Improvement of Power System Stability by Power Electronics Based FACTS Controller

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Abstract - ***The rapid development of power electronics technology provides exciting opportunities to develop new power system equipment for better utilization of existing systems. FACTS devices can be effectively used for power flow control, load sharing among parallel corridor, voltage regulation, and enhancement of transient stability and mitigation of system oscillations. By giving additional flexibility, FACTS controllers can enable a line to carry power closer to its thermal rating. Mechanical switching has to be supplemented by rapid response power electronics. It may be noted that FACTS is an enabling technology, and not a one to one substitute of mechanical switches. FACTS employ high speed thyristors for switching in or out transmission line components such as capacitors, reactors or phase shifting transformers for some desirable performance of the systems. The FACTS technology is not a single high power controller, but rather a collection of controllers, which can be applied individually or in coordination with others to control one or more of the system parameters. In this paper is to set the stage for introducing the PFC (Power Flow Control) through the comparison with better known, FACTS controllers and simulate the IGBT Based PFC through the comparison with SCR Based PFC, FACTS controllers, in simulink.***

Keywords—FACTS, Power system, Power Flow Control, Reative Power.

I. INTRODUCTION

The electric power system consists of three main subsystems: the generation subsystem, the transmission subsystem, and the distribution subsystem. Electricity is generated at the generating station by converting a primary source of energy to electrical energy. The voltage output of the generators is then stepped-up to appropriate transmission levels using a step up transformer. The transmission subsystem then transmits the power close to the load centers. The voltage is then stepped-down to appropriate levels. The distribution subsystem then transmits the power close to the customer where the voltage is stepped down to appropriate levels for use by a residential, industrial, or commercial customer.

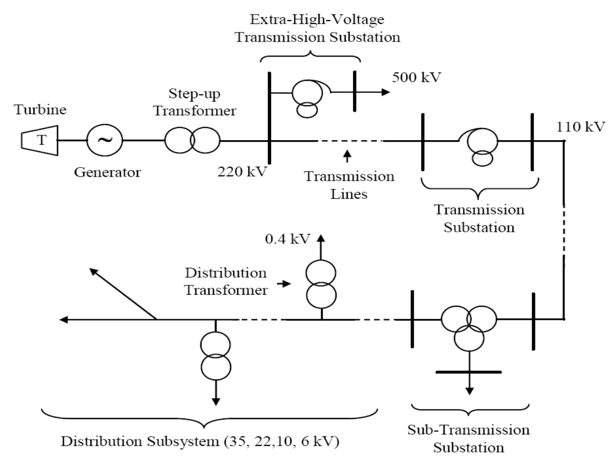

Figure1 Power System

Flexible AC Transmission Systems (FACTS) are the name given to the application of power electronics devices to control the power flows and other quantities in power systems.

IEEE Definitions:

- FACTS: AC transmission systems incorporating the power electronic-based and other static controllers to enhance controllability and increase power transfer capability.
- FACTS Controllers: A power electronic based system & other static equipment that provide control of one or more AC transmission parameters.

The power industry term FACTS covers a number of technologies that enhance the security, capacity and flexibility of power transmission systems. FACTS solutions enable power grid owners to increase existing transmission network capacity while maintaining or improving the operating margins necessary for grid stability. As a result, more power can reach consumers with a minimum impact on the environment, after substantially shorter project implementation times, and at lower investment costs, all compared to the alternative of building new transmission lines or power generation facilities.

The two main reasons for incorporating FACTS devices in electric power systems are:

(i) Raising dynamic stability limits (ii) Provide better power flow control

In general, FACTS devices possess the following technological attributes:

- Provide dynamic reactive power support and voltage control.
- Reduce the need for construction of new transmission lines, capacitors, reactors, etc which mitigate environmental and regulatory concerns.

II. PRINCIPLE OF FACTS CONTROLLERS

Controllable reactive power can be generated by ac to dc switching converters which are switched in synchronism with line voltage with which the reactive power is exchanged. A switching power converter consists of an array of solid state switches which connect the input terminal to the output terminals. It has no internal storages so the instantaneous input and output powers are equal. Further the input and output terminations are complementary that is if the input is voltage source the output will act as current source and vice versa. Thus, the converter can be a voltage source (shunted by a capacitor or battery) or current source (shunted by inductor). For reactive power flow the bus voltage V and the converter terminal voltage Vo are in phase. Then on per phase basis:

$$I = V - Vo/X$$

The reactive power exchange is,

$$Q = VI = V\,(V - Vo/X)$$

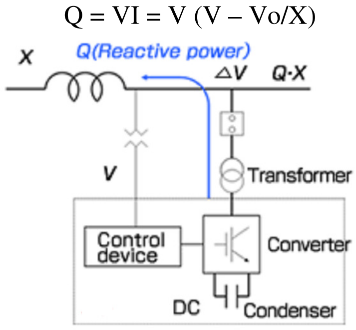

Figure 2 FACTS Controller

The switching circuit is capable of adjusting Vo the output voltage of the converter. For Vo > V, I lags V and Q drawn from the bus is leading, while for Vo<V, then Q drawn from the bus is lagging. Reactive power drawn can be easily changed by varying Vo by changing the on time of solid state devices. It is to be noted that transformer leaks\age reactance is quiet small (0.1 to 0.15 pu), which means that a small differences in voltages (V – Vo) causes the required I and Q to flow. Thus, a converter acts like a static synchronous condenser.

As the converter draws only reactive power the real power drawn from the capacitor is zero. Also, at dc the capacitor does not draw any reactive power. Therefore the capacitor voltage does not change and the capacitor establishes only a voltage level for a converter. The switching causes the converter to interconnect the 3 phase lines so that reactive current can flow between them. The converter draws a small amount of real power to provide for the internal loss (in switches).

The above mentioned converter is connected in shunt with the line. On similar lines a converter can be connected in series with the line. During this case it has to carry the line current and provide a suitable magnitude (or phase) voltage in series with the line. In such a connection it would act as impedance modifier of the line.

2.1 Types of FACTS Controllers

The development of FACTS controllers has followed two different approaches. The first approach employs reactive impedance or a tap changing transformer with thyristor switches as controlled elements, the second approach employs self commutated static converters as controlled voltages sources. FACTS controllers based on the type of compensation.

They can be classified into the following categories:

- Shunt Connected Controller
- Series Connected Controller
- Combined Shunt-Series Connected Controller

2.2 Shunt Connected Controllers

Shunt controllers used for reactive power and voltage control. This may be variable impendence, variable source or a combination of these. In principle all shunt controllers inject current into the system at the point of connection.

Shunt Connected Controllers are:

- Thyristor Controlled Reactor (TCR)
- Thyristor Switched Capacitor (TSC)
- Fixed Capacitor (FC) + TCR
- Static Var Compensator (SVC)
- Gate-Turn-Off (GTO)-based voltage source converter (VSC) : STATCOM

2.3 Series Connected Controllers

The principle of the series controllers is to compensate the voltage drop in the line by an inserting the capacitive voltage. In other words to reduce the effective reactance of the transmission line. The voltage of series capacitor is proportional and in phase quadrature with the line current. The reactive power support is proportional to the square of the current.

Series Connected Controllers are:

- Static Synchronous Series Compensator (SSSC)
- Thyristor Controlled Series Capacitor (TCSC)
- Thyristor Switched Series Capacitor (TSSC)
- Thyristor Controlled Series Reactor (TCSR)
- Thyristor Switched Series Reactor (TSSR)

2.4 Thyristor Controlled Series Capacitor (TCSC)

A capacitive reactance compensator which consists of a series capacitor bank shunted by a thyristor-controlled reactor in order to provide a smoothly variable series capacitive reactance. The combination allows the smooth control of fundamental frequency reactive capacitance over a wide range.

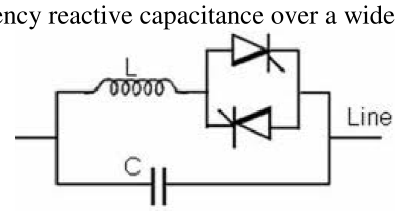

Figure 3 Thyristor Controlled Series Capacitor (TCSC)

2.5 IGBT (Insulated Gate Bipolar Transistors)

It is a voltage controlled four-layer device with the advantages of the MOSFET driver and the Bipolar Main terminal. IGBTs can be classified as punch-through (PT) and non-punch-through (NPT) structures. In the punch-through IGBT, a better trade-off between the forward voltage drop and turn-off time can be achieved. Punch-through IGBTs are available up to about 1200 V. NPT IGBTs of up to about 4 KV have been reported in literature and they are more robust than PT IGBTs particularly under short circuit conditions. However they have a higher forward voltage drop than the PT IGBTs. Its switching times can be controlled by suitably shaping the drive signal. This gives the IGBT a number of advantages: it does not require protective circuits, it can be connected in parallel without difficulty, and series connection is possible without dv/dt snubbers. The IGBT is presently one of the most popular device in view of its wide ratings, switching speed of about 100 KHz a easy voltage drive and a square Safe Operating Area devoid of a Second Breakdown region.

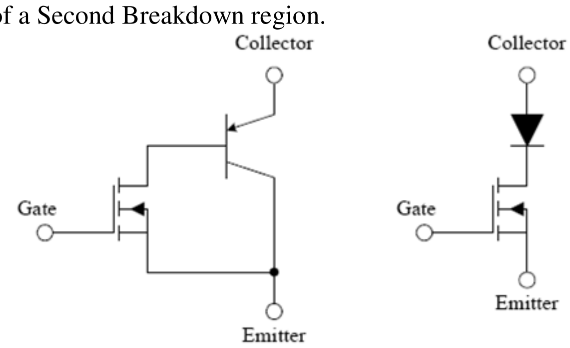

Figure 4 IGBT simplified Equivalent Circuits

III. CIRCUIT DIAGRAMS AND EXPLANATION

3.1 For TCSC

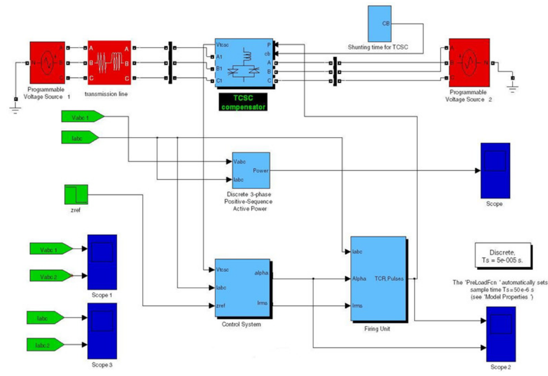

Figure 5 Simulation Model TCSC

Three phase programmable voltage source block to generate a three-phase sinusoidal voltage with time-varying parameters. We can program the time variation for the amplitude, phase, or frequency of the fundamental component of the source. In addition, two harmonics can be programmed and superimposed on the fundamental signal. presently it is programmed to 500kV and second voltage source of just 10 percent less than one and with a phase shift of 5 deg. Lagging, Both sources are connected through a long transmission line with only RL components and TCSC compensator. Three phase positive sequence power measurement block. Control system to decide the firing time of SCR by measuring the current and voltage from first voltage source. Firing unit generates the firing pulses for firing the SCR according to input provided by Control block.

When TCSC operates in the constant impedance mode it uses voltage and current feedback for calculating the TCSC impedance. The reference impedance indirectly determines the power level, although an automatic power control mode could also be introduced. The firing circuit uses three single-phase PLL units for synchronization with the line current. Line current is used for synchronization, rather than line voltage, since the TCSC voltage can vary widely during the operation.

3.2 For IGBT

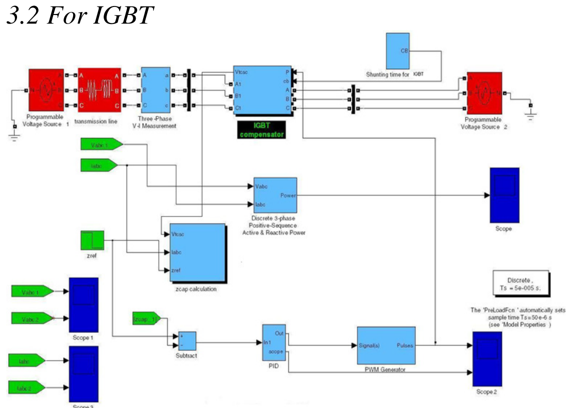

Figure 6 Simulation Model IGBT

For IGBT all the blocks are same except that TCSC block is modified by IGBT and the firing block is replaced by PWM.

For the calculation of firing angle of IGBT circuit we use equivalent capacitance of IGBT circuit and calculate error between required or reference capacitance. To minimize this error by controlling triggering pulse of IGBT. The controlling is done by PID and PWM generators. The boundation of firing angle calculation for IGBT based system not required because PID controller is used and it can automatically adjusted pulse width (firing angle delay).

IV. SIMULATION AND RESULTS

4.1 For TCSC

After running the simulation we can observe waveforms on the main variables scope block. The TCSC is in the capacitive impedance control mode and the reference impedance is set to 128 Ohm. For the first 0.75s, the TCSC is bypassed using the circuit breaker, and the power transfer is 110 MW. At 0.75s TCSC begins to regulate the impedance to 128 Ohm and this increases power transfer to 610MW. Note that the TCSC starts with alpha at 90deg to enable lowest switching disturbance on the line.

Dynamic Response

At 2.5s a 5% change in the reference impedance is applied. The active power flow response indicates that TCSC enables tracking of the reference impedance and the settling time is around 500ms. At 3.3s a 4% reduction in the source voltage is applied, followed by the return to 1p.u. at 3.8s. It is seen that the TCSC controller compensates for these disturbances and the TCSC impedance stays constant. The TCSC response time is 200ms-300ms.

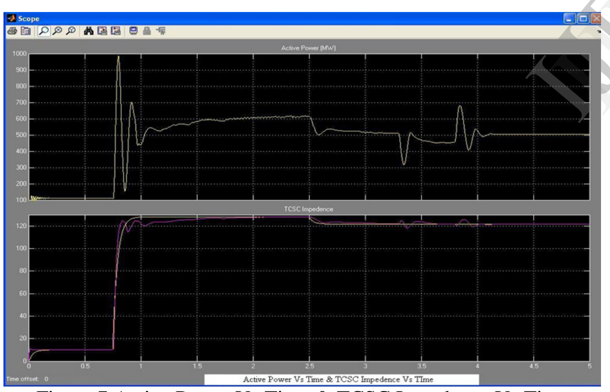

Figure 7 Active Power Vs Time & TCSC Impedance Vs Time

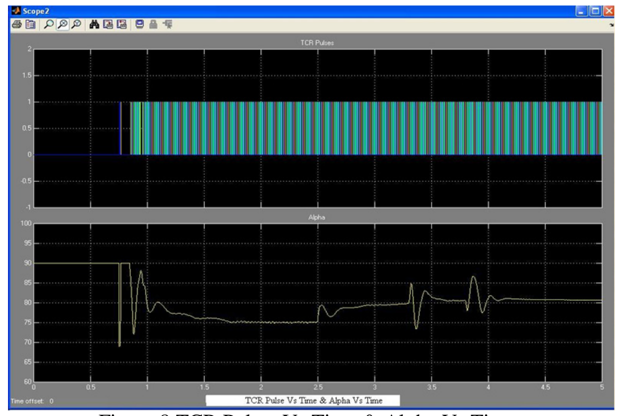

Figure 8 TCR Pulses Vs Time & Alpha Vs Time

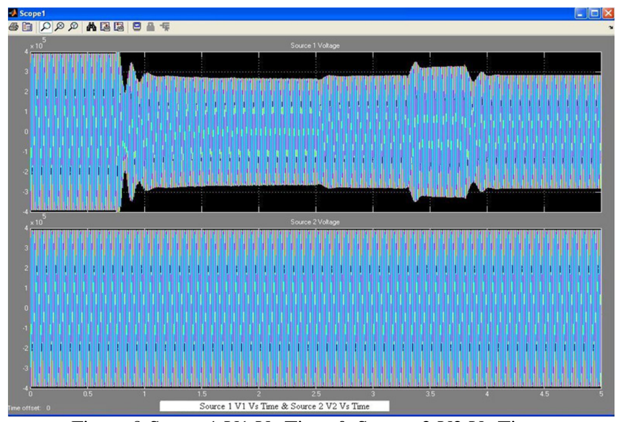

Figure 9 Source1 V1 Vs Time & Source 2 V2 Vs Time

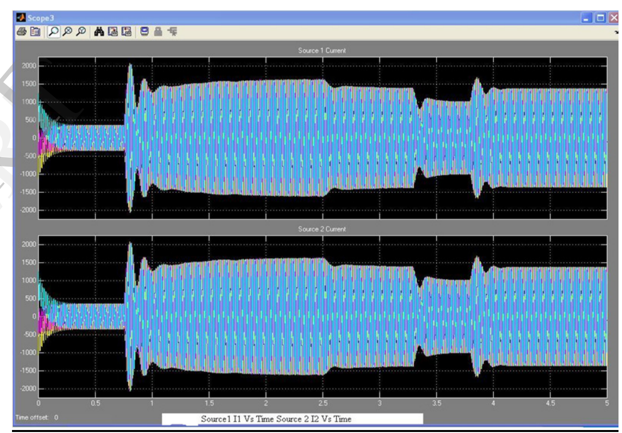

Figure 10 Source1 I1 Vs Time & Source 2 I2 Vs Time

4.2 For IGBT

After running the simulation we can observe waveforms on the main variables scope block. The IGBT is in the capacitive impedance control mode and the reference impedance is set to 128 Ohm. For the first 0.75s, the IGBT is bypassed using the circuit breaker, and the power transfer is 110 MW. At 0.75s IGBT begins to regulate the impedance to 128 Ohm and this increases power transfer to 800MW.

Dynamic Response

At 2.5s a 5% change in the reference impedance is applied. The active power flow response indicates that IGBT enables tracking of the reference impedance and the settling time is around 200ms. At 3.3s a 4% reduction in the source voltage is applied, followed by the return to 1p.u. at 3.8s. It is seen that the IGBT controller compensates for these disturbances and the IGBT impedance stays constant. The IGBT response time is 100ms-200ms.

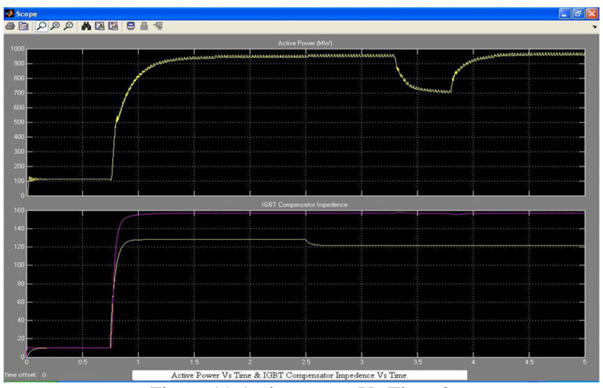

Figure 11 Active power Vs Time &
IGBT Compensator Impedance Vs Time

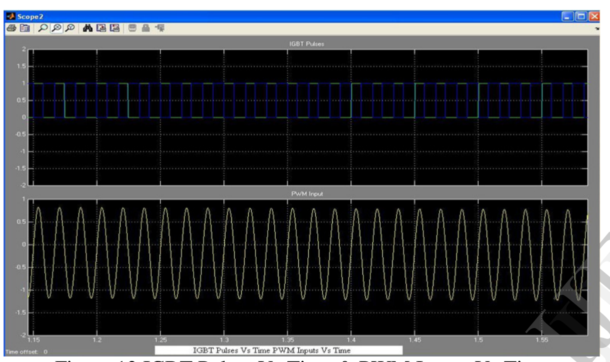

Figure 12 IGBT Pulses Vs Time & PWM Inputs Vs Time

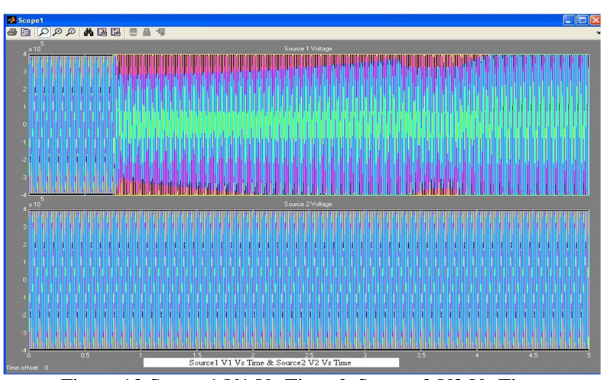

Figure 13 Source1 V1 Vs Time & Source 2 V2 Vs Time

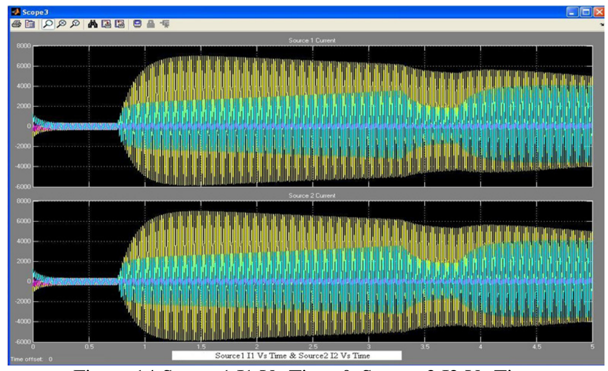

Figure 14 Source1 I1 Vs Time & Source 2 I2 Vs Time

The IGBT is catch the value faster and smoother way then TCSC. IGBT controller compensates the disturbances and the IGBT impedance stays constant. The IGBT response time is 100ms-200ms.

V. CONCLUSION & FUTURE DEVELOPMENT

FACTS Controllers are very effective in improving transient stability and damping power system oscillations. A wide range of compensating devices to mitigate PQ problems is discussed. The modern compensators are power electronic based controllers which are very fast and accurate in operation. The increasing use of FACTS controllers is guaranteed. What benefits are required for the given system would be principle justification for the choice of the FACTS controller. Its final form and operation, of course, depend not only on the successful development of the necessary control and communication technologies and protocols, but also on the final structure of the evolving newly restructured power system. FACTS Controllers are very effective in improving transient stability and damping power system oscillations. A wide range of compensating devices to mitigate PQ problems is discussed. The modern compensators are power electronic based controllers which are very fast and accurate in operation.

Further development of semiconductor devices and configurations will increase the use of power electronics in case of economic manufacturing for high power applications. Exchange of electrical energy in extended systems requires flexible transmission systems to provide solutions with regard to reactive power balance. Conventional system components only provide limited adjustments Up to now power electronics like HVDC, SVC and TCSC have proven reliable functioning.

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