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# IGBT SWITED TCSC FOR ENHANCEMENT OF SWITCHING FOR OVERALL SYSTEM STABILITY

Jitendra Gupta[1], Rahul Gupta[2]

***Abstract: This paper presents test results for a power system using TCSC switched by IGBT's to compensate the inductive impedance of the synchronous generator and control the active power injection. Different switching angles were evaluated at some compensation levels and simulations are done to analyze the effectiveness and robustness of the proposed controller project. Due to the use of IGBT switching several enhancements are levied which are studied herewith.***

***Index Terms: TCSC, series compensation, IGBT, Thyristor, switching.***

## I. INTRODUCTION

THE safety and continuity of energy production from a Hydroelectric Power Plant (HPP) depends greatly on the auxiliary power system reliability. This reliability is dependent on the power supply methodology; both direct current (DC) and alternating current (AC) are possible configurations [1]. In AC supply systems the loads are primarily motors, illumination, heating elements and equipments for general use, where the voltage level is usually 220 or 380V. In DC systems, the common loads are control and protection circuits, transducers, startup of excitation systems, among others, where the usual voltages levels are 24 and 125V. The energy provided by auxiliary services systems is delivered to various consumption points within the plant through an internal distribution system and in the studied case, with ring configuration. This ring distribution system can operate in a radial configuration through operation switches located at strategic points, allowing the power flow through different paths, increasing system reliability [2]. The Synchronous Generators (SG) excitation system performs control and protection functions, which are essential for the correct performance of the Electric Power System (EPS). The excitation system can be classified into three categories according to the excitation power source, namely: direct current system (CC), alternating current systems (AC), and static systems [3]. The advent of statics excitation systems caused them to replace the original rotating systems, however, the old auxiliary synchronous generator were mechanically held in the turbine-generator set, objecting to not change the original dynamic characteristic. In this sense, the use of auxiliary generators in electrical power supply for auxiliary service, even if already installed, is not trivial, since they were originally projected as an excitation system of the main generator. Moreover, its mechanical connection with the primary machine makes the control system act only on the angular opening of the main generator, which does not allow active power regulation on the auxiliary machine. Developed originally for power transmission systems, FACTS devices (Flexible AC Transmission System) provide to the power system greater operational flexibility. In particular, a TCSC device (Thyristor Controlled Series Capacitor) can be used in optimizing stability margins, increasing the limits of power transfer and damping EPS inherent oscillations [4]-[8]. This paper presents the initial project and test results of an active power control scheme for an auxiliary generator mechanically connected to a Hydraulic Generation Unit Main Machine. The auxiliary generator is connected to a 400 V power system auxiliary bus. A TCSC is used on the active power control scheme, with its equivalent series reactance controlled without necessary change of the generator opening angle.

## II. BASIC CONCEPT OF TCSC

TCSC is one of the best known series FACTS controllers, which has been used for many years to increase line power transfer capability as well as to enhance system stability [9]-[12]. Moreover, it can have various roles in the operation and control of power systems, such as scheduling power flow, providing voltage support, decreasing unsymmetrical components, reducing net loss, damping the power oscillation, providing voltage support, limiting short-circuit currents, mitigating subsynchronous resonance and enhancing transient stability [9]. TCSC module consists of three components: a series capacitor (C), bypass inductor (L) and bidirectional thyristors, as shown in Fig. 1. Also in parallel, same as in conventional series capacitor applications is a metal-oxide varistor (MOV) for overvoltage protection and a bypass circuit breaker (CB). A complete TCSC system may consist of several modules such as parallel controlled reactors and improve the overall power system performance controllable power electronic element in the whole power circuit, and line impedance can be adjusted by phase control of its thyristor switches [13]-[14].

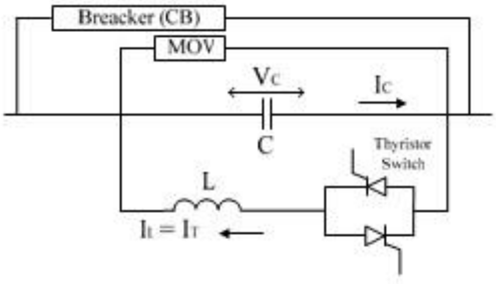
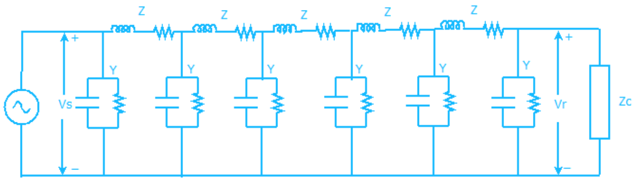


Fig. Basic TCSC scheme

The TCSC device has four steady-state operating modes:
Block mode, Bypass mode, capacitive Vernier mode, and inductive Vernier mode. Theoretically, there are 12 mode switching possibilities. Since the Inductive Vernier mode is not often adopted in practice due to a serious waveform distortion of the capacitor voltage and current, which contains too much harmonics and does harm to safety and

economic operation of power system, there are 6 mode switching combinations for the three operating states. Traditionally, we consider the mode switching from Block mode to capacitive Vernier mode as an impedance control action; mode switching from Bypass mode to capacitive Vernier mode can be conducted by line current synchronization; to complete mode switching from Bypass mode to Block mode, we can switch Bypass mode to capacitive Vernier mode first and then to Block mode by changing firing angles The presence of dual impedance solutions phenomenon gives higher requirement to the mode switching control method. Only by changing firing angles, TCSC impedance will merely vary according to the original impedance curve and will not switch to TCSC Configuration. The equivalent impedance of TCSC consists of the partial cancellation of the capacitance of fixed capacitor for conducting part of the IGBT (Insulated Gate Bipolar Transistor), so for the fundamental frequency is Thus, the TCSC represents a parallel LC circuit for the generator current. By varying the angle α the TCSC impedance can change from its minimum capacitance. If a large disturbance occurs during the process of adjusting impedance, TCSC impedance may jump from one curve to the other to cause the impedance adjustment failure. It is very important to develop an appropriate control method of mode switching to guarantee the accuracy and reliability of TCSC operation.

## III. REACTIVE POWER COMPENSATION



Long Transmission Line Model

It has series inductive reactance(XL) & shunt capacitive reactance (XC). The series inductive reactance gives inductive voltage drop IXL which varies with line load current (I).Shunt capacitance supplies reactive power (-Q) which is a function of voltage V2. Due to distributed series inductance & shunt capacitance the transmission line absorbs reactive power throughout it's length.The reactive power supplied varies with voltage. Hence the supply & absorption by distributed inductance & capacitance varies throughout the length of the line.Therefore the voltage of the line goes on varying along the line and the voltage variation along the line depends upon load current & it's power factor.

## IV. SURGE IMPEDANCE LOADING (NATURAL LOADING)

If the load on the line is such that the reactive power produced by the line (QC) is equal to the reactive power supplied to the line (QL) the load impedance is called surge impedance (ZS). The line is said to have natural load or unit surge impedance load.

Thus for unit surge impedance loading or natural loading

QC = QL

L & C parameters of the line and are independent of line length.Surge impedance of a overhead line with single conductor is about 400Ω & with twin bundle conductors is about 300Ω. Surge impedance of oil filled cables is of the order of 25Ω.

Surge impedance loading or natural loading is given by,

Pn = VI watts

Where, Pn = Natural load or surge impedance loading

Zs = Surge impedance of the line.

V = Rated voltage of line.

When a line is loaded with unit impedance the VAR's generated by the line capacitance are equal to VAR's absorbed by the line inductance. Hence the line does not take any reactive power from the terminals. Surge impedance loading gives an approximate idea of line. To maintain constant voltage throughout the length of line:

Reactive power should be absorbed during low loads i.e. shunt reactors should be switched in. Reactive power should be supplied during heavy loads i.e. shunt capacitors should be switched in. Reactive power requirement increases as the length of line increases. This calls for intermediate substations.

Proposed Methodology:

The main purpose of this thesis is to set the stage for introducing the PFC (Power Flow Control) through the comparison with better known, FACTS controllers .

To describes the functionality of different fact devices.

On other side of this thesis I simulate the IGBT Based PFC (Power Flow Control) through the comparison with SCR Based PFC (Power Flow Control), FACTS controllers, in simulink.

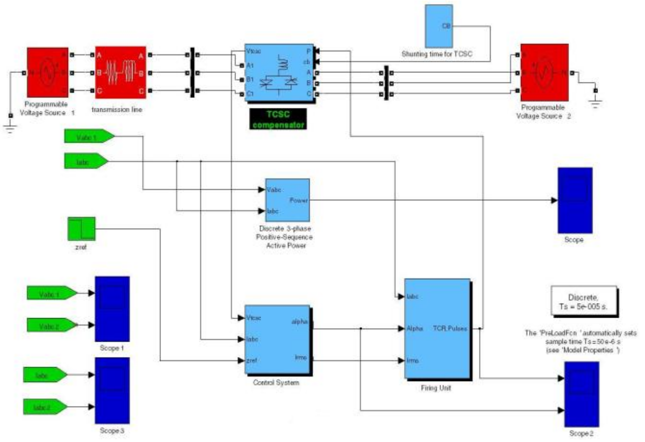
## PERMISSIBLE LINE LOADING AS PER CEA STANDARDS

+/- 500 kV HVDC bi-pole line=Pole Capacity X Number of Pole in service 765 KV line having 4 X 686 sq. mm conductor =2250 MW per circuit 765 KV line having 4 X 686 sq. mm conductor operating at 400 kV =614 MW per circuit 400 KV line having 2 X 520 sq. mm conductor with shunt reactor =410 MW per circuit 400 KV line having 2 X 520 sq. mm conductor without shunt reactor =533 MWper circuit 400 KV line having 2 X 520 sq. mm conductor operating at 220 kV =155 MW per circuit 220 kV line =132 MW per circuit 132 kV Line =50 MW per circuit Reactive power compensation requirements of transmission line varies with line loading. By means of controllable series compensation & static VAR systems the reactive power compensation can be optimized. For long transmission lines the permissible transmission line loading based on thermal ratings of conductors is much higher than Pa = 1.5 Pn . But the increased requirements of compensation & voltage regulation problems set a limit of power transfer to about 1.3 Pn. This difficulty is likely to be overcome by controllable series compensation & SVS. Presently long EHV-AC transmission lines can be loaded upto P = kPn where K=0.85 to 1.3 depending upon natural load Pn of the line & length of the line (0.85 for long line & 1.3 for shorter line). Long EHV transmission line need an intermediate switching sub-station to enable installation of series capacitors & shunt reactors.

Simulation Model TCSC:

Explanation
We create the transmission system by using the following components are given below:
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.
Some other subsystem blocks which used are:
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.

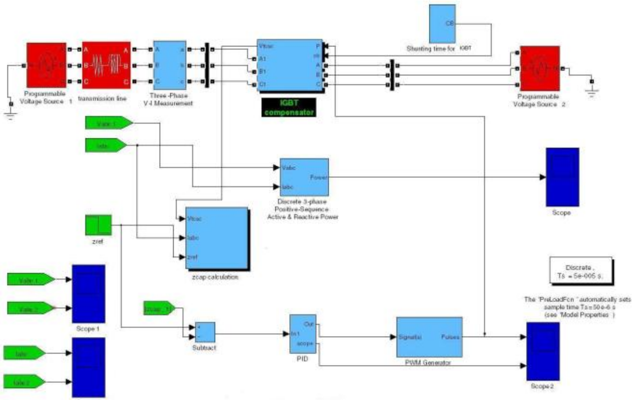
Explanation



A TCSC is placed on a 500kV, long transmission line, to improve power transfer. Without the TCSC the power transfer is around 110MW, as seen during the first 0.75s of the simulation when the TCSC is bypassed. The TCSC consists of a fixed capacitor and a parallel Thyristor Controlled Reactor (TCR) in each phase. The nominal compensation is 75%, i.e. using only the capacitors (firing angle of 90deg). The natural oscillatory frequency of the TCSC is 163Hz, which is 2.7 times the fundamental frequency. The test system is described in figure. The TCSC can operate in capacitive or inductive mode, although the latter is rarely used in practice. Since the resonance for this TCSC is around 58deg firing angle, the operation is prohibited in firing angle range 49deg - 69deg. Note that the resonance for the overall system (when the line impedance is included) is around 67deg. The capacitive mode is achieved with firing angles 69-90deg. The impedance is lowest at 90deg, and therefore power transfer increases as the firing angle is reduced. In capacitive mode the range for impedance values is approximately 120-136 Ohm. This range corresponds to approximately 490-830MW power transfer range (100%-110% compensation). Comparing with the power transfer of 110 MW with an uncompensated line, TCSC enables significant improvement in power transfer level. 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. A separate PI controller is used in each operating mode. The capacitive mode also employs a phase lead compensator. Each controller further includes an adaptive control loop to improve performance over a wide operating range. The controller gain scheduling compensates for the gain changes in the system, caused by the variations in the impedance. 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.

## V. SIMULATION MODEL IGBT

Explanation
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)



Results Analysis

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.
Results Analysis
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.

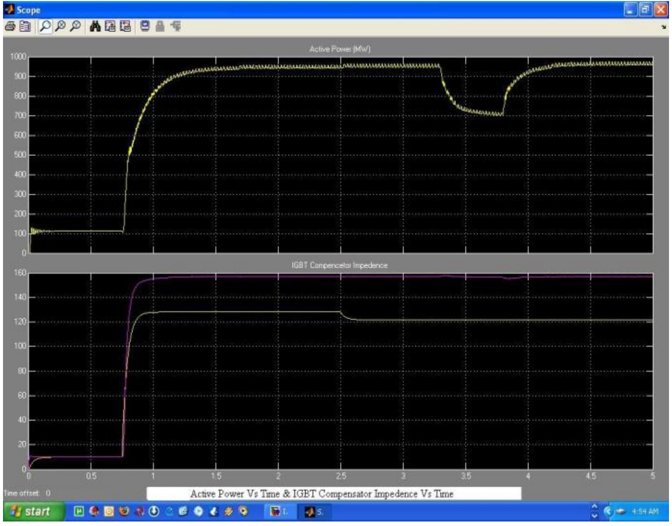


Figure 1 Active Power Vs Time & TCSC Impedance Vs Time

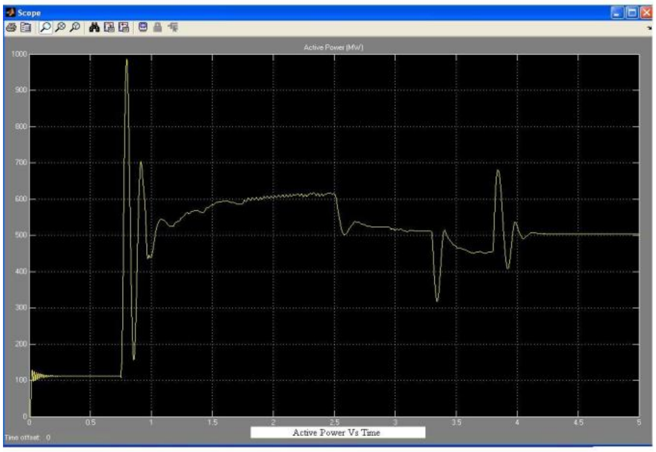


Figure 2 Active Power Vs Time

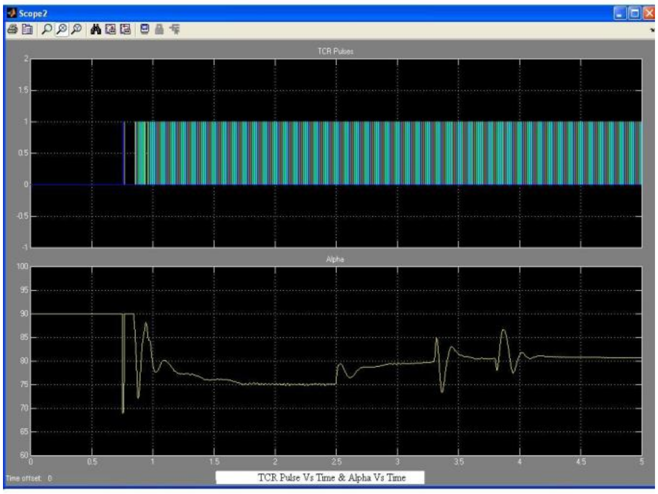


Figure 3 TCR Pulses Vs Time & Alpha Vs Time

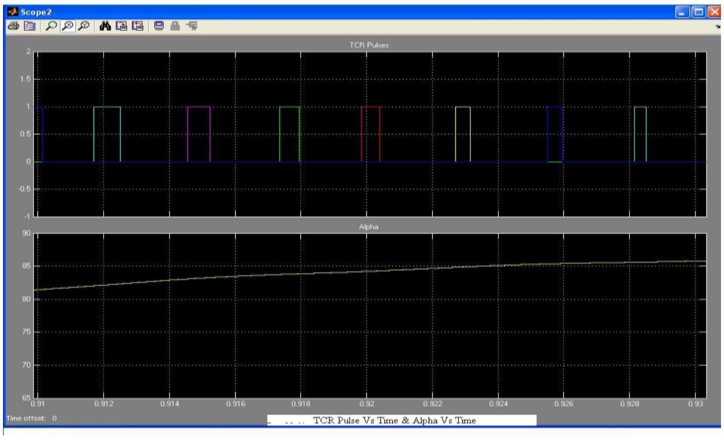


Figure 4 TCR Pulses Vs Time & Alpha Vs Time

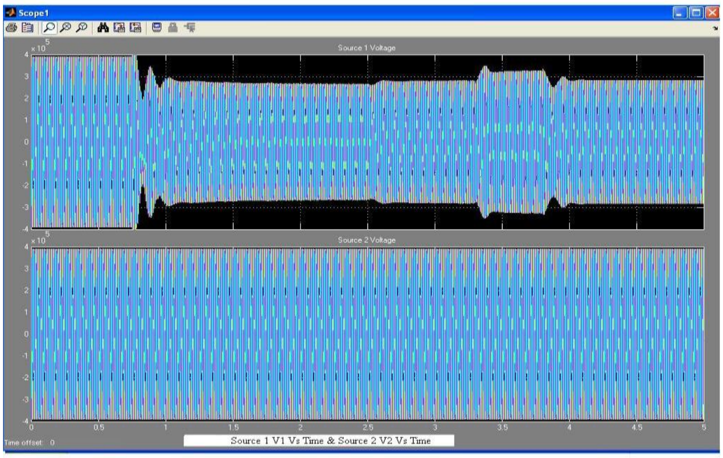


Figure 5 Source1 V1 Vs Time & Source 2 V2 Vs Time

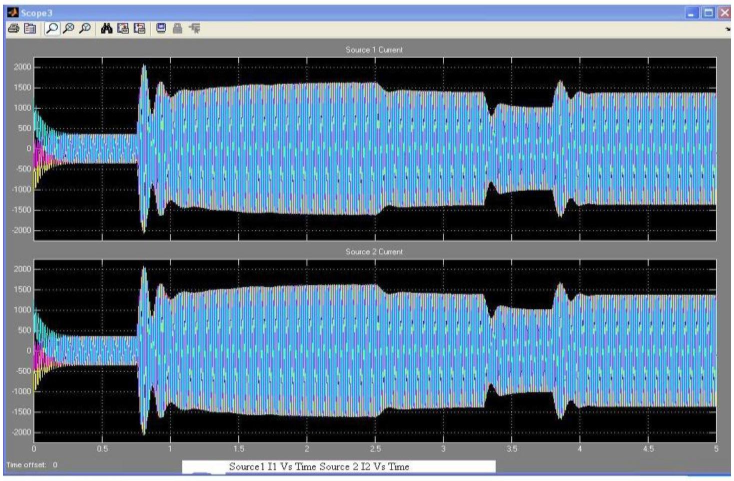


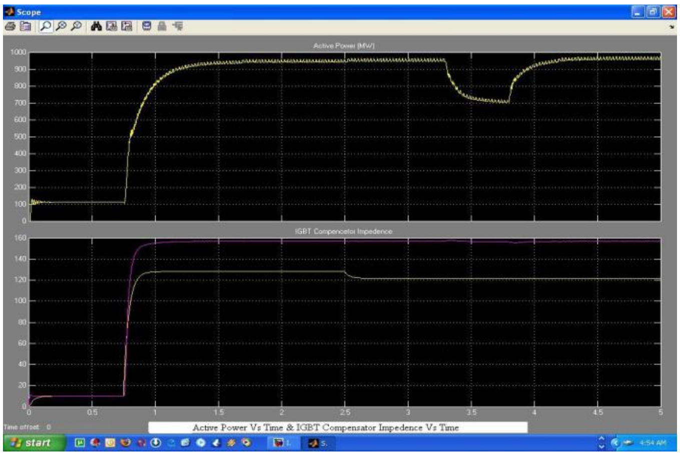
Figure 6 Source1 I1 Vs Time & Source 2 I2 Vs Time

Result Analysis
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.

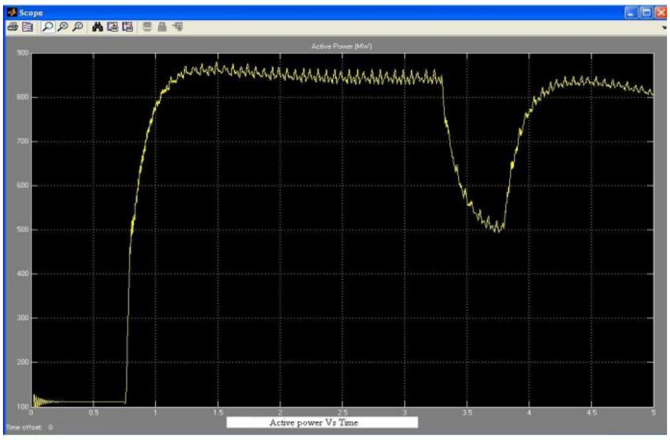
Result Analysis

Dynamic Response:

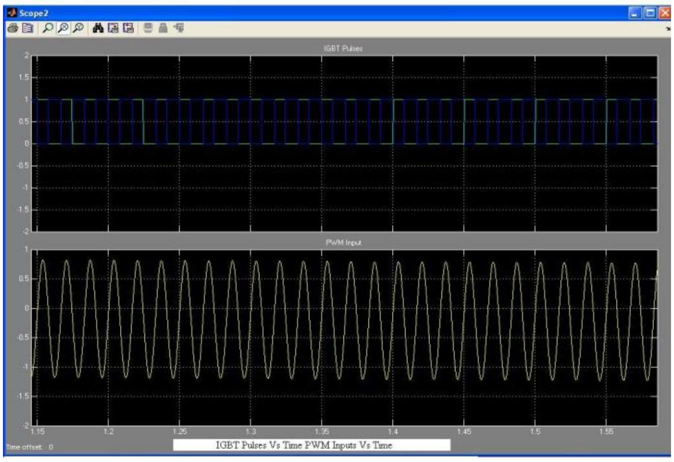
At 2.5s a 5% change in the reference impedance is applied. The Active power flow response indicates that IGBT enables tracking of the reference impedance and the settling time is around 200ms. At 3.3s a 4% reduction in the source voltage is applied, followed by the return to 1p.u. at 3.8s. It is seen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



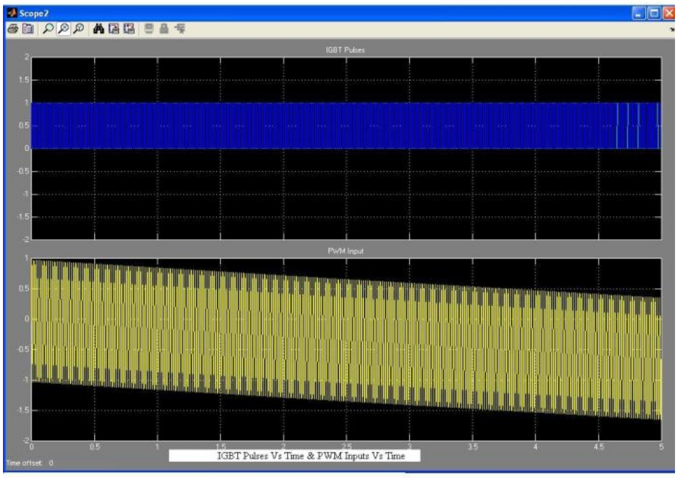
Active power Vs Time & IGBT Compensator Impedance Vs Time



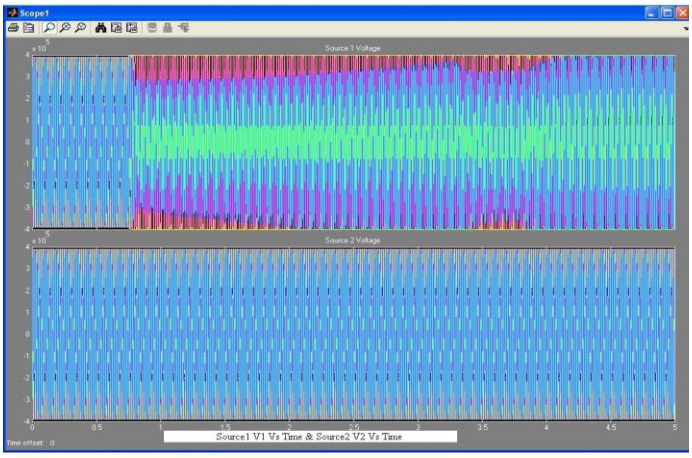
Active Power Vs Time



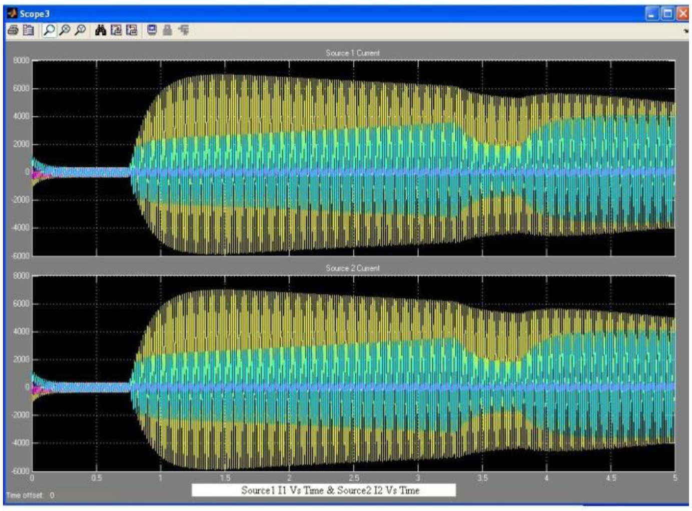
IGBT Pulses Vs Time & PWM Inputs Vs Time



IGBT Pulses Vs Time & PWM Inputs Vs Time



Source1 V1 Vs Time & Source 2 V2 Vs Time



Source1 I1 Vs Time & Source 2 I2 Vs Time

Result Analysis

Simulation Result:

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.

## VI. CONCLUSION

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.

## VII. FUTURE WORK

The technology behind thyristor-based FACTS controllers has been present for several decades and is therefore considered mature. More utilities are likely to adopt this technology in the future as more promising GTO-based FACTS technology is fast emerging. Recent advances in silicon power-switching devices that significantly increase their power ratings will contribute even further to the growth of FACTS technology. A relatively new device called the Insulated Gate Bipolar Transistor (IGBT) has been developed with small gate consumption and small turn-on and turn-off times. The IGBT has bi-directional current carrying capabilities. More effective use of pulse width modulation techniques for control of output magnitude and harmonic distortion can be achieved by increasing the switching frequencies to the low kHz range. However, IGBT has until recently been restricted to voltages and currents in the medium power range. Larger devices are now becoming available with typical ratings on the market being 3.3 kV/1.2 kA (Eupec), 4.5 kV/2 kA (Fuji), and 5.2 kV/2 kA. The Integrated Gate Commutated thyristor (IGCT) combines the excellent forward characteristics of the thyristor and the switching performance of a bipolar transistor. In addition, IGCT does not require snubber circuits and it has better turn-off characteristics, lower conducting and switching loss, and simpler gate control compared with GTO and IGBT . The ratings of IGCT reach 5.5 kV/1.8 kA for reverse conducting IGCTs and 4.5 kV/4 kA for asymmetrical IGCTs . Currently, typical ratings of IGCTs on the market are 5.5 kV/2.3 kA (ABB) and 6 kV/6 kA.

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