REACTIVE POWER COMPENSATION AND VOLTAGE REGULATION USING A 48-PULSE CONVERTER BASED STATCOM AND SSSC

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ABSTRACT

In this paper we presented reactive power compensation in two FACTS devices both SATCOM and SSSC. Here we propose to tackle the existing problem in power transmission systems with multiple controller systems. The comprising a 48-pulse Gate Turn-Off thyristor voltage source converter for combined reactive power compensation and voltage stabilization of the electric grid network. This simulation of STATCOM and SSSC are developed in MATLAB/simulink environment by utilizing the blocks from the power system block set mean while control system is modeled. The proposed work is to decouple the both voltage and current control strategy with two controllers by SATACOM and SSSC. This problem is ensure that the system operates in stable condition with STATCOM with various loads and the phase locked loop inherent delay has a great effect on dynamic operation of SSSC and also is to regulate the proposed technique and to enhance the dynamic performance of SSSC this proposed 48 pulse control schemes are validated.

Keywords: Mitigate Voltage Dips, Static Synchronous Compensator, Reactive Power Compensation

I. INTRODUCTION

In the past, equipment used to control industrial process was mechanical in nature which was rather tolerant of voltage disturbances. Nowadays modern industrial equipment typically uses a large amount of electronic components such as program logic control (PLC) adjustable speed drives and optical devices which can be very sensitive to the voltage disturbances. The majority of disturbances that cause problems for electronic equipment's are voltage dip or voltage sag as in [1]-[2]. Voltage dips may cause tripping production disturbances and equipment damages. Voltage dips are huge problem for many industries and they have been found especially troublesome

Because they are random events lasting only a few cycles. However they are probably the most pressing power quality problem [3]. The concern for mitigation of voltage dip has been gradually increasing due to the huge usage of sensitive electronic equipment in modern industries. When heavy loads are started such as large induction motor drives,the starting current is typically 600% to 700% of the full load current drawn by the motor. This high current cause dips in the voltage during starting intervals because there is a lot of voltage drop across the distribution conductor. Since the supply and the cabling of the installation are dimensioned for normal running current and the high initial current causes a voltage dip. This voltage dips are short duration reductions in rms input voltage as shown in Fig.1. It is specified in terms of duration and retained voltage usually expressed as the percentage of nominal rms voltage remaining at the lowest point during the dip. Another reason for high starting current is the inertia of the load as high starting torque and required to start the high inertia loads which can be obtained by using high starting current. This problem becomes more severe at peak loading time. This is due to the fact that at peak loading time the voltage of the system is less than the rated voltage.

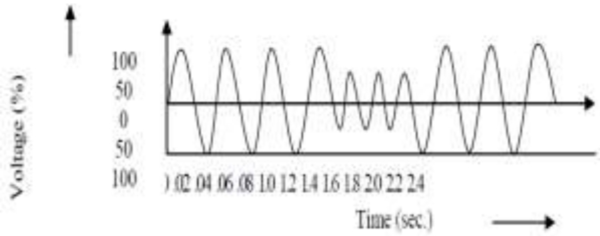

Fig.1. Voltage Dip

II. RELATED WORK

As the STATCOM is a solid-state voltage source converter coupled with a transformer tied to a line can injects reactive current or power to the system to compensate the voltage-dip. The Voltage-Source Converter (VSC) is the main building block of the STATCOM. It produces square voltage waveforms as it switches the direct voltage source ON and OFF. The main objective of VSC is to produce a near sinusoidal AC voltage with minimum waveform distortion or excessive harmonic content. This can be achieved by employing multiple-pulse converter configuration [4]. To obtain the multiple-pulse converters i.e. 12- pulse 24-pulse and 48-pulse VSC a two four or eight 6-pulse VSC can be used with the specified phase shift between all converters. A 48-pulse VSC can be used for high power applications with low distortion because it can ensure minimum power quality problems and reduced harmonic contents. A 48-pulse GTO based VSC can be constructed using two (24-pulse GTO based) converters shifted by 7.5° from each other. In this kind of converters there is no need of AC filters due to its low harmonic distortion content on the ac side. This new multiple-pulse converter configuration produces almost three phase sinusoidal voltage and maintains THD (Total Harmonic Distortion) well below 4%. [5] Srinivas K. V. et al in [6] developed a three-level 24-pulse STATCOM with a constant dc link voltage and pulse width control at fundamental frequency switching validated the inductive and capacitive operations of the STATCOM with satisfactory performance. The harmonic content of the STATCOM current is found well below 5% as per IEEE standards. Sahoo A. K. et al in [7] developed a simulation model of 48-pulse VSC based STATCOM FACTS devices. This full model is validated for voltage stabilization reactive power compensation and dynamic power flow control. It produces a sinusoidal AC voltage with minimal harmonic distortion from a DC voltage with variable loads. Huang S. P. et al in [8] also investigated that the GTO based STATCOM consisting a 48-pulse three-level inverter regarding minimal harmonic distortion. It has fine dynamic response and can regulate transmission system voltage efficaciously.

III. PROPOSED METHOD

A novel complete model using the 48-pulse digital simulation of the STATCOM within a power system is presented in this paper. The digital simulation is performed using the MATLAB/Simulink software environment and the Power System Block set (PSB). The basic building block of the STATCOM is the full 48-pulse converter-cascade implemented using the MATLAB/Simulink software it was shown in the Fig.2. The control process is based on a novel decoupled current control strategy using both the direct and quadrature current components of the STATCOM. The operation of the full STATCOM model is fully studied in both capacitive and inductive modes in a power transmission system and load excursion. The use of full 48–pulse STATCOM model is more accurate than existing low-order or functional models.

3.1 48-Pulse Voltage Source Gto –Converter

Two 24-pulse GTO-converters phase-shifted by 7.5 ° from each other can provide the full 48-pulse converter operation. Using a symmetrical shift criterion the 7.5 ° are provided in the following way: phase-shift winding with -3.75º on the two coupling transformers of one 24-pulse converter and +3.75º on the other two transformers of the second 24-pulse converter. The firing pulses need a phase-shift of +3.75º respectively.

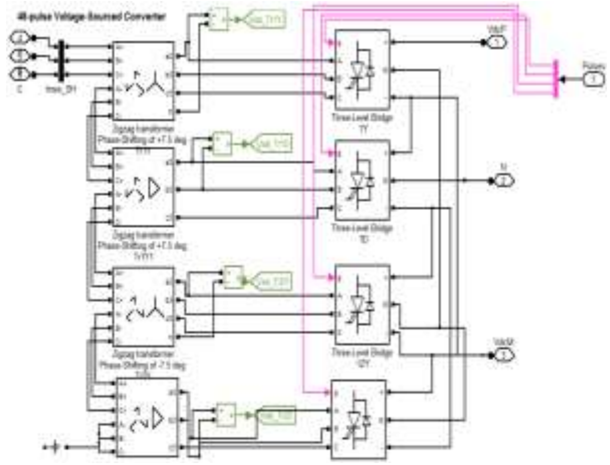

Fig.2. 48-pulse GTO's Voltage Source Converter

The 48-pulse converter model comprises four identical 12-pulse GTO converters interlinked by four 12-pulse transformers with phase-shifted windings. Fig. 3 depicts the schematic diagram of the 48-pulse VS-GTO converter model. The transformer connections and the necessary firing-pulse logics to get this final 48-pulse operation are modeled.

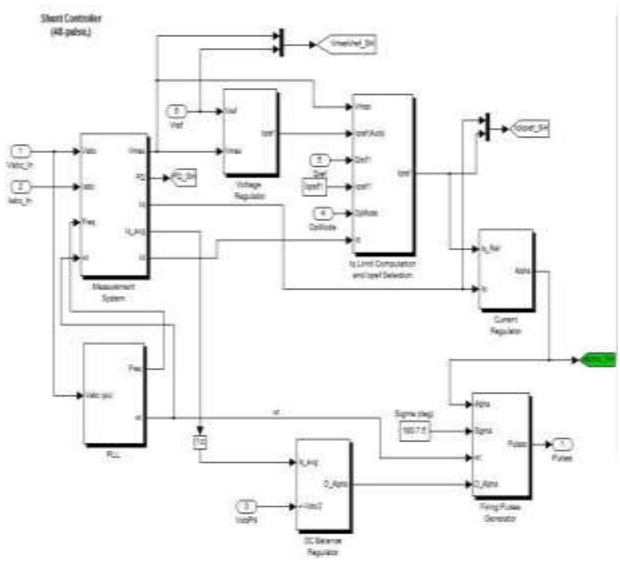

Fig.3. 48-Pusle Generation Block

The 48-pulse converter can be used in high-voltage high-power applications without the need for any ac filters due to its very low harmonic distortion content on the ac side. The output voltages have normal harmonics n=48± 1 where r=012…… i.e. 47th 49th95th 97th …. With typical magnitudes (1/47th 1/49th 1/95th 1/97th ….) respectively with respect to the fundamental; on the dc side the lower circulating dc current harmonic content is the 48th. The phase-shift pattern on each four 12-pulse converter cascade is as follows. 1st 12-Pulse Converter: It is shown in the equation at the bottom of the page. The resultant output voltage generated by the first 12-pulse converter is PST: 7.5° Necessary to eliminate the 24 -pulse harmonics

υ ab12(t) 1 = 2[Vab1 sin (ωt+30 º) + Vab 11 sin (11 ωt+195 º) + Vab 13sin (13 ωt+225 º) + Vab23 sin (23ωt+60º) + Vab 25 sin (25ωt+120 º)+………..]. ------------------- (1)

3.75 ° Necessary to eliminate the 48 -pulse harmonics Total 11.25° winding turn rate 1: tan (11.25 °) Drive:- 7.5 ° Necessary to eliminate the 24-pulse harmonics 3.75° Necessary to eliminate the 48 -pulse harmonics. Total 11.25° Total 3.75° 2nd 12-Pulse Converter: It is shown in the second equation at the bottom of the previous page. The resultant output voltage generated by the second 12-pulse converter is υ ab12(t)2 = 2[Vab1 sin (ωt+30°) Vab 11 sin (11 ωt+15 °) + Vab 13sin (13 ωt+75 °) + Vab23 sin (23ωt+60°) + Vab 25 sin (25ωt+120 °)+………..]. -------------------(2)

3rd 12-Pulse Converter: It is shown in the first equation at the bottom of the page. The resultant output voltage generated by the third 12-pulse converter is υ ab12(t)3 = 2[Vab1 sin (ωt+30°) + Vab 11 sin (11 ωt+285 °) + Vab 13sin (13 ωt+345 °) + Vab23 sin (23ωt+240°) + Vab 25 sin (25ωt+300 °)+………..]. ------------------- (3)

4th 12-Pulse Converter: It is shown in the second equation at the bottom of the page. The resultant output voltage generated by the fourth 12-pulse converter is υ ab12(t)3 = 2[Vab1 sin (ωt+30°) + Vab 11 sin (11 ωt+105 °) + Vab 13sin (13 ωt+165 °) + Vab23 sin (23ωt+240°) + Vab 25 sin (25ωt+300 °)+………..]. -------------------(4)

These four identical 12-pulse converter provide shifted ac output voltages described by (1)–(4) are added in series on the secondary windings of the transformers. The net 48-pulse ac total output voltage is given by υ ab48(t)= υ ab12(t)1+υ ab12(t)2+ υ ab12(t)3+ υ ab12(t)4 _________(5)

υ ab48(t)= 8[Vab1 sin (ωt+30°) + Vab 47 sin (47ωt+150 °) + Vab 49sin (49ωt+210°) + Vab95 sin (95ωt+330°) + Vab 97 sin (97ωt+30°)+………..]. _________________(6)

The line-to-neutral 48-pulse ac output voltage from the STATCOM model is expressed by υ ab48(t)= 8/ n)_________(7)

n=(481) r=012….. Voltages υ ab48(t) and υ cn48(t)have a similar near sinusoidal shape with a phase shifting of 120 and 240 respectively from phase a υ an48(t) . Fig. 4 depicts the net resultant 48-pulse line-to-line output voltage of the 48-pulse GTO-Converter control scheme.

3.2 Current Control Operation

The new decoupled control system is based on a full d-q decoupled current control strategy using both direct and quadrature current components of the STATCOM ac current. The decoupled control system is implemented phase locked loop (PLL) synchronizes as shown in Fig. 4. A on the positive sequence component of the three phase terminal voltage at PST: 7.5° Necessary to eliminate the 24 -pulse harmonics. The output of the PLL is the angle that used to measure the quadrature axis component of the AC three phase voltages and current. To enhance the dynamic performance of the 48 pulse STATCOM device model.

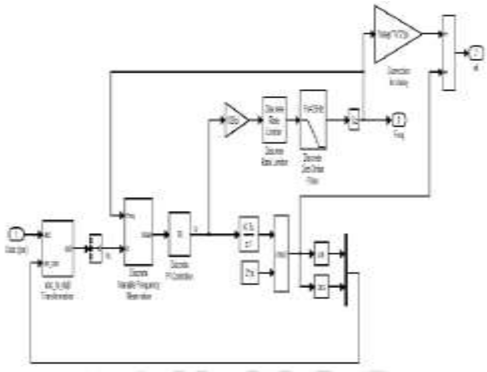

Fig.4. Design of PLL

IV. SIMULATION DIAGRAM OF STATCOM

The model of STATCOM Control System is shown figure 5. Its task is to increase or decrease the capacitor DC voltage, so that the generated AC voltage has the correct amplitude for the required reactive power. The control system must also keep the AC generated voltage in phase with the system voltage at the STATCOM connection bus to generate transformer and inverter losses).

Voltage regulation it is performed by two PI regulators: from the measured voltage Vrms and the reference voltage Vref, the Voltage Regulator block (outer loop computes the reactive current reference Iqref used by the current regulator block (inner loop). The output of the current regulator is the α angle which is the phase shift of the inverter voltage with respect to the system voltage.

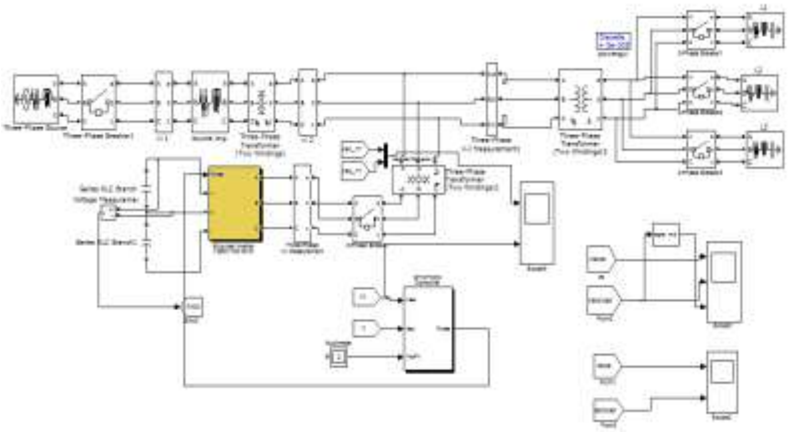

Fig5: Simulation Diagram for STATCOM

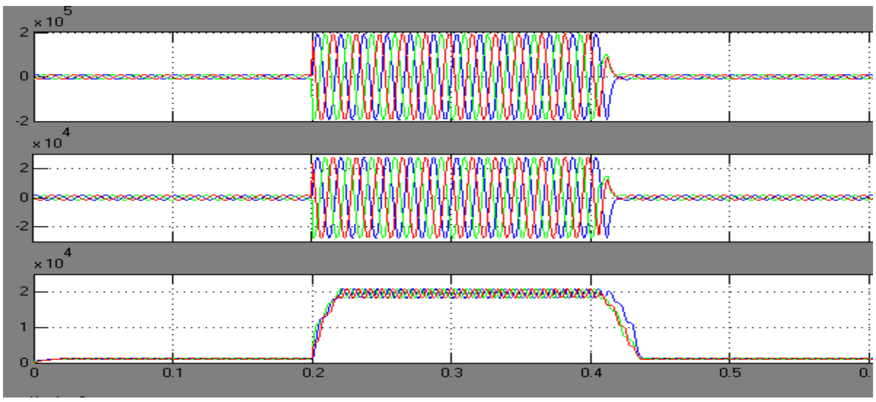

Fig 6: Simulation Result for Source Voltage, Load voltage and R.M.S.voltage

V. DYNAMIC PERFORMANCE OF THE SSSC

The dynamic performance control strategy for the SSSC is also validated in both capacitive and inductive operating modes when the system is subjected to severe disturbances of switching electric loads contingencies. The SSSC device is one of the most important FACTS devices for power transmission line series compensation. It is a power electronic-based synchronous voltage generator (SVG) that generates almost three-phase sinusoidal ac voltages from a dc source/capacitor bank with voltage in quadrature with the reference line current. The SSSC converter blocks are connected in series with the transmission line by a series coupling transformer. The SSSC device can provide either capacitive or inductive voltage compensation If the SSSC-AC voltage Vs lags the line current IL by 90 a capacitive series voltage compensation is obtained in the transmission line and if Vs * leads IL by 90 an inductive series voltage compensation is achieved. By controlling the level of the boost/buck voltage transmission line the amount of series compensation voltage can be fully adjusted. The equivalent injected series voltage Vs is almost in quadrature with the reference transmission line current. A small part of this injected voltage Vs * which is in phase with transmission line current supplies the required losses in the inverter bridge and coupling transformer. Most of the injected voltage Vs * is in full quadrature with the reference transmission line current and hence emulates an equivalent inductive or capacitive reactance in series with the transmission line.

5.1. Digital Simulation Model of Sssc

A complete digital simulation study using the full 48-pulse GTO-SSSC device model for a sample test power system is presented in this paper. The digital simulation is performed in the MATLAB/Simulink software environment using the PSB. The basic building block of the SSSC device is the same cascade of converters forming the 48-pulse GTO converter whose complete digital simulation model was implemented using MATLAB/Simulink. This new full SSSC device compensator can be more accurate in providing fully controllable compensating voltage over a specified identical capacitive and inductive range independently of the magnitude of the line current and better represent realistic improved power quality reduced harmonics.

5.2. Power System Desription

The test system is a simple power system 500-kV network grid equipped with the SSSC and its novel controller which connected in series with the transmission system. Modeling the SSSC compensator including the power network and its controller in MATLAB/Simulink environment requires using ―electric blocks‖ from the power system block set and control blocks from the Simulink library. AMvar SSSC device is connected to the 500-kV grid network. Fig. 5 shows the single line diagram that represents the SSSC and the 500/33-kV grid network. The feeding network is represented by an its equivalent Thevenin (bus B1) where the voltage source is a 500 kV with 10 000 MVA short circuit level with a resistance of 0.1 p.u. and an equivalent reactance of 0.3 p.u. followed by the 500-kV radial transmission system connected to bus B2. The full system parameters are given in appendix. The SSSC FACTS device consists mainly of the 48–pulse GTO-voltage source converter model that is connected in series with the transmission line at Bus B1 by the coupling transformer T1. The dc link voltage Vdc is provided by capacitor C which is charged with an active power taken directly from the ac network. The novel full 48-pulse GTO-VSC model results in less harmonic distortion than other 6- 12- and 24-pulse converters or functional models usually used to represent SSSC device operation.

5.3. Control Scheme for the 48-pulse SSSC

The control system for the SSSC device is shown in Fig. 5. The basic synchronization signal is the phase angle of the transmission line current. The SSSC equivalent impedance Xs is measured as the ratio of the q-axis voltage of the SSSC device Veq to the magnitude of transmission line current. This equivalent inserted or equivalent (positive/negative) impedance is then compared with the reference level of the compensation impedance (S).

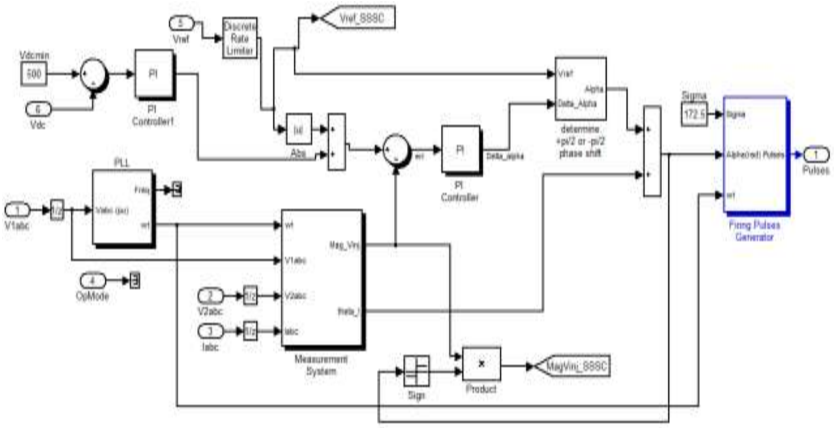

Fig.7 Control System for SSSC

VI. SIMULATIONDIAGRAM AND RESULTS

A combination of SHUNT controller and SERIES controller action is works as a unified power flow controller (UPFC) is used to control the power flow in a 500 kV transmission system. The SSSC and STATCOM located at the left end of the 75-km line L2 between the 500 kV buses B1 and B2 is used to control the active and reactive powers flowing through bus B2 while controlling voltage at bus B1. It consists of two 100-MVA three-level 48-pulse GTO-based converters one connected in shunt at bus B1 and one connected in series between buses B1 and B2. The shunt and series converters can exchange power through a DC bus. The series converter can inject a maximum of 10% of nominal line-to-ground voltage (28.87 kV) in series with line L2. This pair of converters can be operated in three modes: Unified Power Flow Controller (UPFC) mode when the shunt and series converters are interconnected through the DC bus. When the disconnect switches between the DC buses of the shunt and series converter is opened two additional modes are available:

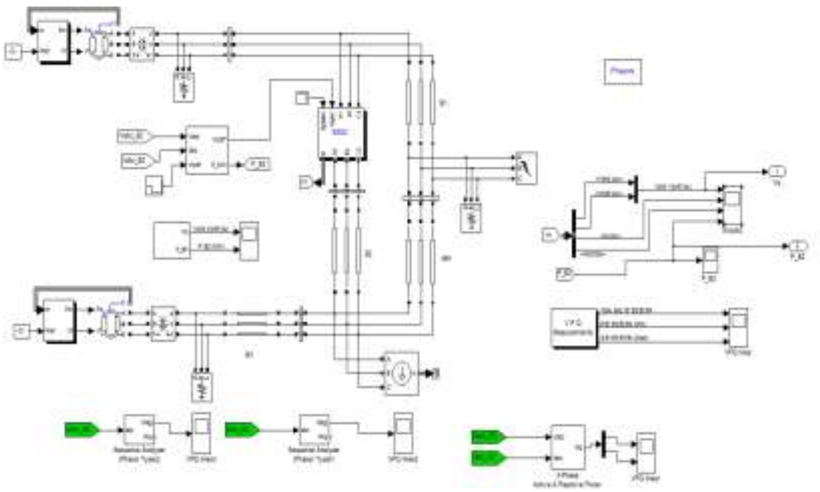

Fig 8: Simulation Diagram for SSSC

Shunt converter operating as a Static Synchronous Compensator (STATCOM) controlling voltage at bus B1Series converter operating as a Static Synchronous Series Capacitor (SSSC) controlling injected voltage while keeping injected voltage in quadrature with current. The principle of operation of the harmonic neutralized converters is explained in entitled ―Three-phase 48-pulse GTO converter‖. This power 48pulse GTO converter is accessible in the Power simulation.

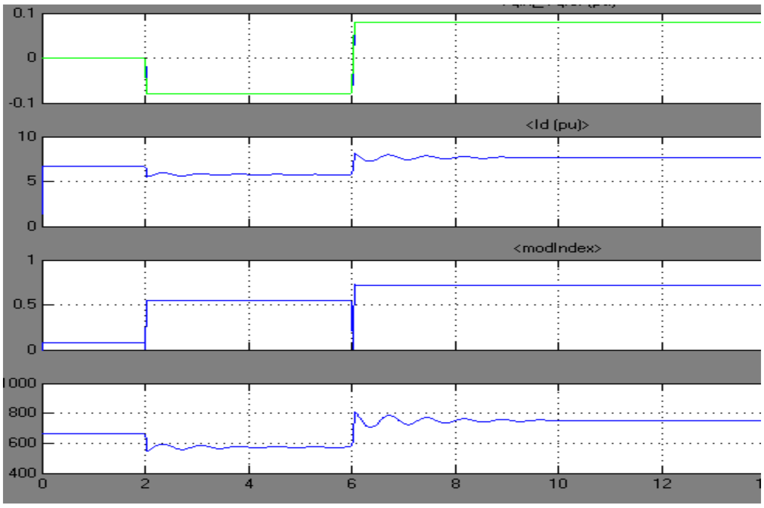

Fig 9: Simulation Results for SSSC

The main function of the SSSC device is to dynamically control the transmission line power flow. This can be accomplished by either direct control of the line current (power) or alternatively by the indirect control of either the compensating impedance X_s or the level of injected compensating voltage V_c [10]. The degree of impedance series compensation S is usually expressed as the ratio of the series reactance X_s to the transmission line reactanceX_L, where$X_s=SX_L$. Similarly, for an inductive series compensation, the line series reactance is$X_{line}=X_L+X_s$, where $X_s=SX_L$. Therefore, the basic function of the effective control system is to keep the SSSC voltage V_c in quadrature with the transmission line current I_L and only control the magnitude of V_c injection to meet the desired compensation level.

VII. CONCLUSION

The paper presents a novel full 48-pulse GTO voltage source converter of STATCOM and SSSC FACTS devices. These full descriptive digital models are validated for voltage stabilization reactive compensation and dynamically power flow control using three novel decoupled current control strategies. The control strategies implement decoupled current control and auxiliary tracking control based on a pulse width modulation switching technique to ensure fast controllability minimum oscillatory behavior and minimum inherent phase locked loop time delay as well as system instability reduced impact due to a weak interconnected ac system

REFERENCES

[1] N. G. Hingorani and L. Gyugyi Understanding FACTS Concepts and Technology of Flexible AC Transmission Systems. Piscataway NJ: IEEE Press 2000.

[2] L. Gyugyi ―Dynamic compensation of ac transmission lines by solidstate synchronous voltage sources‖ IEEE Trans. Power Del. vol. 9 no. 2 pp. 904–911 Apr. 1994.

[3] C. Schauder and H. Mehta ―Vector analysis and control of advanced static var compensator‖ in Proc. Inst. Elect. Eng. Int. Conf. AC DC Transmission 1991 pp. 299–306. Paper no. 345.

[4] D.Soto and C. Green ―A comparision of high-power converter topologies for the implementation of facts controllers‖ IEEE Trans. Indust. Electron. vol. 49 no. 5 pp. 1072–1080 Oct. 2002.

[5] K. K. Sen ―SSSC—static synchronous series compensator: Theory modeling and application‖ IEEE Trans. Power Del. vol. 13 no. 1 pp. 481–486 Jan. 1998.

[6] R. M. Mathur and R. K. VarmaThyristor-Based FACTS Controllers for Electrical Transmission Systems. Piscataway NJ: IEEE Press 2002.

[7] Sahoo A. K. Murugesan K. Thygarajan T. "Modelling and Simulation of 48-pulse VSC based STATCOM using Simulink's Power System Blockset" Proceedings of India International Conference on Power Electronics pp. 303-308 December 2006.

[8] Huang S. P. Li Y. J. Jin G.B. Li L. "Modelling and Dynamic Response Simulation of GTO-based STATCOM" Proceedings of the International Conference on Electrical and Control Engineering pp. 1293-1296June2010

[9] X.-P. Zhang, "Advanced modeling of the multicontrol functional static synchronous series compensator (SSSC) in Newton power flow," IEEE Trans. Power Syst., vol. 18, no. 4, pp. 1410–1416, Nov. 2003.

[10] Y. Liang and C. O. Nwankpa, "A new type of STATCOM based on cascading voltage-source inverter with phase-shifted unipolar SPWM," IEEE Trans. Ind. Appl., vol. 35, no. 5, pp. 1118–1123, Sep./Oct. 1999.