DIGITAL SIMULATION OF MULTILEVEL INVERTER BASED STATCOM

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ABSTRACT

This paper deals with simulation of STATCOM used for harmonic reduction with the aid of multilevel VSI circuit. The harmonics in STATCOM due to the voltage ripple are reduced. As a result, the size of inductor and DC capacitor can be reduced. The STATCOM has the great advantage of a fewer number of devices. The VSI is extremely fast in response to reactive power change. The simulation of the STATCOM is performed in the Simulink environment and the results are presented.

Keywords: STATCOM, DC Capacitor, Voltage Ripple

I. INTRODUCTION

A Flexible AC Transmission System (FACTS) is an AC transmission system incorporating power electronic-based or other static controllers which provide better power flow control and enhanced dynamic stability by control of one or more ac transmission system parameters (voltage, phase angle. and impedance) The STATCOM is traditionally modeled for power flow analysis as a PV or PQ bus depending on its primary application. The active power is either set to zero (neglecting the STATCOM losses) or calculated iteratively.

The STATCOM voltage and reactive power compensation are usually related through the magnetic of the STATCOM. This traditional power flow model of the STATCOM neglects the impact of the high frequency effects and the switching characteristics of the power electronics on the active power losses and the reactive power injection (absorption). The STATCOM used to regulate voltage and to improve dynamic stability. There are some variations of the STATCOM. It is composed of inverters with a capacitor in its dc side, coupling transformer, and a control system. The inverters are, in conventional STATCOM's, switched with a single pulse per period and the transformers are connected in order to provide harmonic minimization. The equipment action is made through the continuous and quick control of capacitive or inductive reactive power. Its output voltage is a waveform composed of pulses that approaches a sinusoidal wave.

II. STATCOM & ITS OPERATING PRINCIPLE

The STATCOM is basically a DC-AC voltage source converter with an energy storage unit, usually a DC capacitor. It operates as a controlled Synchronous Voltage Source (SVS) connected to the line through a coupling transformer. Fig. 1 shows the schematic configuration of STATCOM. The controlled output voltage is maintained in phase with the line voltage, and can be controlled to draw either capacitive or inductive current from the line in a similar manner of a synchronous condenser, but much more rapidly.

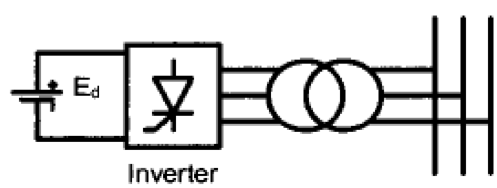

Fig. 1 Schematic configuration of STATCOM

STATCOM has the ability to maintain full capacitive output current at low system voltage, which also improving the transient stability.

A Phase-shifted Unipolar SPWM switching scheme is proposed to operate the switches in the system. The scheme which is a slightly modified version of phase-shifted SPWM. The switching frequency of the individual switch is 1 kHz. The harmonics of the STATCOM output voltage only appear around 6 kHz, 12 kHz and so on.

Basically, a STATCOM output voltage always contains harmonics, due to the switching behavior of the VSI. These voltage harmonics will generate harmonic currents and further cause power losses in the system network. If the impedance of the lines that connect a STATCOM to the power system is neglected, the harmonic losses are primarily apparent on the connection transformer. The effect of these losses in the transformer can by analyzed by considering an expansion of the transformer impedance.

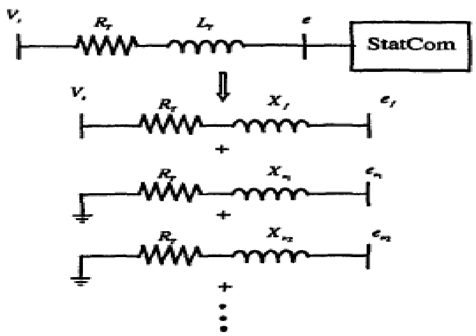

Fig.2. STATCOM Model for Harmonic losses

Fig.2 shows the circuit of a STATCOM connected to a power system by a connection transformer, where V, and e represent the system RMS voltage and the STATCOM's RMS output potential respectively, and RT and 4 denote the resistance and leakage reactance of the connection transformer. Assuming that there are not any harmonics in the system voltage V,, the STATCOM's output voltage e consists of fundamental and high-order harmonics, and may be represented as:

$$e = e_f + e_{n1} + e_{n2} + \dots\dots\dots$$

$$= e_f + \sum_{i=n1,n2\dots} e_i \qquad (1)$$

where e_f, is the RMS value of the fundamental harmonic, e, represents the RMS values of high-order harmonics, and n_1, n_2 *are* the harmonic indices. Thus, the first diagram of Fig 2 can be represented as the sum of the other harmonic diagrams

$$P_{loss} = P_{fundamental} + P_{harmonics}$$

(where X_f, X_{n1}, X_{n2}….denote the transformer's inductance under different harmonic frequencies). The harmonic losses on the connection transformer can be expressed as:

$$= P_{fundamental} + \sum_{i=n1,n2} \frac{e_i^{\,2} * R}{R^2 + X_f^{\,2}} \qquad (2)$$

$$= P_{fundamental} + \sum_{i=n1,n2} \frac{e_i^{\,2} * R}{R^2 + i^2 X_f^{\,2}}$$

Usually, the magnitude of a STATCOM's output voltage relates to the STATCOM's DC side voltage and the conduction mode of h e STATCOM's VSI. For example, if the VSI applies the square wave conduction mode, the output voltage magnitude is a function of the DC side voltage and the firing angles of the VSI. If the PWM mode is used, the output voltage magnitude is a function of the DC side voltage and the duty cycle ratio of the PWM. In the following parts of this paper all derivations will be based on PWM assumption. Therefore using PWM, the output voltage magnitude of the Statcom can be expressed as

$$e_i = f_i(V_{dc}, K) \qquad where\ i = n_1, n_2 \dots\dots \qquad (3)$$

where K is the duty cycle ratio. Since, e, is directly proportional to the DC side voltage V, , equation (3) can be simplified as

$$e_i = V_{dc} * f_i(K) \qquad where\ i = n_1, n_2 \dots\dots \qquad (4)$$

Substituting equation (4) into equation (2), the losses caused by the high order harmonics can be expressed as

$$P_{harmonics} = V_{dc}^{\,2} + \sum_{i=n1,n2} \frac{f_i^{\,2}(K) * R_r^{\,2}}{R^2 + i^2 X_f^{\,2}} \qquad (5)$$

Where

$$\frac{1}{R_h} = \sum_{i=n1,n2} \frac{f_i^{\,2}(K) * R_r^{\,2}}{R^2 + i^2 X_f^{\,2}} \qquad (6)$$

From equation *(6)* it can be seen that the high order harmonic losses relate to the STATCOM's operating point and vary with the duty cycle ratio. Typically, when a STATCOM is in steady-state operation, the duty cycle ratio does not change or changes in a very limit range. The STATCOM's output reactive power is regulated through firing angle change. Then R_h is treated as a constant. Equation *(5)* also implies that the high order harmonic losses can be equivalently represented as the active power losses caused by a DC side shunt resistor.

(i) Control of Reactive power

It is well known that the amount and type (capacitive or inductive) of reactive power

exchange between the STATCOM and the system can be adjusted by controlling the magnitude of STATCOM output voltage with respect to that of system voltage. The reactive power supplied by the STATCOM is given by Equation (7) below,

$$Q = \frac{V_{STATCOM} - V_s}{X} V_s \qquad (7)$$

Where $V_{STATCOM}$,, and V, are the magnitudes of STATCOM output voltage and system voltage respectively and X is the equivalent impedance between STATCOM and the system. When Q is positive, the STATCOM supplies reactive power to the system. Otherwise, the STATCOM absorbs reactive power from the system.

Since the modulating signals are the same for the inverters in the system, the fundamental component of the STATCOM output voltage is N times of that of each inverter, provided that the voltage across the DC capacitor of each inverter is the same. As a result, the STATCOM output voltage can be controlled by the Modulating Index (Ma). $V_{STATCOM}$ is proportional to m_a, as long as the individual inverter is in the linear modulating region. Due to its ability to control the output voltage by the modulating index, the proposed STATCOM has extreme fast dynamic response to system reactive power demand.

(ii) Control of DC capacitor voltage

If all the components were ideal and the STATCOM output voltage were exactly in phase with the system voltage, there would have been no real power exchange between STATCOM and system therefore the voltages across the DC capacitors would have been able to sustain. However, a slight phase difference between the system voltage and the STATCOM output voltage is always needed to supply a small amount of real power to the STATCOM to compensate the component loss so that the DC capacitor voltages can be maintained. This slight phase difference is achieved by adjusting the phase angle of the sinusoidal modulating signal. If the real power delivered to the STATCOM is more than its total component loss, the DC capacitor voltage will rise, and vice versa. The real power exchange between STATCOM and the system is described by Equation (8) below,

$$P = \frac{V_s V_{STATCOM}}{X} \sin(\delta) \qquad (8)$$

where δ is the phase angle difference between STATCOM voltage and the system voltage

III. RIPPLE OF DC CAPACITOR VOLTAGES & SIZING OF THE DC CAPACITOR

DC capacitors not only play an important role in STATCOM system performance, but comprise a big chunk of the total system cost as well. Hence, proper sizing of the DC capacitors is essential to the low system cost and high performance of the proposed STATCOM.

(a) DC Capacitor Voltage

Under the assumptions that 1) the harmonic components centered around switching frequency and its multiples are negligible; 2) the DC capacitor voltage ripple is small and 3) system voltage e(t) is sinusoidal, we have in steady state, the following equations.

$$sw(t) = m_a \sin\omega t \qquad (9)$$

$$i_L(t) = I \sin(\omega t + \varphi_i) \qquad (10)$$

In the above equations, *I* is the inductor peak current, m_a is the Modulating Index (MI), and $\Phi i = 90°$ when the resistor R approaches zero. Equations (3) (5) and (6) result in Equation (11) below

$$V_c(t) = V_{DC} + \frac{1}{4\omega C} m_a Im \cos 2\omega t \qquad (11)$$

(b) Sizing of the DC Capacitors

From Equation (8), once the ripple value is specified, the size of DC capacitor can be calculated by equation (9) below.

$$C = \frac{m_a I}{2\omega \Delta V_c} \qquad (12)$$

To keep the ripple voltage within the specified value in the full range of reactive power of the STATCOM, m_a in Equation (12) should be set to 1.

IV. REJECTION OF CURRENT HARMONICS CAUSED BY DC CAPACITOR VOLTAGE RIPPLE

We know that the DC capacitor voltage ripple will cause inductor current *iL* to have third order harmonic component. If this harmonic component can be rejected, the size of the inductor L and DC capacitors can be further reduced.

A technique to reject harmonic caused by DC voltage ripple, where the DC voltage ripple is independent of the inverter current. Unfortunately, the DC voltage ripple is proportional to the inverter current in the proposed STATCOM. In Equation (4), if the switching function can be expressed by Equation (1 3) below the inductor current will be pure sinusoidal. Equations (3) (6) and (10) will result in Equations (1 4) and (15) below,

$$sw(t) = \pm \frac{V_{STATCOM}\ sin\omega t}{V_c(t)} \qquad (13)$$

$$\frac{d(V_c^{\,2})}{d(2\omega t)} = \pm \frac{1}{2\omega C} V_{STATCOM}\ I \cos 2\omega t \qquad (14)$$

Where

$$V_c(t) = V_{DC}\ (1 \pm k \cos 2\omega t)^{\frac{1}{2}} \qquad (15)$$

and

$$k = \frac{m_a I}{2\omega C V_{DC}} \qquad (16)$$

$$m_a = V_{STATCOM} / V_{DC}$$

As we can see, Equation (8) is the first order approximation of Equation (12). From Equations (10) (12) and (14), we have Equation (1 7).

$$sw(t) = m_a\ sin\omega t\,(1 \pm k \cos 2\omega t)^{\frac{1}{2}} \qquad (17)$$

Instead of m_a sinωt, a slightly modified version, i.e. , Equation (17), is chosen as the modulating signal. In this case, the inductor current will have no low order harmonic components.

Another option to reject the harmonic component is to use equation (10) directly as the modulating signal. Since the DC voltage ripple frequency is much lower compared to the resultant STATCOM switching frequency (2Nf,), the switching function will approach Equation (l6), if Equation (10) is used as the modulating signal.

V. SIMULATION RESULTS

Matlab model of two bus system with STATCOM is shown in Fig 3a. Multilevel inverter is represented as a sub system. Three level inverter is represented as a sub system. Three level inverter circuit is shown in Fig 3b. Injected voltage, voltage across loads 1 & 2 are shown in Fig 3c. The frequency spectrum for the injected voltage is shown in Fig 3d. It can be seen that the voltage across loads 1 & 2 reaches normal value due to the voltage injection.

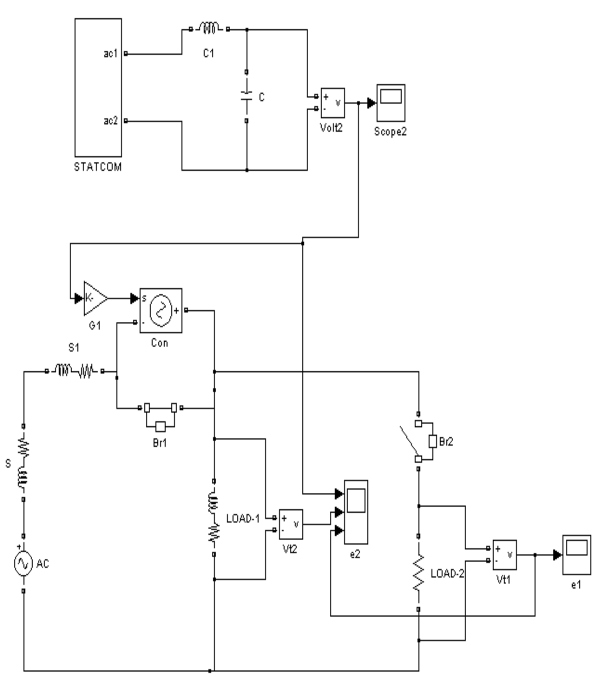

Fig 3a Model of a 2 Bus with STATCOM

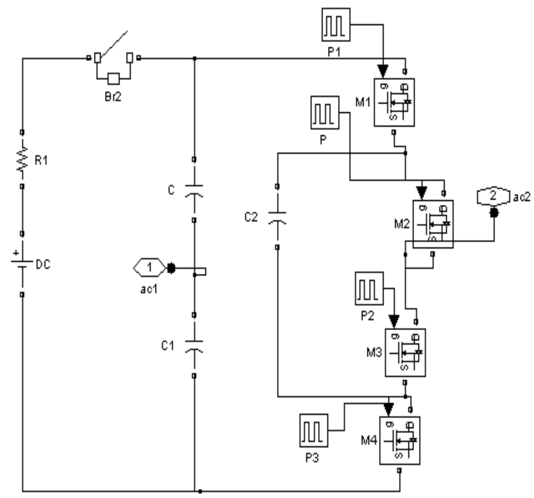

Fig 3b   Three Level Inverter

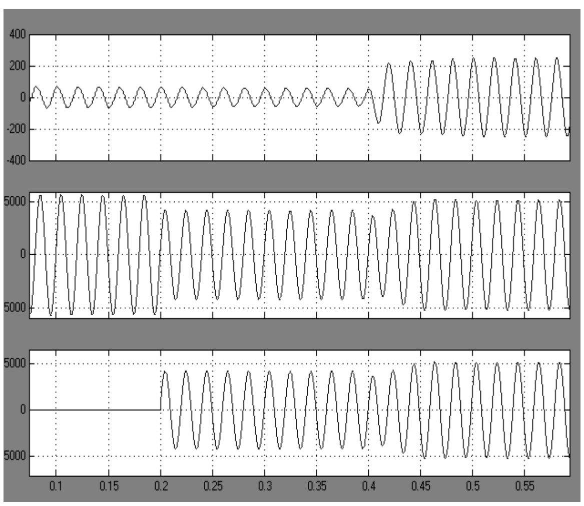

Fig 3c   Voltage across external, load-1 &load-2 waveforms

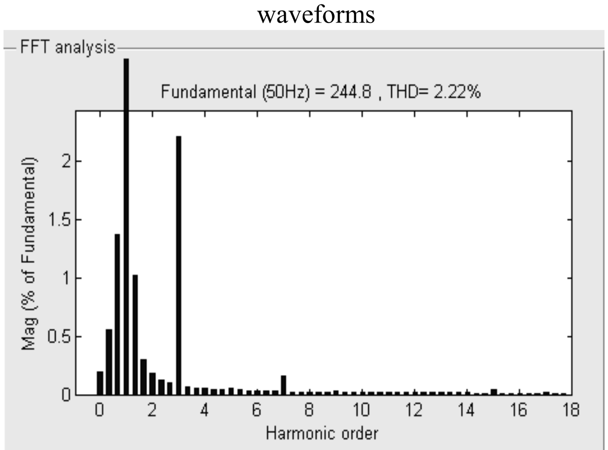

Fig 3d   Frequency Spectrum

VI. CONCLUSION

Multilevel inverter based STATCOM is modelled and simulated using the blocks of Simulink. This work has proposed a multilevel inverter for the reduction of harmonics in the receiving end voltage. The simulation is based on the assumption of balanced load. Single phase circuit model is considered for simulation studies. Simulation results are presented and they are in line with the predictions.

REFERENCES:

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

[2] Yong Hua Song, Allan T.Johns, Flexible AC transmission systems FACTS. IEE Power and Energy Series 30, 1999.

[3] R.Mohan and R.K.Varma, "*Thyristor-Based FACTS Controllers for Electrical Transmission Systems,"* Pisctaway, NJ: IEEE Press, 2002..

[4] 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

[5] P.Giroux, G.Sybille, and H.Le-Huy, "Modeling and simulation of a distribution STATCOM using simulink's power system blockset," in *Proc. Annu. Conf. IEEE Industrial Electronics Society – 2001*, pp. 990–994.

[6] R.Mohan and R.K.Varma, *Thyristor-Based FACTS Controllers for Electrical Transmission Systems,* Pisctaway, NJ: IEEE Press, 2002.

[7] F. Z. Peng and J. S. Lai, "A multilevel voltage-source inverter with separate DC sources for static var generation," *IEEE Trans. Ind. Applicat.*, vol. 32, pp. 1130–1138, Sept./Oct. 1996.

[8] Q.Yu, P.Li, and Wenhua, "Overview of STATCOM technologies," in *proc. IEEE Int. Conf. IEEE Industrial Electric Utility Deregulation, Restructing, Power Technologies,* Hong Kong, Apr. 2004, pp 647-652.

[9] Y. Chen *et al*., "Regulating and equalizing DC capacitance voltages in multilevel STATCOM," *IEEE Trans. Power Delivery*, vol. 12, pp. 901–907, Apr. 1997.

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