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Modeling and Simulation of Distribution STATCOM

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Abstract: My dissertation presents a study on the modeling of a STATCOM used for reactive power compensation a distribution network. The power circuit of the distribution -STATCOM and the distribution network. Simulation performances obtained with modeling approaches are presented. Models of power circuit and control system have been implemented in the same Simulink diagrams. my dissertation investigates the operation of control scheme for Static Synchronous Compensator (STATCOM) based on a new full model comprising a 48-pulse Gate Turn-Off thyristor voltage source converter for combined reactive power compensation and voltage stabilization of the electric grid network. The STATCOM scheme and the electric grid network are modeled by specific electric blocks from the power system block set. The performances of STATCOM connected to the 230-kV grid are evaluated. The proposed control schemes for the STATCOM fully validated by digital simulation.

Keywords: FACTS devices, 48-pulse Gate Turn-Off (GTO) thyristor model STATCOM.

I. INTRODUCTION

Electricity suppliers are nowadays connected about the quality of the power delivered to customers with the developments of power electronics, several solutions have been proposed to compensate for the fluctuations observed on the distribution network in order to ensure highest possible power quality for the customers

1. These “power quality devices” are power electronics converters connected in parallel or in series with the lines and the operation is controlled by a digital controller
2. The interaction between the PQ device and the network is preferably studied by simulation. The modeling of these complex systems that contain both power circuits and control systems can be done of different bases.

We are ready to accept and on the degree of accuracy of what we want to study. The modeling abstraction degree in these systems can be thus adapted to the study requirements.

Commercial availability of Gate Turn-Off (GTO) thyristor switching devices with high-power handling capability and the advancement of the other types of power-semiconductor devices such as IGBTs have led to the development of fast controllable reactive power sources utilizing new electronic switching and converter technology. These switching technologies additionally offer considerable advantages over existing methods in terms of space reductions and fast effective damping (2).

The GTO thyristors enable the design of the solid-state shunt reactive compensation and active filtering equipment based upon switching converter technology. These Power Quality Devices (PQ Devices) are power electronic converters connected in parallel or in series with transmission lines and the operation is controlled by digital controllers. Flexible Alternating current transmission systems (FACTS) devices are usually used for fast dynamic control of voltage, impedance, and phase angle of high -voltage ac lines. FACTS devices provide strategic benefits for improved transmission system power flow management through better utilization of existing transmission assets, increased transmission system security and reliability as well as availability, increased dynamic and transient grid stability, and increased power quality for sensitive industries The FACTS systems is giving rise to a new family of power electronic equipment for controlling and optimizing the dynamic performance of power system, e.g., STATCOM, SSSC, and UPFC. The use of voltage-source inverter (VSI) has been widely accepted as the next generation of flexible reactive power compensation to replace other conventional VAR compensation, such as the thyristor-switched capacitor (TSC) and thyristor controlled reactor (TCR) (3).(4).

This paper deals with a novel cascaded multilevel converter model, which is a 48-pulse (three levels) source converter (5). The voltage source converter described in this paper is a harmonic neutralized, 48-pulse GTO converter. It consists of four three-phase, three-level inverters and four phase-shifting transformers. In the 48-pulse voltage source converter, the dc bus V_{dc} is connected to the four three-phase inverters. The four voltage generated by the inverters are applied to secondary windings of four zigzag phase-shifting transformers connected in Y or the four transformer primary windings are connected in series, and the converter pulse patterns are phase shifted so that the four voltage fundamental components sum in phase on the primary side.

II. STATIC SYNCHRONOUS COMPENSATOR

The basic STATCOM model consists of a step-down transformer with leakage reactance Xt a three-phase GTO VSI, and a dc side voltage. The ac voltage difference across this transformer leakage reactance produces reactive power exchange between the STATCOM and the power system at the point of interface. The voltage can be regulated to improve the voltage profile of the interconnected power system, which is the primary duty of the STATCOM. A secondary damping function can be added to the STATCOM for enhancing power system dynamic stability [10]–[12].

The STATCOM's main function is to regulate key bus voltage magnitude by dynamically absorbing or generating Reactive power to the ac grid network, like a thyristor static compensator. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary transform r voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-source PWM inverter and is always in quadrature to the STATCOM current.

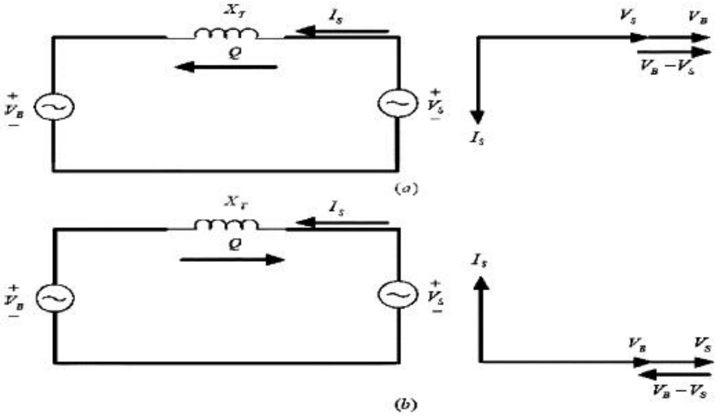


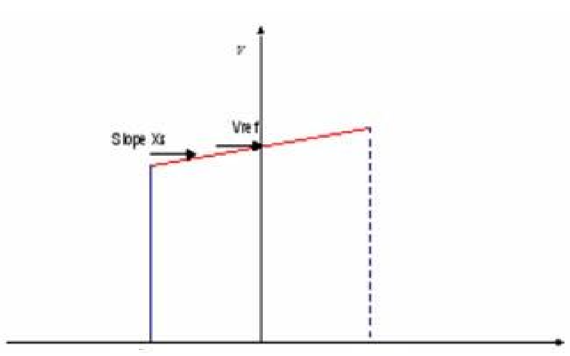
Fig. 1 STATCOM operation. (a) Inductive operation. (b) Capacitive operation.

The STATCOM device operation can be illustrated by the phasor diagrams shown in Fig. 1. When the secondary voltage (VS) is lower than the grid system bus voltage (VB), the STATCOM acts like an inductance absorbing reactive power from the grid bus. When the secondary voltage (VS) is higher than the bus voltage (VB), the STATCOM acts like a capacitor generating reactive power to the grid bus [7]. In steady-state operation and due to inverter losses, the bus voltage (VB) always leads the inverter ac voltage by a very small angle to supply the required small active power losses.

The voltage source-converter or inverter (VSC or VSI) scheme is the building block of any STATCOM device and other FACTS devices. A simple inverter produces a square voltage waveform as it switches the direct voltage source on and off. The basic objective of a good VSI-converter scheme is to produce a near sinusoidal ac voltage with minimal wave form distortion or excessive harmonics content. Three basic techniques can be used for reducing the harmonics produced by the converter switching [13], [14].

Harmonic neutralization using magnetic coupling (multipulse converter configurations), harmonic reduction using multilevel converter configurations, and novel pulse- width modulation (PWM) switching techniques. The 24- and 48-pulse converters are obtained by combining two or four (12-pulse) VSI, respectively, with the specified phase shift between all converters. For high -power applications with low distortion, the best option is the 48-pulse converter, although using parallel filters tuned to the 23th–25th harmonics with a 24-pulse converter could also be adequately attentive in most applications, but the 48-pulse converter scheme can ensure minimum power quality problems and reduced harmonic resonance conditions on the interconnected grid network.

The STATCOM basically consists of a step -down transformer with a leakage reactance, a three-phase GTO voltage source converter (VSC), and a DC voltage [14]. The STATCOM regulates the voltage magnitude at its terminals by controlling the amount of reactive power injected in to or absorbed of reactive power system. When system voltage is low, the STATCOM generate the reactive power (STATCOM capacitive); when system voltage is high, it absorbs reactive power (STATCOM inductive) shown Fig. 2 V-I Characteristic of STATCOM [10].



Capacitive inductive

Fig. 2 shows the STATCOM V-I characteristics.

III. STATIC PHASE SHIFTING TRANSFORMER

A. *General:*

Phase shifting transformers (PST) have been in use for control of power flows in transmission lines in steady state. The primary objective is to control loop flows and ensure the power flow in the contracted path. They are not meant to increase power transfer in a line and hence not intended to be used in long lines. By applying power electronic controllers, the operation of PSTs can be made fast which enables dynamic regulation of power flow and improvement of system stability and dynamic security. These are called Static Phase Shifting Transformers (SPST) or Thyristor Controlled Phase Angle Regulator (TCPAR) as thyristor devices have been primarily suggested to achieve the objective. However, with the advent of Voltage Source Converter (VSC) based FACTS controllers it is also possible to apply a STATCOM type device for PST.

B. *Basic Principle of a PST:*

Consider an ideal phase shifting transformer shown in Fig-3. This also shows the-venin's equivalents connected at the two ports of PST. The turns ratio of the transformer is a complex quantity of magnitude unity (a =[illegible]).where Φ is the phase angle shift (positive or negative). From

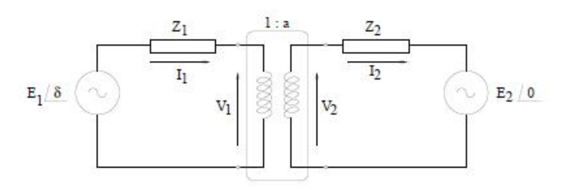


Fig-3 A PST connected in a network

The voltage Vq injected in series is a voltage in quadrature with V1. The current Ip is the shunt current drawn by the PST. It is obvious that

$$V_1I^*p = VqI^*2$$

Indicating that the complex power drawn by the shunt current source (Ip) supplies the power supplied by the series quadrature voltage (Vq).

In a three phase system with a balanced set of source voltage applied to the primary windings of the PST (connected in delta), the voltage Vcb (Vc-Vb) leads Va by 90˚. Similarly Vac leads Vb and Vba leads Vc by 90˚ each. This indicates a scheme to construct a PST as shown in Fig. 4. Here the secondary windings of the excitation transformer (ET), connected in shunt, supply the Boost Transformer (BT) connected in series with the line. In Fig. 4, only one phase of the ET and BT is shown in detail for clarity. The arrangement in other two phases is similar. The converter shown in Fig. 4 is connected between the ET and BT for controlling the magnitude and polarity of the quadrature voltage injected in series.

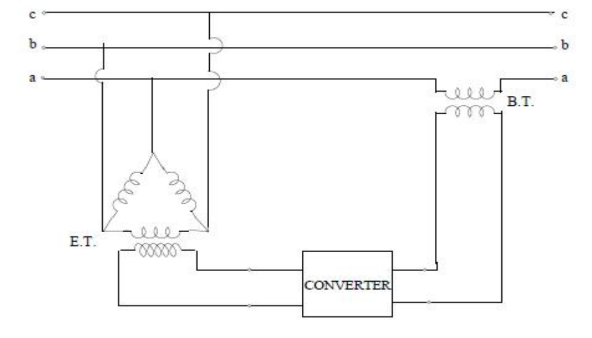


Fig-4 schematic diagram of a PST

IV. DIGITAL SIMULATION MODEL

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.

The control process is based on a novel decoupled current control 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. Making a Full simulation based on the diagram of simulation modal so shown in Fig-5.

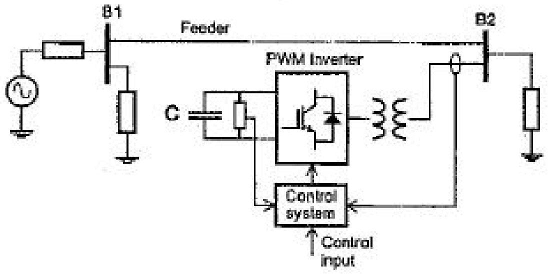


Fig-5 diagram of simulation model

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. 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.

A. *Power System Description:*

Modeling the unified ac grid sample system with the STATCOM and its decoupled current controller is done using MATLAB/Simulink as shown in Fig. 6. It requires the use of electric blocks from the power system and control blocks from the Simulink power block set library. A Mvar STATCOM device is connected to the 230- kV (L-L) grid network. Fig. 6 shows the single line diagram representing the STATCOM and the host sample grid network. The feeding network is represented by a thevenin equivalent at (bus B1) where the voltage source is represented by a kV with 10 000 MVA short circuit power level with a followed by the transmission line connected to bus B2.

The STATCOM device comprises the full 48-pulse voltage source converter-cascade model connected to the host electric grid network through the coupling transformer. The dc link voltage is provided by the capacitor C, which is charged from the ac network. The decoupled current control system ensures full dynamic regulation of the bus voltage (VB) and the dc link voltage. The 48-pulse VSC generates less harmonic distortion and, hence, reduces power quality problems in comparison to other converters such as (6, 12, and 24) pulse. This results in minimum operational overloading and system harmonic instability problems as well as accurate performance prediction of voltage and dynamic stability conditions.

B. *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 -3.75˚ on the two coupling transformers of one 24-pulse converter and +3.75˚ on the other two transformers of the second 24 -pulse converter. The firing pulses need a phase-shift of +3.75˚ respectively.

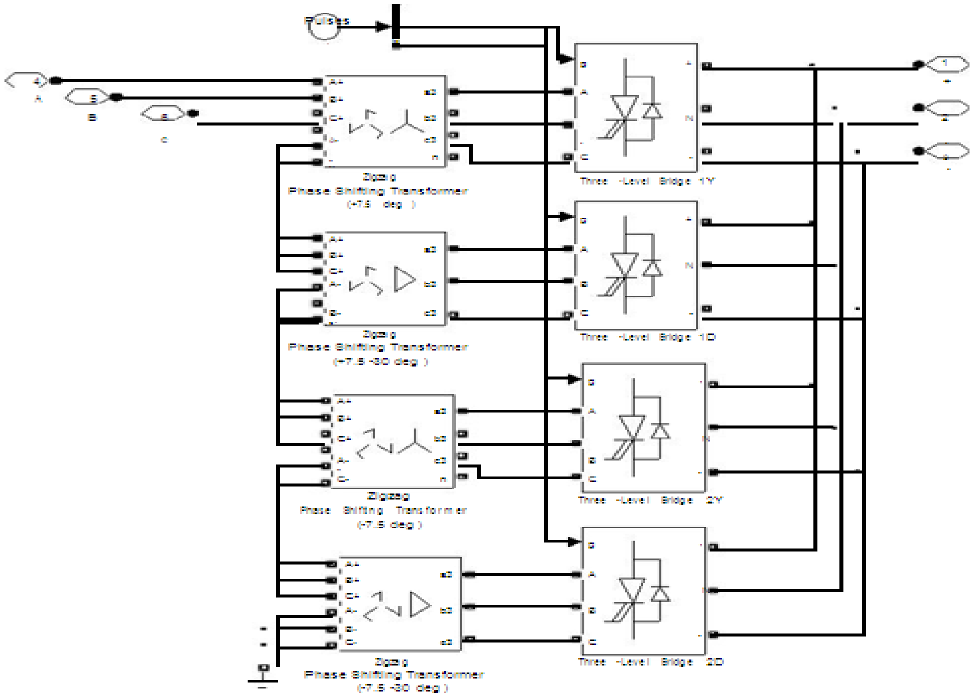


Fig- 6 48 pulse of statcom

1st 12-Pulse Converter:

$V_{ab12}(t)_1 = 2[\,V_{ab1}\sin(\omega t+30^\circ) + V_{ab11}\sin(11\omega t+195^\circ) + V_{ab12}\sin(13\omega t+255^\circ) + V_{ab22}\sin(23\omega t+60^\circ) + V_{ab25}\sin(25\omega t+120^\circ) + \ldots\ldots\ldots\ldots\ldots\ldots]$.

2nd 12-Pulse Converter:

$Vab12(t)2 = 2[Vab1\sin(\omega t+30^\circ) + Vab11\sin(11\omega t+15^\circ) + Vab12\sin(13\omega t+75^\circ) + Vab22\sin(23\omega t+60^\circ) + Vab25\sin(25\omega t+120^\circ) + \ldots\ldots\ldots\ldots\ldots\ldots]$.

3rd 12-Pulse Converter:

$V_{ab12}(t)_3 = 2[V_{ab1}\sin(\omega t+30^\circ) + V_{ab11}\sin(11\omega t+285^\circ) + V_{ab12}\sin(13\ \omega t+345^\circ) + V_{ab22}\sin(23\omega t+240^\circ) + V_{ab25}\sin(25\omega t+300^\circ) + \ldots\ldots\ldots\ldots\ldots\ldots]$.

4th 12-Pulse Converter:

$V_{ab12}(t)_4 = 2[V_{ab1}\sin(\omega t+30^\circ) + V_{ab11}\sin(11\omega t+105^\circ) + V_{ab12}\sin(13\ \omega t+165^\circ) + V_{ab22}\sin(23\omega t+240^\circ) + V_{ab25}\sin(25\omega t+300^\circ) + \ldots\ldots\ldots\ldots\ldots\ldots]$.

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

$$V_{ab48}(t) = V_{ab12}(t)_1 + V_{ab12}(t)_2 + V_{ab12}(t)_3 + V_{ab12}(t)_4$$

$$V_{ab48}(t) = 8[V_{ab1}\sin(\omega t+30^\circ) + V_{ab47}\sin(47\omega t+105^\circ) + V_{ab47}\sin(49\omega t+210^\circ) + V_{ab95}\sin(95\omega t+210^\circ) + V_{ab97}\sin(97\omega t+30^\circ) + \ldots\ldots\ldots\ldots\ldots\ldots].$$

V. SIMULATION & RESULTS

The power grid in shown in fig. 7 represents a 230 KV system with a 100 MVAR STATCOM embedded with the purpose of regulating the voltage at the bus.

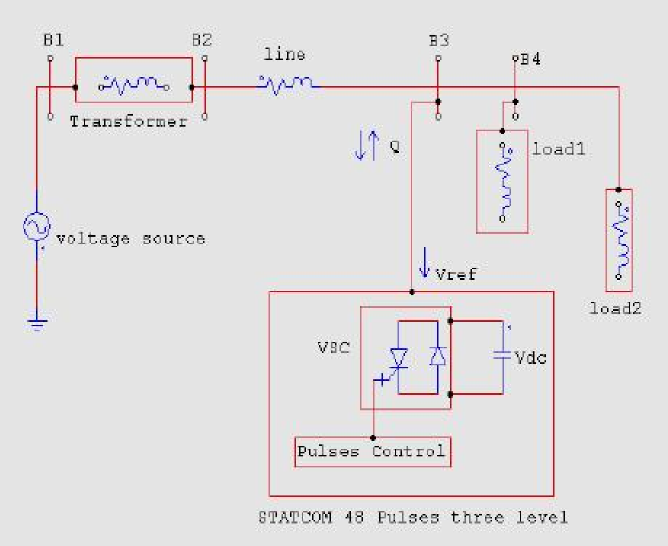


Fig-7 block diagram of statcom

Hear shown Fig.8 the waveform creating voltage magnitude, Fig.9 the reactive power in MVAR & Fig.10. The applied the voltage of modal. So this Fig creating the run the simulation modal.

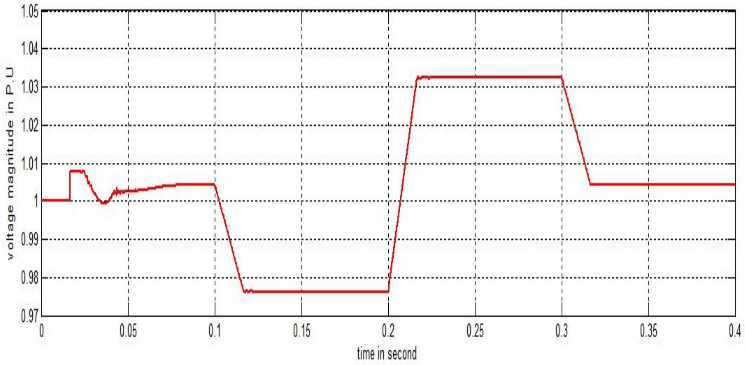


Fig-8 voltage measurement

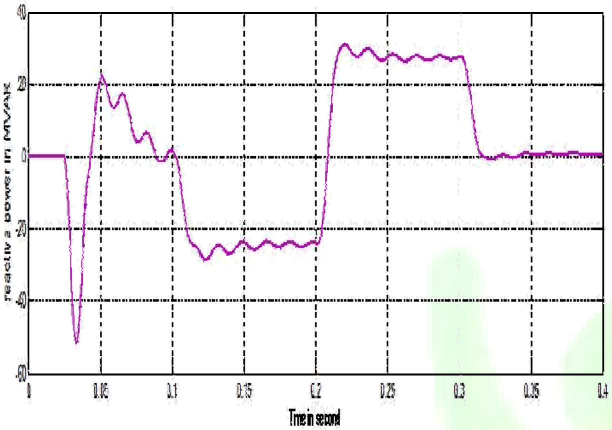


Fig. 9 change in reactive power

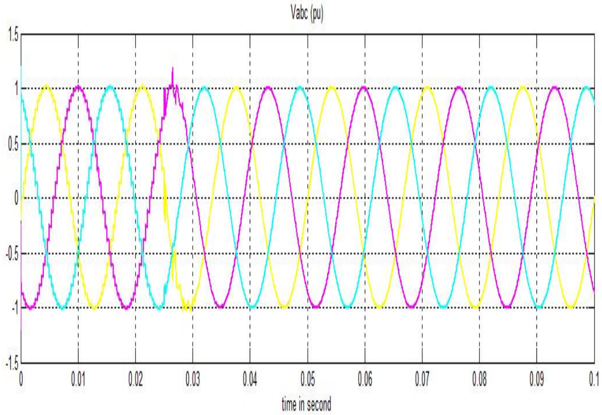


Fig. 10 input voltage of this model

VI. CONCLUSION

An important aspect considered in the design is the control system. The control strategy for the D-STATCOM is the AC side voltage or reactive power control. PI controller is used to control the flow of reactive power to and from the DC capacitor. Phase Lock Loop components are used in the control to generate the switching signal. PWM switching control is used to switch on and off the IGBT's. The IGBT's are connected inversely and parallel to the diodes for commutation purposes and to charge the capacitor.

IGBTs are used in this simulation because it is easy to control the switch on and off of their gates and suitable for the designed D-STATCOM. From the simulation results, the construction designed D-STATCOM responded well in mitigating voltage sag caused by three-phase balanced fault. The DC capacitor value is dependent on the percentage of voltage sag. The difference of step drop load current during sag is the amount of reactive current needed to be compensated. Lastly, construction the D-STATCOM is a promising device and will be a prominent feature in power systems in mitigating power quality related problems in the near future.

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