Injecting the STATCOM in electric networks for sustainable energy development

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Abstract

Some lines on roads privileged can be overloaded. Therefore, it is interesting for the network manager to control the power flows to operate the network more efficient and safer. FACTS technology is a way to fulfill this function. With their ability to modify the apparent impedance of the lines, Flexible AC transmission system (FACTS) devices can be used both to control active power for the reactive power or voltage. Several types of FACTS exist and the choice of device depends on appropriate targets. The objective of the present work to design a control strategy for voltage and for reactive power flows passing through that network. The static synchronous compensator (STATCOM) used in this work is a device that is parallel type compensator based on the absence of parallel voltage source converters (VSC).The performance of the system chosen ± 100 Mvar STATCOM system connected to the 230KV network is evaluated the operation of STATCOM is validated in both capacitive and inductive modes of operation. Subsequently, a control strategy of reactive power and voltage on a transmission system will be developed under the Matlab environment.

Keywords: *FACTS, STATCOM modeling, The voltage source converter (VSC), Control voltage, Control strategy.*

I. Introduction

Insert Electrical networks until recent years are controlled mechanically despite the use of microelectronics, computers and rapid means of telecommunications networks in the control, the last action in these control systems is made with mechanical devices with a response time shorter and more action with which boot and reboot can be performed repeatedly at a high frequency compared to devices based static switches (semiconductors).[1][2]
The contribution of this technology for FACTS electricity companies is to open up new prospects for controlling the flow of power in networks General Introduction and increase the capacity of existing lines used similar to extensions in the past. These contributions result from the ability of FACTS controllers to control the interrelated parameters that govern the transport operation of electric power including series impedance, shunt impedance, current, voltage, phase angle ... etc.[3]
The new generation of FACTS systems consists mainly of voltage converters (or current), based on modern solid-state switches (GTO and IGBT) controlled opening and closing related to capacitors as DC source. These converters based on their connection to the network are distinguished by compensating shunt, series and hybrid such as STATCOM, UPFC, respectively [4]

II. Static Synchronous Compensator (STATCOM)

The basic concept of the STATCOM was proposed by Gyugyi in 1976. The first STATCOM, based on two levels converters, used in transport networks are:

- ✓ The STATCOM applied to a 154KV transmission network in Inuyama Japan and has been marketed since 1991 by Kansai Electric Power Corporation and Mitsubishi Electric Power Corporation.
- ✓ THE STATCOM installed at 161 KV Station Sullivan Northeast Tennessee for Westinghouse Electric Corporation in the United States in 1995.

The STATCOM is the version of SVC consists of a voltage converter based on semiconductor high technology (IGBT, IGCT) with a capacitor as a voltage source and all connected in parallel to the

network by means of a coupling transformer as shown in Figure 1. [1] [2] [3] [4]

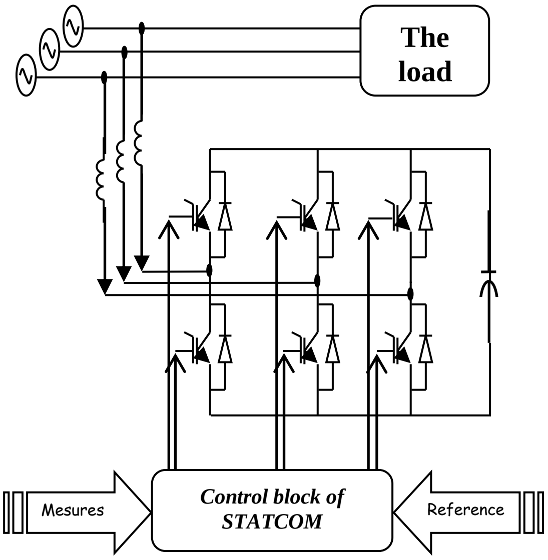

Figure 1. basic structure of a STATCOM connected to the grid

III. Principle of Operation

The shunt compensation are well recognized in the compensation of reactive power and consequently the regulation of voltage bus bar where they are connected. The STATCOM is a static synchronous generator that generates a three-phase AC

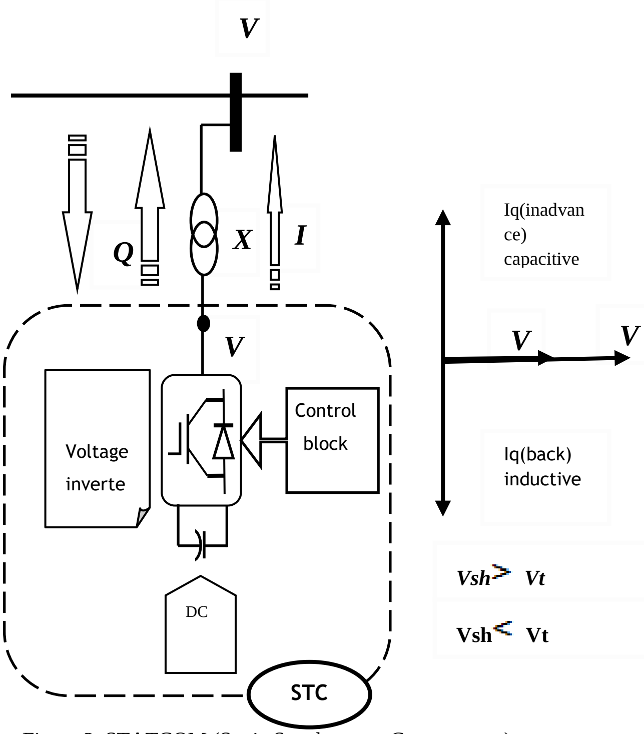

Figure 2. STATCOM (Static Synchronous Compensator)

synchronous with the mains voltage from a DC source. The amplitude of the voltage of the STATCOM can be controlled to adjust the amount of reactive power exchange with the network. In general STATCOM voltage V_ (sh) is injected in phase with the voltage V_t line and in this case There is no exchange of energy with the active network, but only reactive power to be injected (or absorbed) by the STATCOM as summarized in Figure 2. [5] [6] [7]

IV. Simplified Mathematical Model

Equations (01 and 02) as the equation of state of STATCOM system taking into account the changes in the voltage of the DC Circuit is written in matrix form as follows:

$$\frac{d}{dt}\begin{bmatrix} I_{shd} \\ I_{shq} \\ U_{dc} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_{sh}} & w & \frac{-m}{2c}\cos\theta \\ -w & \frac{-R}{L_{sh}} & \frac{3m}{2c}\cos\theta \\ \frac{3m}{2c}\cos\theta & \frac{-3m}{2c}\cos\theta & \frac{-R}{L_{sh}} \end{bmatrix} \begin{bmatrix} I_{shd} \\ I_{shq} \\ U_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{sh}} & 0 \\ 0 & \frac{1}{L_{sh}} \\ 0 & 0 \end{bmatrix} \begin{bmatrix} V_d \\ V_q \end{bmatrix}$$

(01)

It can be observed that there are two control parameters in this system with three state variables to control variables and only two can be controlled independently. This system we should Linear around an operating point will be of the form.

$$\frac{d}{dt}\begin{bmatrix} I_{shd} \\ I_{shq} \\ U_{dc} \end{bmatrix} = \begin{bmatrix} \frac{-R}{L_{sh}} & w & \frac{-m}{2c}\cos\theta \\ -w & \frac{-R}{L_{sh}} & \frac{3m}{2c}\cos\theta \\ \frac{3m}{2c}\cos\theta & \frac{-3m}{2c}\cos\theta & \frac{-R}{L_{sh}} \end{bmatrix} \begin{bmatrix} I_{shd} \\ I_{shq} \\ U_{dc} \end{bmatrix} + \begin{bmatrix} \frac{1}{L_{sh}} & 0 & \frac{m}{L_{sh}}U_{dc0}\sin\theta_0 \\ 0 & \frac{1}{L_{sh}} & \frac{m}{L_{sh}}U_{dc0}\cos\theta_0 \\ 0 & 0 & \frac{-3m}{2c}(I_{shd}\sin\theta + I_{shq}\cos\theta_0) \end{bmatrix} \begin{bmatrix} V_d \\ V_q \\ \theta \end{bmatrix}$$

(02)

The reactive current is controlled independently to control the reactive power flow and other parameters are used to maintain constant DC voltage

V. Control of STATCOM

In all practical applications of the STATCOM is used primarily to compensate the reactive power at bus bar connection and therefore maintain the tension of the latter. For this purpose the device injects or absorbs a current I^{*}_{sh} , which is the image of the power offset. These currents I^{*}_{shd}, I^{*}_{shq} are the magnitudes of the reference STATOM we determine from the injected power to.

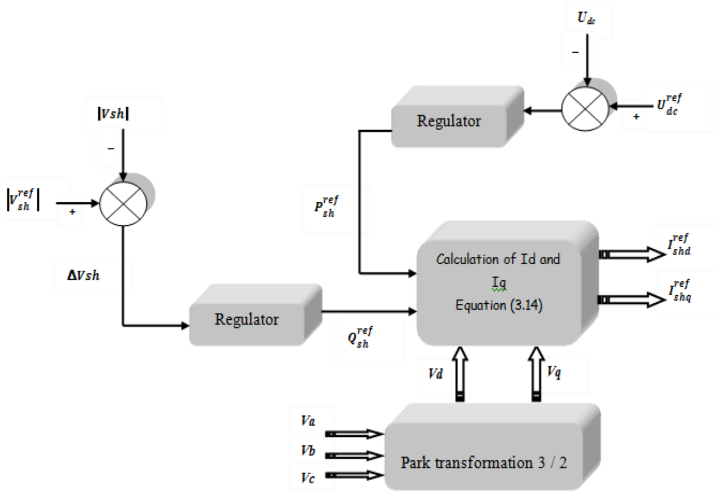

Figure 3. Identification of reference currents

Finally arriving at the control scheme of STATCOM by the Watt-Var method decoupled from the figure 4 follows:

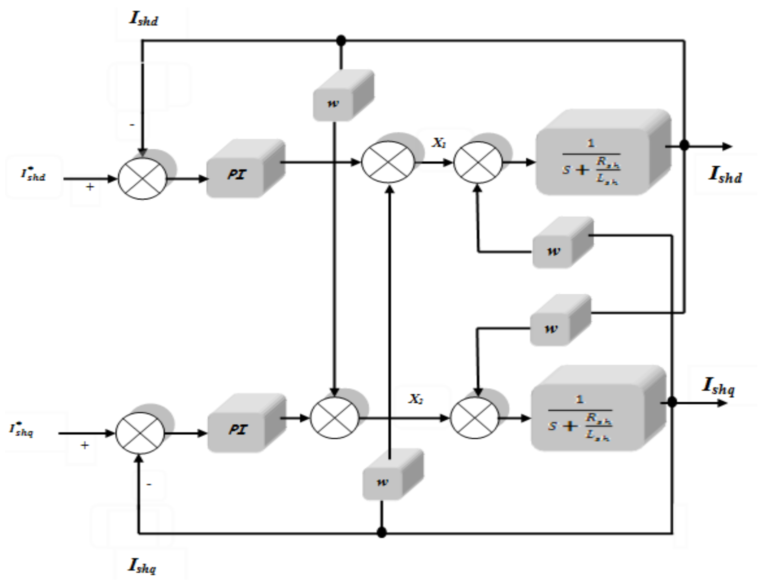

Figure 4. Regulation of STATCOM scheme (Watt-Var decoupled)

We used to regulate currents of STATCOM integral proportional controller (PI) as shown in the diagram in the following figure 5:

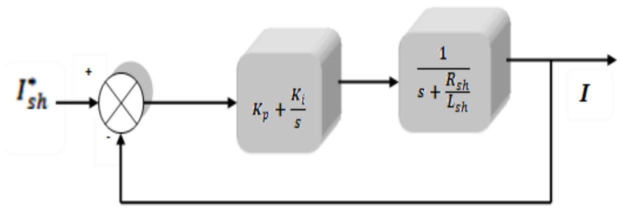

Figure 5. Block diagram of PI control current of STATCOM

The transfer function of the open loop control is FTBO:

$$G(s) = (K_p + \frac{K_i}{s})(\frac{1}{s + R_{sh}/L_{sh}}) = K_p(\frac{s + K_i/K_p}{s})(\frac{1}{s + R_{sh}/L_{sh}}) \quad (3)$$

A. Regulation of voltage

The voltage across the capacitor must be maintained at a constant value. The correction of this voltage must be done by adding a current active reference current of the STATCOM which will reflect the absorption or the provision of active power on the network. Power exchanged with the capacitor can be expressed by the following equation: [7-9].

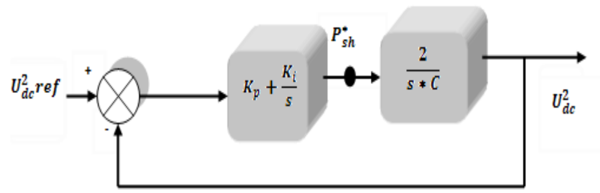

Figure 6. Regulation of voltage

The closed loop transfer function of the system in the form of Bode is:

$$F(s) = (\frac{U_{dc}^2}{U_{dc\_ref}^2}) = \frac{2SK_p/C + 2K_i/C}{S^2 + 2SK_p/C + 2K_i/C} \quad (04)$$

B. Simulation and results of the STATCOM

The single line diagram of the network of electric power used to validate the operation of the STATCOM is represented by Figure 7.

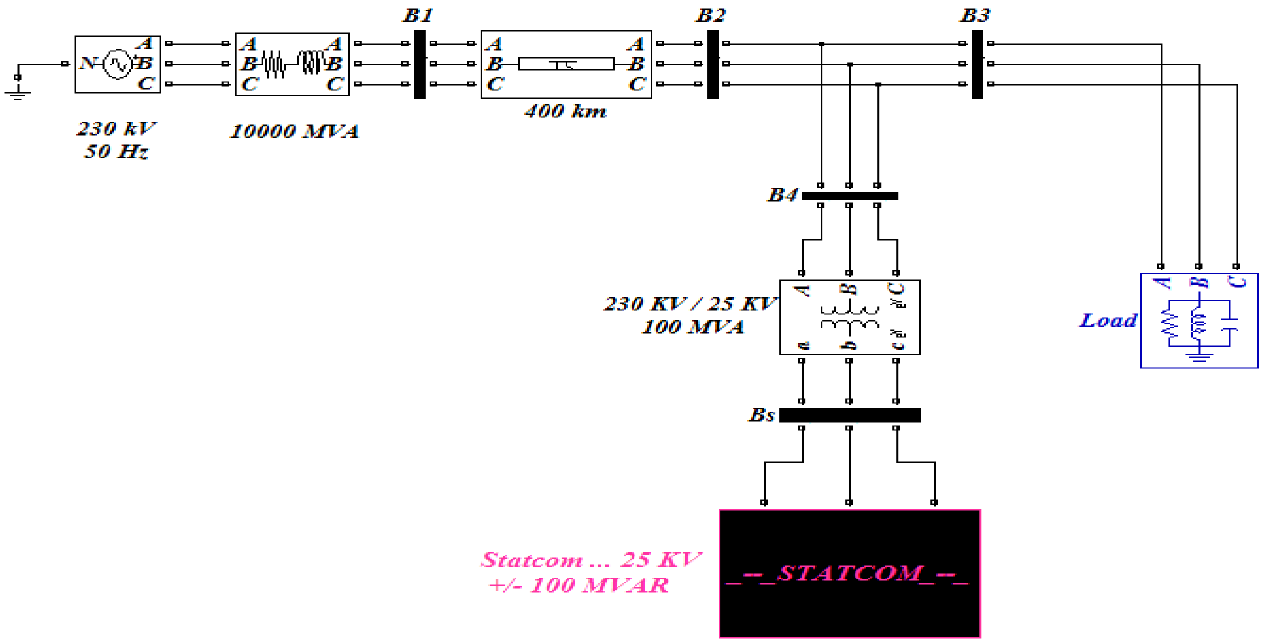

Figure 7. Network studied

Table1. Different system parameters

The three-phase source		Frequency	50 [Hz]
The rated voltage	230*1.03 [kV]	The storage capacitor	10000[μF]
Frequency	50 [Hz]	**STATCOM switches(IGBT)**	
The rated power	10000[MVA]	Resistance	1e5 [ohm]
The base voltage	230 [kV]	the capacitor	inf
X/R	08	The internal resistance	1e-4 [ohm]
The transmission line		N0 of bridge	03
Resistance	0.05 [pu]	**The three-phase loads**	
the reactance	0.2 [pu]	**Load_01**	
The coupling transformer		The active power	01 [pu]
The rated power	100[MVA]	The reactive power	0.4 [pu]
Frequency	50 [Hz]	**Load_02**	
The primary voltage	230 [kV]	The active power	01 [pu]
The secondary voltage	25 [kV]	The reactive power	0.7 [pu]
STATCOM		**Load_03**	
The rated voltage	25 [kV]	The active power	0.3 [pu]
The rated power	100[MVAR]	The reactive power	0.35 [pu]

The network consisted of a 230 KV generator with a rated capacity of 10,000 MVA and a transmission line of 400 km modeled π for every 100 km. The transformer was used to lower the Tsh 230 kV (voltage network) at 25 kV (input voltage converters) and the line supplied a load (L_1, L_2, L_3) at bus bar 'B3' (Vr). The diagram of the network is presented in Figure 8:

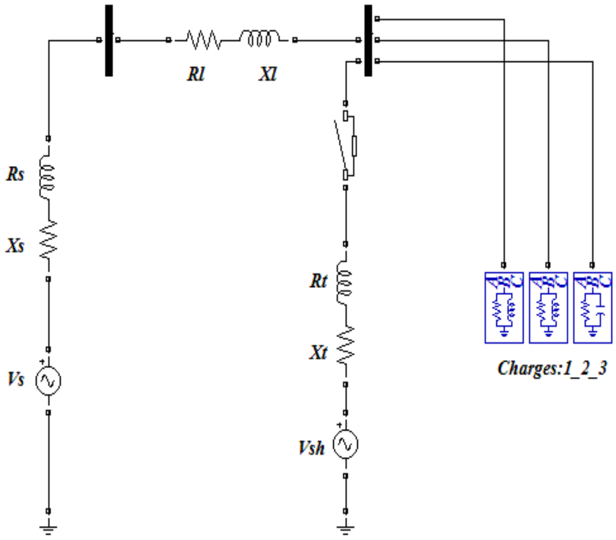

Figure 8. Equivalent circuiting [PU]

C. Simulation tests

Initially the capacitor was charged and the STATCOM voltage to these terminals was 1.0 pu. The voltage of the bus bar generation was Vs = 1.0, the energy system and spite on an inductive load of L_1: P = 1.0 pu; QXL = O.4 in a steady state. In the tests an inductive load L_2: P2 = 01 could was added at t = 0.5 s, could and QXL = 0.7 at time (t = 1 s) was charged over the line by another capacitive load L_3: P3 = 0.3 pu; QXC = 0.35 could, and finally at time (t = 1.5) it would disconnect all loads and leaving the capacitive load L_3. Figure 9 shows the voltage drop caused by the inductive load L_2 at time t = 0.5 s. This fall would be cushioned by the natural connection of the capacitive load L_3. Disconnection of inductive loads in the last transition and flow of the capacitive load might cause a surge in high voltage bus bar load (B3) as shown in Figure 9.

By taking these tests, with the same loads on the network associated with a controller FACTS (STATCOM) at the bus bar of reception (load), the STATCOM injected a voltage Vsh_d (Vsh_q ≈ 0) in phase with the voltage Vabc_L (Vabc_L = Vsh_d, Vsh_q = 0) increased by charging more and more line with inductive loads L_1 + L_2 as shown in Figure 10.This tension Vsh mode inductive over voltage Vabc_L determined the direction of reactive power injected by the STATCOM Ish_q Network: positive mode indicating that the inductive reactive power compensator delivered green network, and negative in the charging phase to show the capacitive reactive absorption from the network by the STATCOM in Figure 11.

The currents in this system, STATCOM, and Ish_d Ish_q followed their reference quantities (which were calculated from the reference power and necessary to compensate the reactive power in line and keep the voltage bus bar B3) which validated the proper functioning of proportional integral regulators "PI" placed in the Watt-Var-coupled model used. Before t = 0.5 s the STATCOM injected a small amount of reactive power in the range of Qsh (Qsh ≈ 0.08) could to raise the voltage to 1.0 Vabc_L could. But after the introduction of the charge to L_2+L_1 + (t = 1 s), more reactive power was required for clearing and STATCOM in capacitive mode contributes approximately 0.7 ≈ qsh could, as observed in Figure 12. A small amount of active power was absorbed in this phase to maintain the voltage at the terminal of the capacitor constant. By connecting the capacitive load at t = 1.5 s the reactive power supplied by the STATCOM decreased due to the capacitive effect of the load on the transmission line. In the last step the capacitive load connected to line voltage caused the game to load bar Vabc_L and that the STATCOM operated in inductive mode and absorbed reactive power from the network to maintain the voltage profile Vabc_L, thus the voltage dropped below Vsh, blood Vabc_L demonstrating the theory outlined in the literature. Always to validate the laws and the adopted assumptions Figure 13 was recorded to observe the phase shift between the voltages V_L; Vsh-a and-a was almost zero (in phase), the small shift seen in Figure 14 permitted the transit of a small amount of active power to compensate for losses in the switches of the converter (inverter).The voltage of the bus bar was connected and the device was adjusted to the value of the starting voltage could Vabc_L ≈ 1.0. The static error between the voltage set Vabc_L reference voltage V = 1.0 pu was due to simplifications made in the expression of the reactive power reference requested by the controller STATCOM to inject as shown in Figure 15.

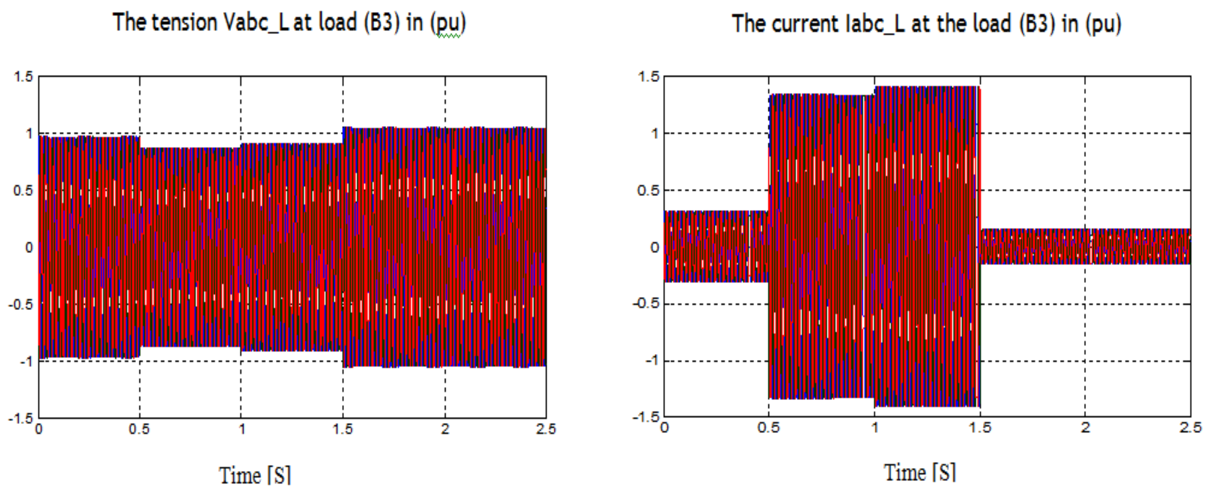

Figure 9. The voltage and current at the load

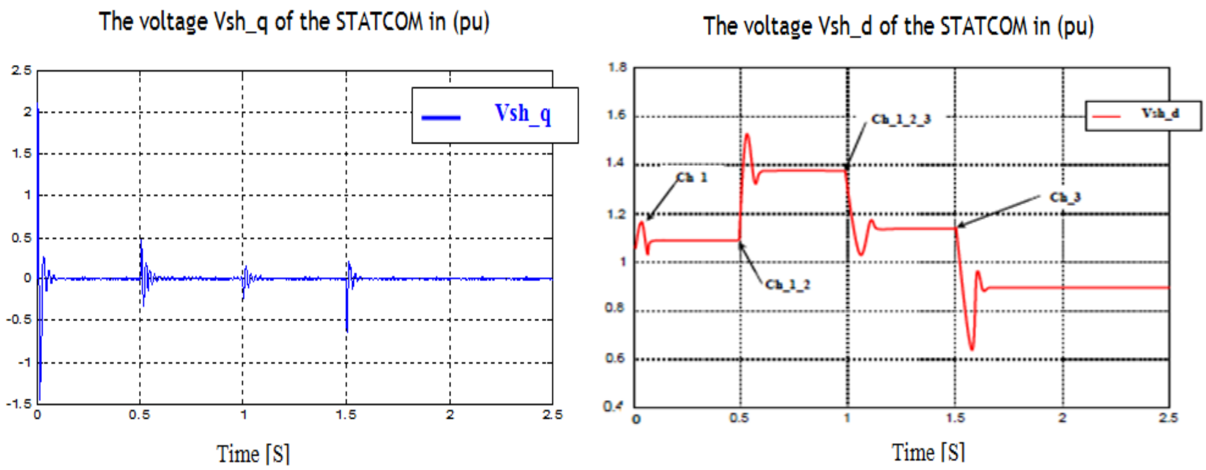

Figure 10. The voltage Vshq annd Vshd of the STATCOM

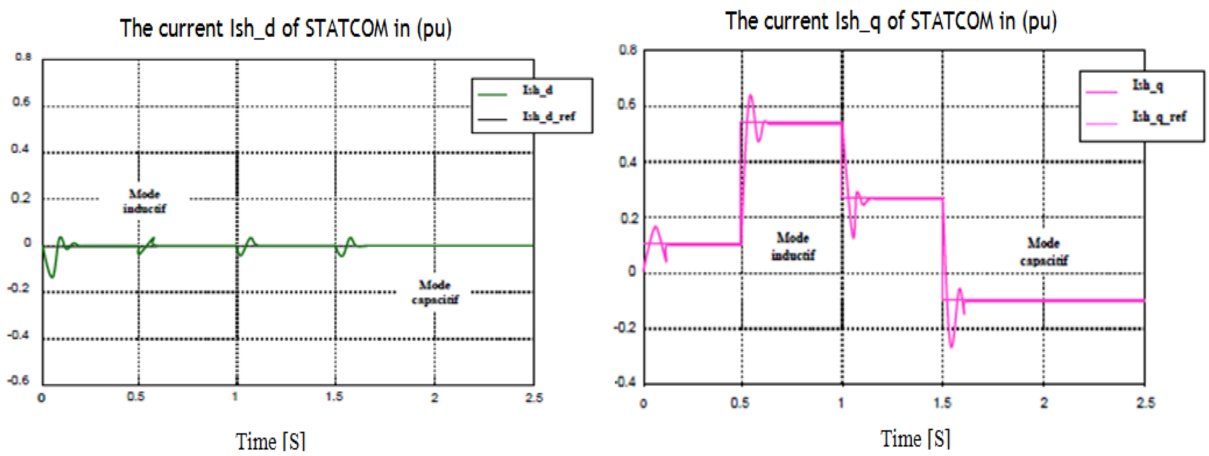

Figure 11. The Current Vshq annd Vshd of the STATCOM

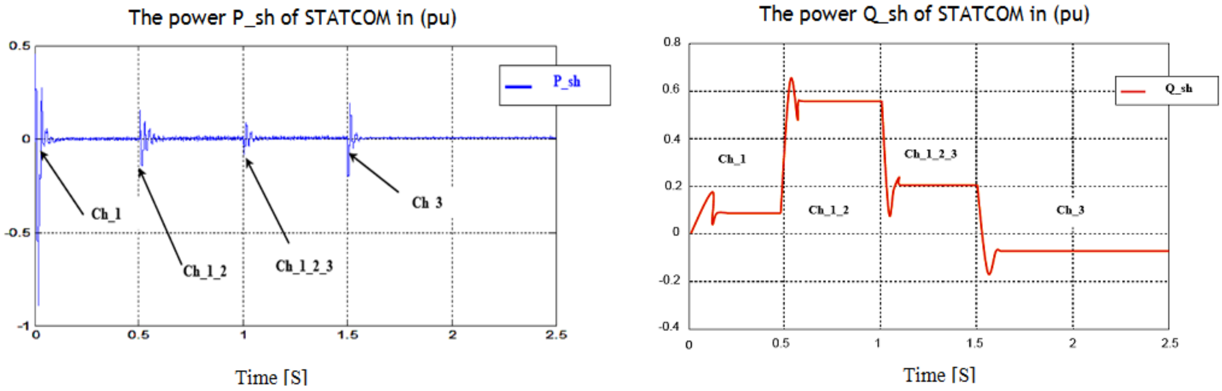

Figure 12. The Power Psh and Qsh of the STATCOM

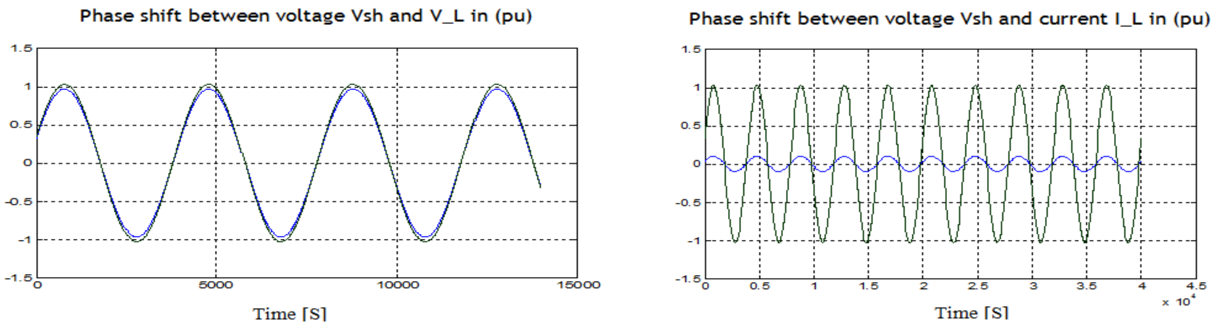

Figure 13. Phase shift between voltage and current

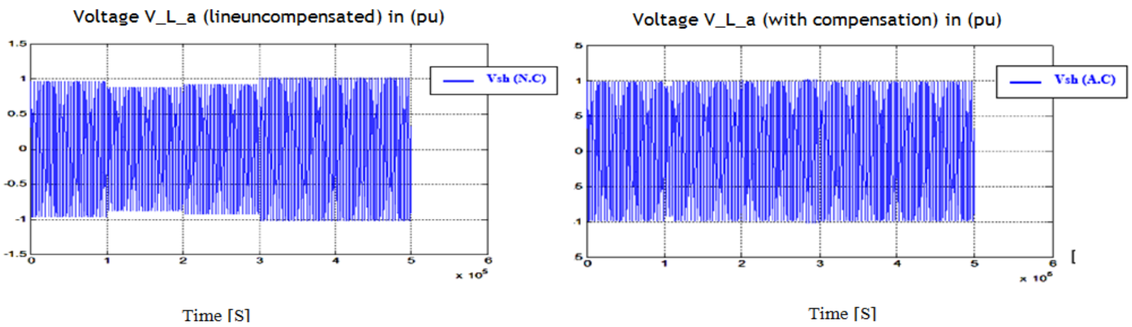

Figure 14. The voltage before and after compensation

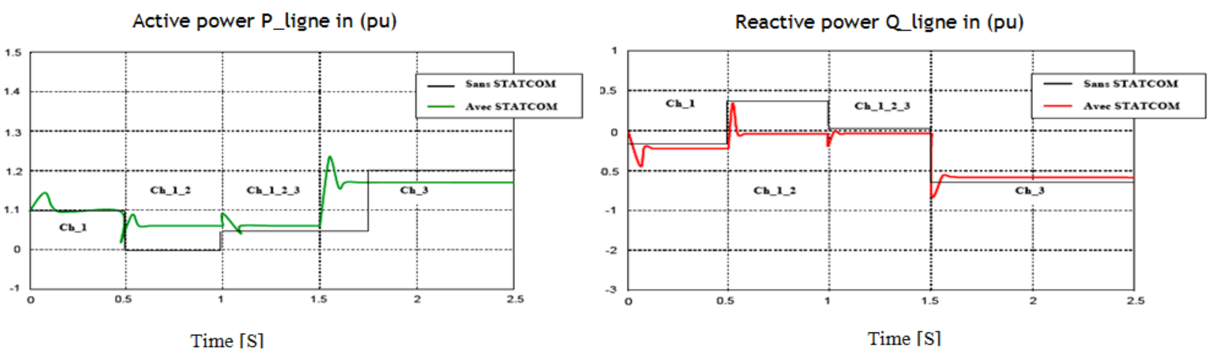

Figure 15. The active and reactive power line

V. Conclusion

The development of power electronics is used to improve the management of power systems by introducing a new concept by the transmission system of energy called flexible AC FACTS with which the flow control and reactive power and increased carrying capacity of the lines are achieved and performed by the injection of voltage (or current) converters designed with modern solid-state switches controlled by opening and closing such as GTO, IGBT for the next generation FACTS of these systems. The study presented in this paper fits into this concept and focuses on the control voltage shunt compensation of reactive power with a device-based FACTS voltage inverter (STATCOM). To achieve this goal we went through several stages: First we started with a brief study of the laws of transport of electricity by exposing the problem of portable power limit based on network parameters and the voltage drop produced by the imbalance of charges. We also discussed the definitions quickly and principle of operation of the main FACTS devices. To validate this theoretical study, in the last chapter, we conducted several tests on a STATCOM simulations inserted into a transmission line in the Matlab-Simulink environment, and view and comment on the results. Simulation results have verified the effectiveness of the control strategy which allows an independent and decoupled active and reactive power of these devices by minimizing the effect of interaction between these powers. Proportional integral regulators used to control the sizes of these devices have made very satisfactory results in terms of response time and damping overruns. Finally, this study allows us to judge this very attractive device for electrical networks by showing flexibility in the control of the majority of network parameters, based on the PWM control converters, which represents the basic building block of these devices. Increasing transport capacity of electric power thermal boundary lines is a valuable solution to the problem of reconstruction of new power lines faced by environmental constraints, ecological and economic.

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