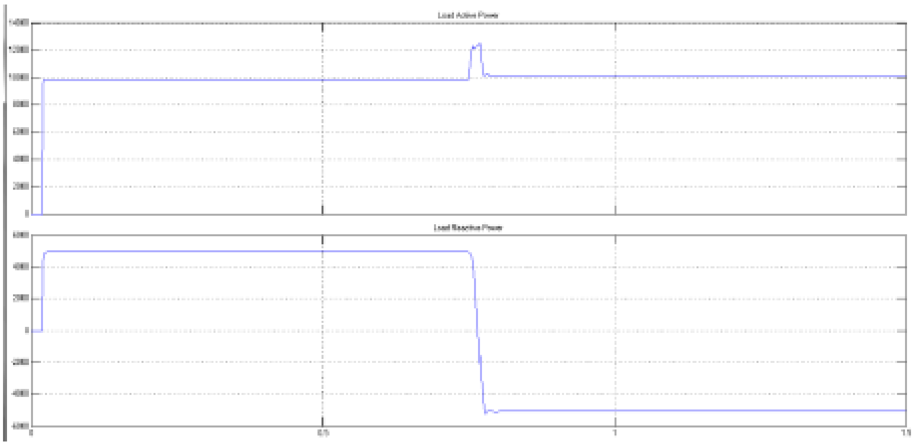

Fig. 12: Active and Reactive Power Demanded by the load

IV. Conclusion

The D-STATCOM designed is capable to inject the entire reactive power demanded by the load, keeping the source power factor near to unity. The simulation done is able to explain the response of D-STATCOM in both, Inductive as well as Capacitive, modes of operation.

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