Voltage Stabilization And Reactive Compensation Using A Novel FACTS- STATCOM Scheme

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Abstract

This paper presents the use of a new full 48 pulse GTO model of voltage source converter FACTS-STATCOM (Static Synchronous Compensator) for reactive power compensation and voltage stabilization on electric grid network. The device is a power electronic GTO converter connected in parallel with the power system bus and is controlled by a novel controller. The complete digital simulation of the STATCOM within a power system is performed in the MATLAB/Simulink environment using the Power System Blockset (PSB). The STATCOM Scheme and the electric grid network are Modeled by specific electric blocks from the power system blockset while the control system is modeled using simulink. The control system is based on a decoupled strategy using the direct and quadrature components of the STATCOM current. The performance of the selected ±100 Mvar STATCOM scheme connected to the 230-kV grid is evaluated. The operation of the STATCOM is validated in both the capacitive and inductive modes of operation. Reactive power compensation and voltage regulation is validated for load and system excursions.

Keywords-48-pulse STATCOM modeling, voltage stabilization, reactive compensation, novel decoupled control strategy.

1. INTRODUCTION

In the last two decades the commercial availability of Gate Turn-Off thyristor (GTO) devices with higher power handling capability, have led to the development of new controllable reactive power sources utilizing electronic switching of voltage source converter technology [1]. These facts technologies offer considerable advantages over the existing devices in terms of space reductions and fast controlling. The GTO switching devices enable the design of power electronic converters that can be either connected in parallel or in series with the power grids. Shunt reactive compensation devices Static Synchronous Compensator (STATCOM) have similar operating characteristics to that of a synchronous machine but without the sluggish mechanical inertia of the synchronous machine condenser and additional maintenance requirements. Flexible AC Transmission System (FACTS) is giving rise to an emerging and optimizing the performance of power system, Family of compensating devices such as SATACOM, SSSC and UPFC. The use of voltage – source inverter (VSI) has been widely accepted as the next generation of effective reactive power controllers replacing the conventional VAR compensation devices, such as the thyristor-switched capacitor (TSC) and thyristor controlled reactor (TCR). The basic STATCOM model consists of a step-down transformer with leakage reactance X_T, a three phase GTO voltage source inverter (VSI), and a DC capacitor. 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 at point 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 [2]. The STATCOM function is to regulate the bus voltage by dynamically absorbing or generating reactive power to the network, like a thyristor static compensator. This reactive power transfer is done through the leakage reactance of the coupling transformer by using a secondary Transformer voltage in phase with the primary voltage (network side). This voltage is provided by a voltage-source PWM inverter and is in quadrature to the STATCOM current. The STATCOM operation can be illustrated by the phasor diagrams shown in Figure 1. when the secondary voltage (VS) is lower than the bus voltage (VB), the STATCOM acts like an inductance absorbing reactive power from the bus. When the secondary voltage (VS) is higher than the bus voltage (VB), the STATCOM acts like a capacitor generating reactive power to the bus [3]. In steady state operation and due to inverter losses the bus voltage VB always leads the inverter voltage by a very small angle to supply the small active power losses.

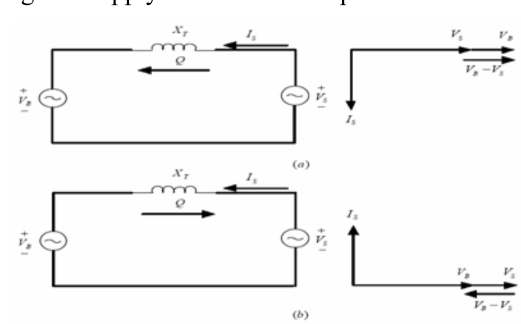

Fig.1 STATCOM operation (a) Inductive operation, (b) Capacitive operation

The voltage source-converter or inverter (VSC or VSI) scheme is the building block of a 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 objectives of a good VSI-converter scheme are to produce a sinusoidal AC voltage with minimal distortion harmonic or excessive content. Three basic techniques can be used for reducing harmonics produced by the converter [4]-[8]. Harmonic neutralization using magnetic coupling (multi-pulse converter configurations), harmonic reduction using multi-level converter configurations. The 24-and 48-pulse converters are obtained by combining two and four 12-pulse-VSI respectively, with a specified phase shift between all converters. For high power applications the best option is the 48-pulse converter, although using parallel filters tuned to the 23^{th} – 25^{th} harmonics the 24-pulse converter could also be adequate in most of the applications but the 48 pulse converter ensuring minimum quality problems.

2. DIGITAL SIMULATION MODEL

A novel complete 48 pulse digital simulation full model 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 Blockset (PSB). The basic building block of the STATCOM is the 48-puls converter cascade implemented by using Matlab/Simulink. The control process is based on a novel decoupled current control strategy using direct and quadrature current components of the STATCOM. The operation of the full STATCOM model is studied in both capacitive and inductive modes in a power transmission system and load excursion. The use of full 48 pulse STATCOM model is made accurate STATCOM models than functional lo-order.

2.1 Power System Description

Modeling the unified scheme sample STATCOM including the power network and its decoupled controller is done using Matlab/Simulink as shown in Figure 1. It requires "electric blocks" from the power system and control blocks from the Simulink power blockset library. A ±100 Mvar STATCOM device connected to the 230-kV (L-L) distribution network. Figure 2 shows the single line diagram representing the STATCOM and the host grid network. The feeding network is represented by a thevenin equivalent (bus B1) where the voltage source represented by a 230*1.03 kV with 10000 MVA short circuit power with a X/R = 8 followed by a transmission line connected to bus B2. The system parameters are given in Table 1. The STATCOM device consists mainly of the full 48 pulse voltage source converter-cascade connected to the host grid network through a coupling transformer. The dc link voltage is provided by the capacitor C which is charged from the AC host network. The decoupled control system ensures the dynamic regulation of the bus voltage (VB) and the dc link voltage Vc. The 48 pulse VSC generates less harmonic distortion and reduce power quality problems than other converters such as (6, 12 and 24) pulse. This result in minimum operational overloading and system harmonic instability problems.

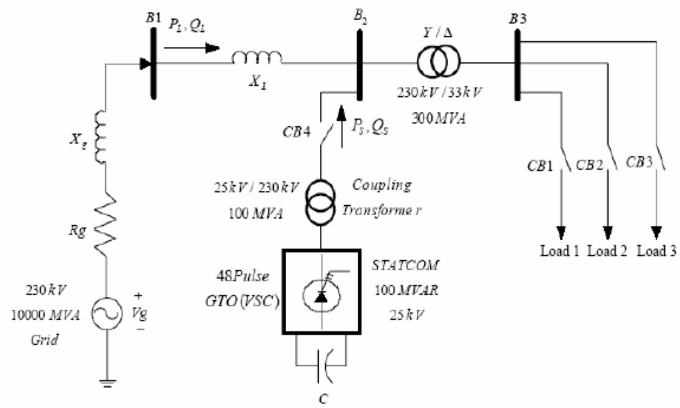

Fig. 2: Sample three-bus study system with the STATCOM located Bus at B2

Table 1 : Table of selected power system parameters

Three Phase AC Source		Active Power	0.7 [pu]
Rated Voltage	230*1.03[kV]	Reactive power	0.5 [pu]
Frequency	60 [Hz]	**Load 3**	
S.C Level	10000[MVA]	Active Power	0.6 [pu]
Base Voltage	230 [kV]	Reactive power	0.4 [pu]
X/R	8	**STATCOM**	
Transmission Line		Primary Voltage	138 kV
Resistance	0.05 [pu]	Secondary Voltage	15 kV
Reactance	0.2 [pu]	Nominal Power	100 MVAR
Power Transformer		Frequency	60 [Hz]
Nominal Power	300 [MVA]	Wq.Capacitance	750 µF
Frequency	60 [Hz]	**Coupling Transformer**	
Prim. Voltage	230 [kV]	Nominal Power	100[MVA
Sec. Voltage	33 [kV]	Frequency	60 [Hz]
Magnitization Resis.	500	Prim. Voltage	138 [kV]
Magnitization Reac.	500	Sec. Voltage	230 [kV]
Three Phase Loads		**GTO Switches**	
Load 1		Snubber Resistance	1e5 [ohm]
Active Power	1 [pu]	Snubber Cap.	inf
Reactive Power	0.8 [pu]	Internal Resistance	1e-4 [ohm]
Load 2		No. of Bridge arm	3

2. 2 Decoupled Control System

The new control system is based on a decoupled control strategy using both direct and quadrature current components of the STATCOM AC current. The decoupled control system is implemented as shown in Figure 3. A phase locked loop (PLL) which synchronizes on the positive sequence component of the three phase terminal voltage at Bus 2.

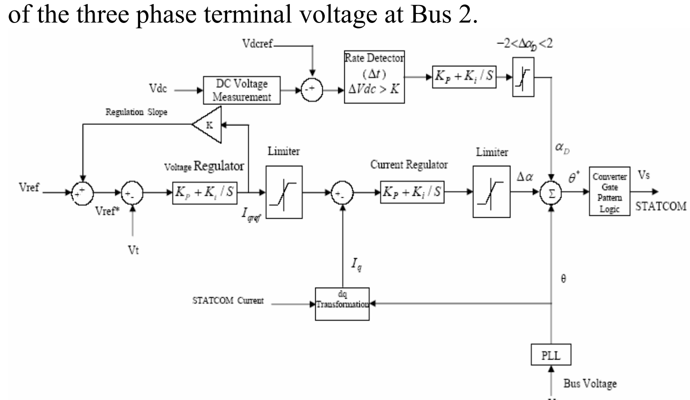

Fig. 3: Proposed STATCOM d-q Current Control System

The output of the PLL is angle (θ) which used to measure the direct axis and quadrature axis component of the AC three phase voltage and currents. The outer regulation loop consisting of an AC voltage regulator which provide the reference current Iqref for the current regulator which is in quadrature with the terminal voltage which control reactive power. The voltage regulator is a PI controller with Kp=12 and Ki=3000. The current regulator is also PI controller with Kp=5 and Ki=40 The Phase-Locked Loop (PLL) system generates the basic synchronizing-signal which is the phase angle of the transmission system voltage Vs, θ, and the selected regulation-slope, k, determines the compensation behavior of the STATCOM device. To enhance the dynamic performance of the full 48-pulse STATCOM device model an supplementary regulator loop is added using the dc capacitor voltage. The dc side capacitor voltage is chosen based on the rate of the variation of this dc voltage. Thus for a fixed specified short time interval Δt, the variations in Vdc magnitude can be measured and any rapid change in this voltage is measured and if $|\Delta V_{dc}|$ is greater than a specified threshold, k, the loop is activated. The main concept is to detect any rapid variations in dc capacitor voltage and Δt is selected be very small and about 1 ms. The strategy of supplementary damping regulator is for the correct the phase angle of the STATCOM device voltage, θ^*, with respect to the sign of this variations. If ΔV_{dc} >0, the dc capacitor is charging very fast. This happens when the STATCOM converter voltage lag behind the AC system voltage, in this way the converter absorbs small amount of real power from ac system to compensate the internal losses and keep the capacitor voltage at the desired level. The same technique can be used to increase or decrease the capacitor voltage and thus, the amplitude of the converter output voltage to control the var generation or absorption.

3. DIGITAL SIMULATION RESULTS

The sample study radial power system is subjected to load switching at bus B3. At starting, the source voltage is such that the STATCOM is inactive. It doesn't absorb nor provide reactive power to the network. The capacitor bank is pre charged to 1 pu voltage. The network voltage, Vg, is 1.03 pu and only inductive load 1 with (P=1 pu and Q=0.8 pu) (at rated voltage) is connected at load bus B3 and the STATCOM B2 bus voltage is 0.955 pu for the uncompensated system and the transmitted real and reactive power are PL=1.2 pu and QL=1.15 pu. The simulation is carried out by using the MATLAB/Simulink and power system blockset and the digital simulation results is given as shown in Figure 4. The following excursion sequence is tested:

Step 1: t = 0.1 Sec, at this time the static synchronous compensator STATCOM is switched and connected to the power system network by switching on the circuit breaker CB4. as shown in Figure 2. The STATCOM voltage lags the transmission line voltage V_B by a small angle $\Delta\alpha = -1.8°$ and therefore the dc capacitor voltage increases. The STATCOM is now operating in the capacitive mode and injects about 0.65 pu of reactive power into the AC power system, as shown in Figure 4(d). The B2 bus voltage is increased to 0.985 pu as shown in Figure 4(b). The STATCOM draws 0.02 pu of real-active power from the network to compensate for the GTO switching losses and coupling transformer resistive and core losses. The voltage regulation leads to an increase in the transmitted real power to the load bus B3 with an PL=1.35 pu, due to the reactive power compensation, the transmitted reactive power also decreases to QL= 0.7 pu. Figure 4(f) shows the resolved d-q STATCOM current components. The STATCOM current is totally a reactive current.

Step 2: t = 0.5 Sec, at this time the second inductive load 2 with P = 0.7 pu and Q = 0.5 pu (at rated voltage) is added to the AC power system at bus B3, therefore more dynamic reactive power compensation is still required. The STATCOM small voltage phase displacement angle increases to $\Delta\alpha = -2.4°$ again and therefore the dc capacitor voltage increases as shown in Figure 4(c). The STATCOM injects about 1.3 pu of reactive power into the AC network at bus B2 and draws about 0.05 pu of real power to compensate the added losses. The regulated bus voltage V_B is now about 0.975 pu. The STATCOM d-axis current temporarily increases in order to charge the dc capacitor.

Step 3: t = 1 Sec, the capacitive load 3 with P = 0.6 pu , Q_C = 0.4 pu (at rated voltage) is now added to the power system at bus B3. The capacitive load has a compensative effect so the STATCOM inject less reactive power into the AC system at bus B2. The injected reactive power is decreased by reducing the dc capacitor voltage, with $\Delta\alpha = -2°$ this in turn leads to a decrease the converter voltage drop. The regulated bus voltage is 0.978 pu while the STATCOM injects 1.15 pu of the reactive power into the system and draws only 0.02 pu real power.

Step 4: t = 1.5 Sec**,** at this time both loads 1 and 2 are removed from bus B3 which is severe load rejection and only the capacitive load 3 remains connected at bus B3. Due to this capacitive load, the STATCOM operates in inductive mode to regulate the resultant overvoltage at bus B2. The dc capacitive voltage drops with $\Delta\alpha = 2.5°$ as shown in Figure 4 (a, c). The STATCOM voltage leads the bus voltage. As a result the dc capacitor voltage drops to 0.97 pu. the regulated bus voltage is 1.08 pu while the STATCOM draws reactive power from the network (inductive operation) and the q-axis current is positive. Figure 4 (e) shows the 48- pulse converter voltage and current and the transition from capacitive mode of operation to inductive mode of operation with no transient overvoltage appeared and this transition for operation mode takes a few millisecond. This smooth transition is due to novel controller which based on the decoupled control strategy and the variation of the capacitor dc voltage. The THD of the output voltage of converter which is very small compared with other low pulses of voltage source converters.

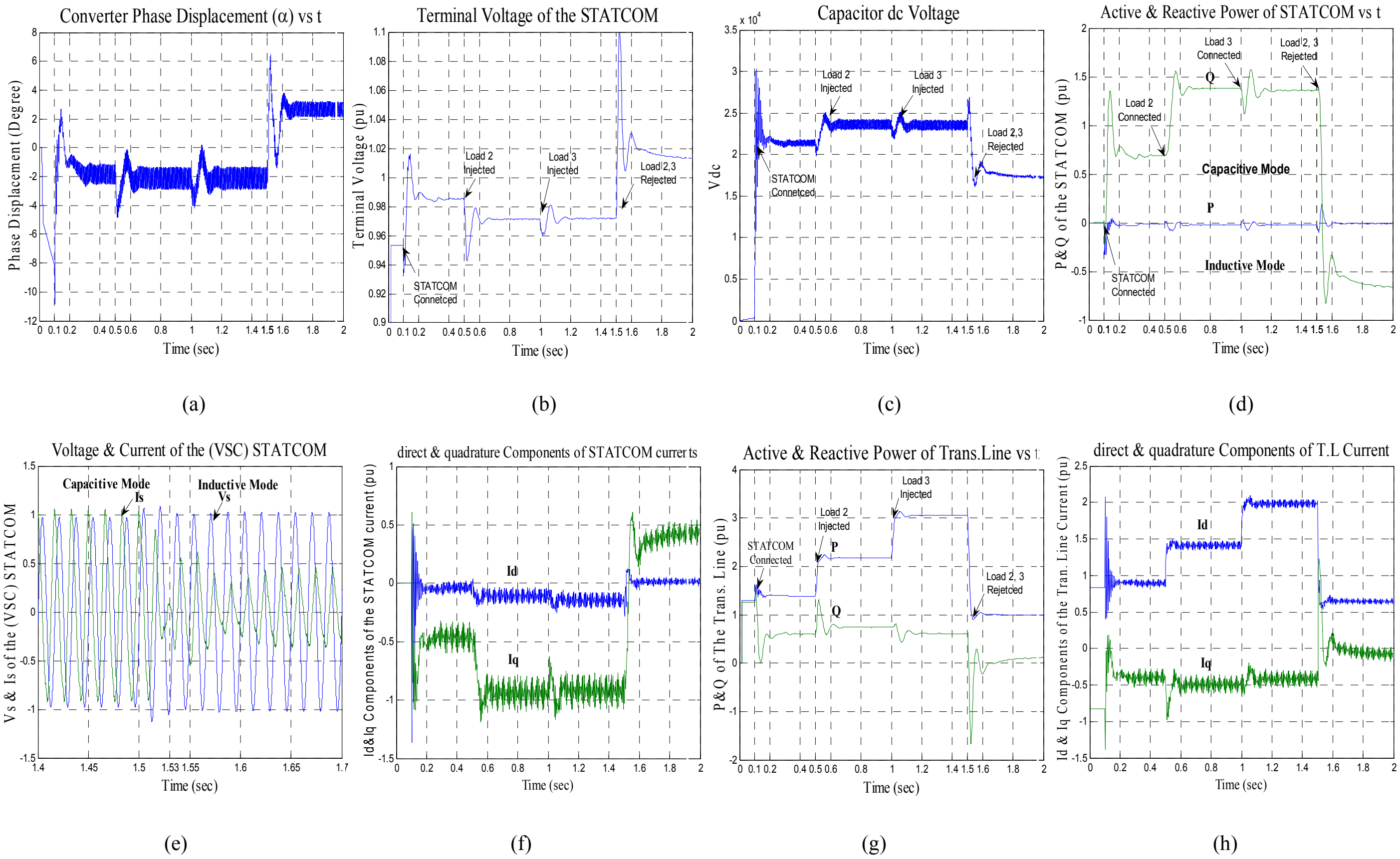

Fig. 4: The Digital Simulation Results of The STATCOM Operation

4. CONCLUSION

This paper presented a novel full STATCOM 48 pulse model of cascade converter and its use for reactive power compensation and voltage regulation. A detailed model of the ±100 MVAR STATCOM has been developed and connected to the 230 kV AC grid network in order to provide the required reactive compensation. The full 48 pulse model of STATCOM is controlled by a novel dual loop current decoupled controller and the STATCOM facts device is validated as an effective reactive power compensator and Voltage stabilization scheme. The control process has been developed based on a decoupled current strategy using direct and quadrature STATCOM current. The operation of the STATCOM is validated in both capacitive and inductive operational modes in the sample power transmission system. The dynamic simulation results have demonstrated the high quality of the 48 pulse STATCOM for reactive power compensation and voltage regulation while the system subjected to disturbances such as switching different types of loads. The full 48 pulse model can be utilized in other Facts device studies such as Active Power Filters and new hybrid stabilization topologies.

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