Simulation of a Three-Level 48-Pulses StatCom

S. HADJERI, Fatiha GHEZAL and S.A. ZIDI

Abstract - *This paper presents the detailed analysis of a 48-pulse StatCom. To achieve a satisfactory harmonic content, in this paper the voltage source inverter (VSI) based on 48-pulses is employed; this is constituted by four three-level converter linked by four phase-shifting transformers. Such device exhibits a low harmonic rate on the AC side, so the 48-pulses StatCom can be utilized in high power applications without AC filters. A state-space representation on a d-q framework is presented. Simulation results are exhibited to show the appropriateness of the proposition.*

Keywords : *Voltage regulation, FACTS devices, SVC, StatCom*

1. INTRODUCTION

The rapid development of the power electronics technology provides opportunities to develop new power equipment to improve the performance of the power system. Flexible alternating current transmission systems (FACTS) technologies have been proposed and implemented based on such technology. FACTS devices can be used for power flow control, loop-flow control, voltage regulation, enhancement of transient stability, and damping of power oscillations. For instance, FACTS devices can be used as series controllers to regulate the line impedance, as shunt controllers to regulate the voltage magnitude, or as series/shunt combination to regulate several signals.

The advancement of power semiconductor devices such as IGBT and the Gate Turn-Off thyristor (GTO) which possess high power handling capability, have led the development of controllable reactive power sources utilising electronic switching converter technology [1]. These technologies additionally offer considerable advantages over the existing ones, in terms of space reductions and performance [1]. FACTS are a result of the development in the power electronics area and aim to rapidly control electrical signals [2].

The Voltage Source Converter is the basic building block of FACTS devices such as StatCom and UPFC. Single phase voltage source converters can be inter-connected to form complex schemes. Combined with appropriate controllers, certain harmonics can be eliminated [4].

The Static Synchronous Compensator (StatCom) is a shunt device of the Flexible AC Transmission Systems (FACTS) family It is based on power electronics devices to control voltage and improve transient stability [5]. Figure 1 shows the basic scheme of a StatCom connected to a bus of the transmission system.

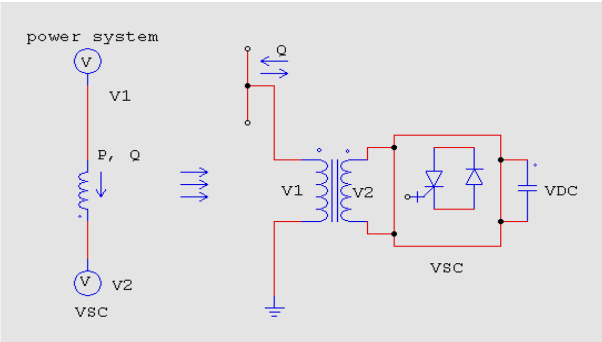

Fig. 1. The StatCom's connection.

The results of applying a StatCom are similar to those by a rotating synchronous condenser, but without its mechanical inertia and slow time response [3].

The StatCom basically consists of a step-down transformer with a leakage reactance, a three-phase GTO voltage source converter (VSC), and a DC capacitor [9]. The StatCom regulates the voltage magnitude at its terminals by controlling the amount of reactive power injected into or absorbed from the power system. When system voltage is low, the StatCom generates reactive power (StatCom capacitive); when system voltage is high, it absorbs reactive power (StatCom inductive) [5]. Figure 2 shows the StatCom V-I characteristic.

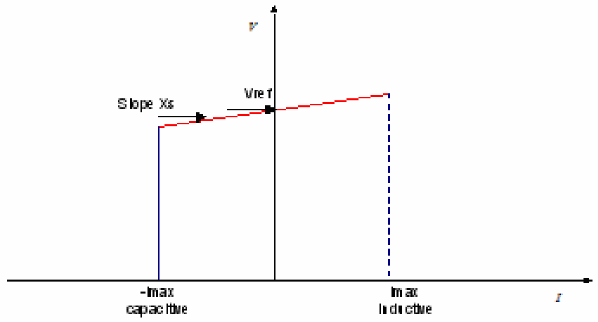

Fig. 2. StatCom V-I characteristic.

$$V = V_{ref} + X_S I$$

where:

V : Positive sequence voltage (in per unit system)

V_{ref} : is the reference voltage

I : Reactive current ($I > 0$ indicates an inductive current $I < 0$ indicates capacitive current

X_S : droop reactance

As long as the reactive current stays within the constant maximum and minimum current values imposed by the converter rating, the voltage is regulated at the reference voltage Vref [5] [6].

2. VSC'S BASIC STRUCTURE

One of the important requirements in high voltage power applications is that harmonics be kept at some satisfactory level [7]. One way of reducing the level of harmonics presents in the converter output waveforms is to increase the number of converters [1], [7]. An elementary voltage source converter, based on a phase control scheme, consists of six self-commuted semiconductor switches. Each switch is shunted by a reverse parallel-connected diode, Fig. 3. With a DC voltage source, the converter can generate a balanced set of three-phase voltage waveforms at a given frequency [8]. By combining two 24-pulse VSC, phase-shifted 7.5° from each other, an equivalent 48-pulse converter [8] is constructed. The 48-pulse converter is displayed in Fig. 3; it is formed by four three-level converter linked by four phase shifting transformers. Fig. 5 depicts the quality of the output-voltage obtained from such converter. It can be deduced that the harmonics are reduced by increasing the number of pulses [1] [10]. This kind of converter give rises to a better voltage control on modern power systems [10].

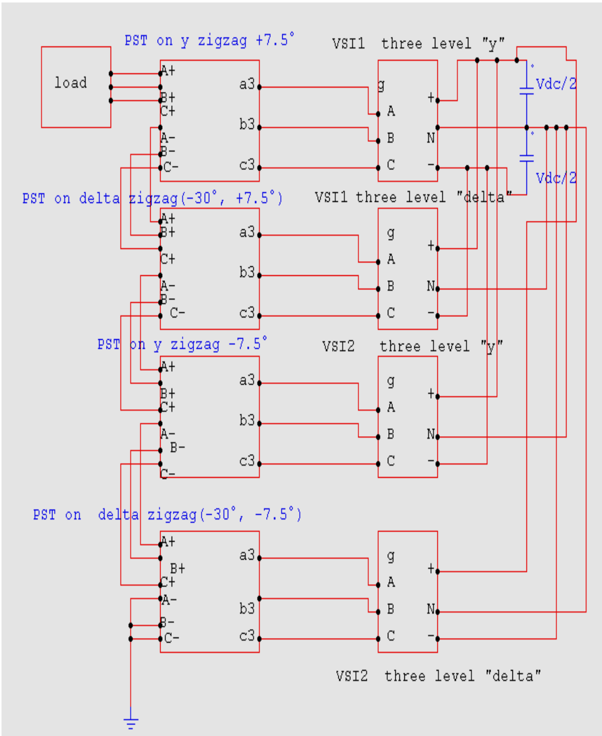

Fig. 3. A three-level 48-pulses VSC.

The simulation of the three-level 48-pulses VSC gives the following results.

Fig. 4 exhibits that the output-voltage waveform is closely a sine wave. Thus, a filter is not required for eliminating low-harmonics.

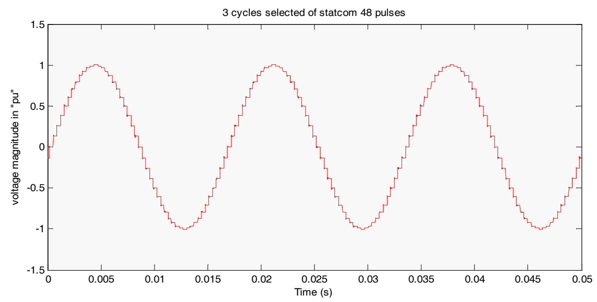

Fig. 4. Three-level 48 pulses VSC output-voltage.

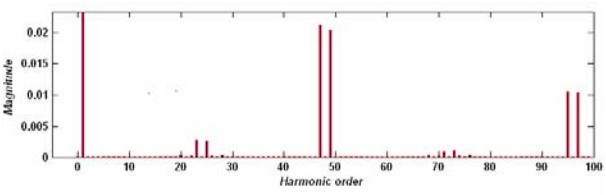

Fig. 5. Harmonic content.

3. TWO-LEVEL 48-PULSES STATCOM MODEL

Figure 6 depicts the simpler and basic representation of the six-pulses StatCom.

R : is the series resistance representing the transformer windings resistances, plus the converter conduction losses.

L : is the transformer's leakage inductance.

C : is the capacitance of the DC side.

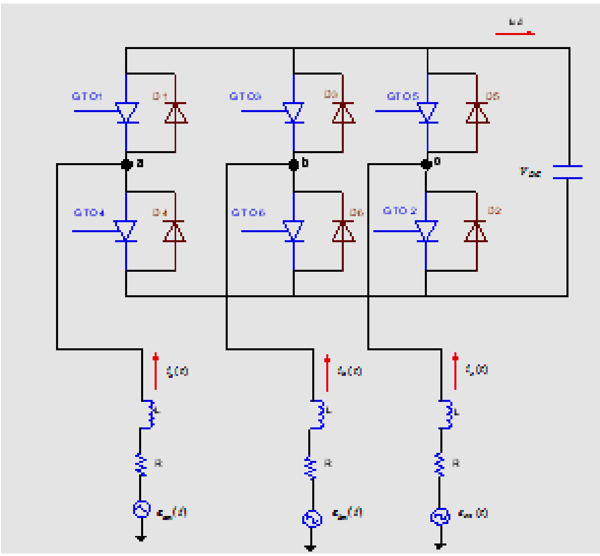

Fig. 6. Six-pulses StatCom.

The mathematical model of such StatCom is developed in [1], and it is given by:

$$e_{an}(t) - v_{an}(t) = L\frac{d}{dt}i_a(t) + Ri_a(t) \qquad (1)$$

$$e_{bn}(t) - v_{bn}(t) = L\frac{d}{dt}i_b(t) + Ri_b(t) \qquad (2)$$

$$e_{cn}(t) - v_{cn}(t) = L\frac{d}{dt}i_c(t) + Ri_c(t) \qquad (3)$$

where $v_{an}(t)$ is the converter output voltage determined by the gating signals and the DC voltage.

The StatCom state space model at fundamental frequency is given by

$$x^{\bullet}(t) = A_s x(t) + B_s u(t)$$

where :

$$x(t) = \left[i_a^0(t), i_b^0(t), i_c^0(t), v_{DC}^0(t)\right]^T$$

and $u(t) = \left[e_{an}(t), e_{bn}(t), e_{cn}(t)\right]^T$

$$A_s = \begin{bmatrix} \frac{-R}{L} & 0 & 0 & -k_1\sin(wt+\alpha) \\ 0 & \frac{-R}{L} & 0 & -k_1\sin(wt+\alpha-120) \\ 0 & 0 & \frac{-R}{L} & -k_1\sin(wt+\alpha-240) \\ k_2\sin(wt+\alpha) & k_2\sin(wt+\alpha-120) & k_2\sin(wt+\alpha-240) & \end{bmatrix}$$

$$B_s = \begin{bmatrix} \frac{1}{L} & 0 & 0 \\ 0 & \frac{1}{L} & 0 \\ 0 & 0 & \frac{1}{L} \end{bmatrix}$$

$k_1 = \frac{2}{\pi L}$; $k_2 = \frac{2}{\pi C}$ for a 6 pulses converters

$k_1 = \frac{4}{\pi L}$; $k_2 = \frac{4}{\pi C}$ for 12 pulses converters

$k_1 = \frac{8}{\pi L}$; $k_2 = \frac{8}{\pi C}$ for 24 pulses converters

$k_1 = \frac{16}{\pi L}$; $k_2 = \frac{16}{\pi C}$ for 48 pulses converters

The Park's transformation is used so that the StatCom's model in the dq0 reference frame becomes [1]:

$$x^{\bullet}_{dqo} = A_{dqo}x_{dqo} + B_{dqo}u_{dqo},$$

where :

$$x_{dqo} = \left[i_d\ ,\ i_q\ ,\ i_o\ , v_{DC}\ \right]^T$$

$$u_{dqo} = \left[e_d\ , e_q\ , e_o , 0\ \right]^T$$

so :

$$A_{dqo} = \begin{bmatrix} \frac{-R}{L} & w & 0 & -k_1 \sin(\alpha) \\ -w & \frac{-R}{L} & 0 & k_1 \cos(\alpha) \\ 0 & 0 & \frac{-R}{L} & 0 \\ \frac{3}{2} k_2 \cos(\alpha) & -\frac{3}{2} k_2 \cos(\alpha) & 0 & 0 \end{bmatrix}$$

$$B_{dqo} = \begin{bmatrix} \frac{1}{L} & 0 & 0 & 0 \\ 0 & \frac{1}{L} & 0 & 0 \\ 0 & 0 & \frac{1}{L} & 0 \\ 0 & 0 & 0 & \frac{1}{C} \end{bmatrix}$$

4. SIMULATIONS AND RESULTS

The power grid in Fig. 7 represents a 500 kV system with a 100 MVAR StatCom embedded with the purpose of regulating the voltage at bus B3.

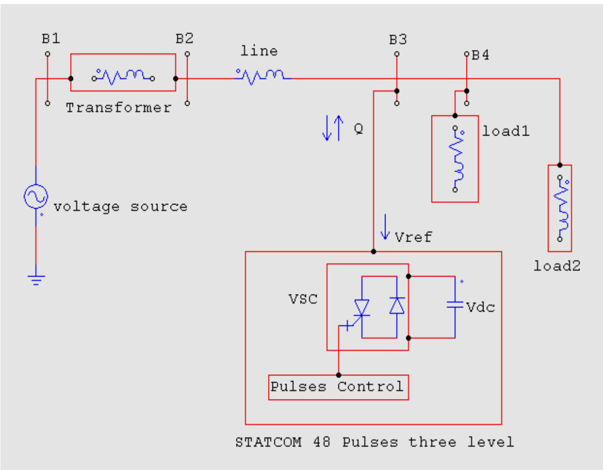

Fig. 7. 48-pulses StatCom connected at bus 3 (B3).

The dynamic response of several important signals are displayed in Figs. 8-11.

The bus voltage B3 is 1.0 p.u when the StatCom is out of service. If the reference voltage Vref is set to 1.0 p.u., the StatCom doesn't exhibit current interchange, Fig. 8. The DC voltage is 19.3 kV, Fig. 11. At t = 0.1 s, the voltage source is suddenly decreased to 0.955 p.u. The StatCom reacts by generating reactive power (Q=+70 Mvar), Fig. 10, and the DC voltage increases, Fig. 11.

Then, at t=0.2 s the voltage source is increased to 1.045 p.u, Fig. 9. The StatCom

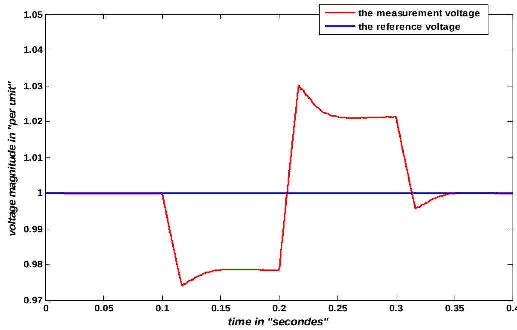

Fig. 8. Voltage measurement.

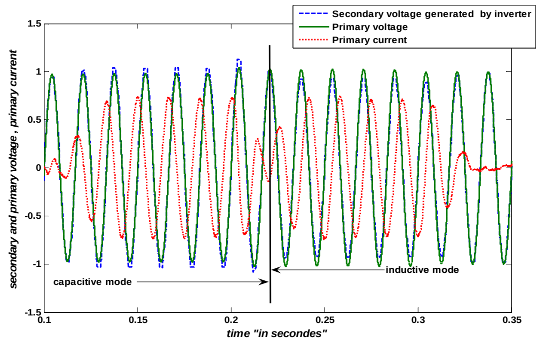

Fig. 9. The dynamic response of StatCom's voltage.

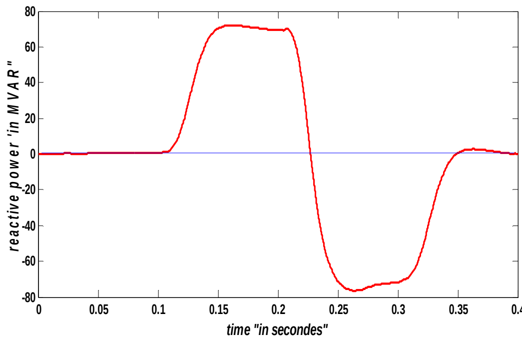

Fig. 10. Change of reactive power.

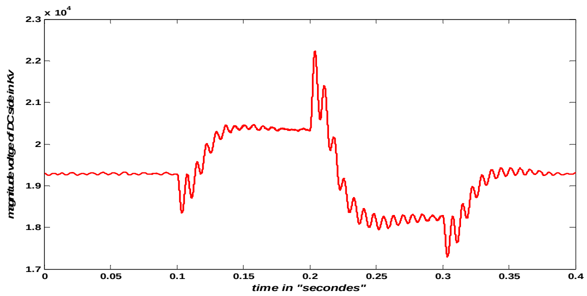

Fig. 11. DC voltage behavior.

reacts by changing its operating point from capacitive to inductive to keep voltage at 1.021 p.u. At this point the StatCom absorbs 72 Mvar, and the DC voltage has been lowered to 18.2 kV.

Finally, at t=0.3 s the voltage source is set back to its nominal value, and the StatCom operating point comes back to zero Mvar interchange.

5. CONCLUSIONS

The StatCom is a shunt device used to help in improve the voltage profile in the transmission system. It functions generating or absorbing reactive power through a voltage source converter. Its simplest configuration is the six-pulses converter. However, multi-pulses configuration are able to generate voltage waveforms with a reduced harmonic content ; thus, filters are not required.

The StatCom's dynamic response is fast and able to pass from a capacitive mode of operation to an inductive one, in a few cycles. When the AC voltage decreases, the StatCom reacts by generating reactive power, so the DC voltage increases ; this is the capacitive mode. On the other henad, when the AC voltage increases, the StatCom reacts by absorbing reactive power, so the DC voltage decreased ; this is the inductive mode.

6. REFERENCES :

1. Ricardo Dávalos Marín « *Detailed analysis of a multi-pulse StatCom* » Pre-doctoral thesis, May 2003. available http://www.gdl.cinvestav.mx/jramirezRaymond Senzo Mkhize, Professor B.S. Rigby « *DSP-Based control of a StatCom* » Final Repor, university of kwazulu-natal faculty of engineering, november 2006.Vijay K. Sood, M.A. Pai and Ale Stankovic, «*HVDC and controllers facts applications of static converter in power system* » Klower power electronics and power system series, ISBN 1-4020-7891-9, 2004 Kluwer academic publisher TLFe book.
4. M.G. Molina and P.E. Mercado « *The Real Time Digital Simulation of a Single Phase Voltage Source Converter and its Application* » paper International Conference on Power Systems Transients - IPST 2003 in New Orleans, USA.
5. M.S. El-Moursi. A.M. Sharaf « Novel reactive power controllers for the StatCom and SSSC », *Electric Power.*
6. Eskandar Gholipour Shahraki « *Apport de l'UPFC à l'amélioration de la stabilité transitoire des réseaux électriques* » thesis, Henri Poincaré, Nancy-I university, October 2003.
7. Edvina Uzunovic « *EMTP, Transient Stability and Power Flow Models and Control of VSC Based Facts controllers* » thesis 2001.
8. M.G. Molina and P.E. Mercado « *Controlling a static synchronous compensator with superconducting magnetic energy storage for applications on primary frequency control* », Latin American Applied Research argentina 2004.
9. Iswaran Sothandara Kumar «*flexible alternating current transmission systems: static synchronous compensator (statcom)* » thesis Curtin University of Technology, Western Australia, November 2005.
10. yakoub khadidja « Reduction of effects of the zero sequence voltage in the association of inverter multilevel applied to induction motor » thesis at Batna university, Algeria, 2005.

Samir HADJERI

Intelligent Control and Electrical Power Systems Laboratory ICEPS

Fatiha GHEZAL
Sid-Ahmed ZIDI

Electrical Engineering Departement
Djillali Liabes university
Sidi Bel Abbes, Algeria

Samir HADJERI: He received the diploma of Electrotechnical Engineering degree from the University of Science and Technology of Oran, Algeria. Received the Master's degrees in Electrical Engineering from the University of Laval, Quebec, Canada, in 1990. The PhD from the UDL, SBA, Algeria, in 2003. He was a teaching member. E-mail : shadjeri@univ-sba.dz shadjeri2@yahoo.fr.

Fatiha GHEZAL: Was born in SBA, Algeria. She received the diploma of Electro technical Engineering degree from the UDL, SBA, Algeria. Where she prepare her Magister.
E-mail: nour73_fac@yahoo.fr.

Sid-Ahmed ZIDI: He received the diploma of Electrotechnical Engineering degree from the University of Science and Technology of Oran, Algeria. The Master degree, from the UDL of Sidi Bel-Abbes, Algeria in 1994. The PhD degrees from the University of Sidi-Bel-Abbés, Algeria, in 2005. He is currently interested by the HVDC link, HVDC Light and transient in power systems. E-mail: sazidi@univ-sba.dz sbzidi@yahoo.fr.