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Analysis, Simulation and Comparison of Conventional and SVPWM on STATCOM Operation with Linear loads

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Abstract: In this paper the concept of SVPWM (Space Vector Pulse Width Modulation) is extended, in principle, for the inverter switching of a STATCOM (STATic synchronous COMpensator). As an important element of the STATCOM, the passive component plays an indispensable role in the process of active and reactive energy storing and exchanging. However the coupling of the AC inductance and DC capacitance may lead harmonic DC voltage or AC current at the output. The paper focuses the effect of increased modulation index and lower harmonic distortion has been studied through simulation w.r.t. different performance indices and dynamic response of relevant variables. A proportional integral controller has also been designed for closed-loop control of the system.

Keywords:- STATCOM,SPWM,SVPWM and PI-controller.

I.INTRODUCTION

Reactive power compensation and control has been recognized [1] as an efficient & economic means of increasing power system transmission capability and voltage stability. Capacitor banks, synchronous condensers and inductors were used to supply reactive power to the interconnected system. Power electronic devices later replaced these, namely, TCR (Thyristor controlled Rectifier) with fixed or thyristor switched capacitors. In the same line STATCOM is introduced to as a static replacement of synchronous condenser. Since its introduction some ten years ago, the GTO based static synchronous compensator (STATCOM) has shown more and more evidences, both in theory and practice, of the benefits it can bring to power systems [2] But the present paper employes VSI (voltage source converters) along with IGBT switches. The field current of the synchronous motor controls the amount of VAR absorbed/injected by the same. Similarly the firing angles of instants of the 3-phase inverter control the VAR flow into or out of the STATCOM. So STATCOM may supply as well as absorb reactive power as and when required. In [3] Moran et. al have shown in details how the utilization of SPWM (Sine Pulse Width Modulation) techniques reduce the harmonic distortion. It has also been shown that an increase of modulation index reduces the size of the link reactor and stress on switches, which are the significant issues in respect of practical implementation. Further in [4] Draon et. al have modelled the ASVC(Advanced Static Var Compensator) with SPWM technique to show that a higher modulation index improves the dynamic response of the system and reduces the size of the steady state voltage required on the d.c. link capacitor. However SPWM has its known limitations in the overmodulation range. More importantly the SVPWM gives a much more modulation factor in the undermodulation as well as the over-modulation range i. e. a much higher fundamental content. No bulky capacitor bank or any other passive element is required for its operation. Only a small capacitor provides the required inverter voltage. PWM (Pulse Width Modulation) converters with high switching frequency for VAR compensation is reported in [5]. Hence STATCOM can be regarded as an active energy-exchanging device. The main circuit of STATCOM contains inductive and capacitive components, which under certain conditions such as distorted line voltage or nonsinusoidal modulation function, will cause harmonics in DC voltage and AC currents, which may damage the device and also limit the capability of STATCOM.So passive parameters evaluation is of fundamental importance in design process of STATCOM. This paper focuses on designing of inductor on the basis of increasing of modulation index. It is arranged as follows. The SVPWM technology and its operation is described in Section II and Section III describes in detail the simplified mathematical model of STATCOM in synchronous frame. The steady state and transient response are described in Section IV. The closed loop control is the subject matter of Section V.

II. SVPWM

The operation of STATCOM is based on principle of Pulse Width Modulation (PWM) and it is described as a circuit model of a single-phase inverter with a centre-taped grounded DC bus is illustrated in Fig.1.Fig.2 illustrates the principle of pulse width modulation. It is depicted from Fig.2, the inverter output voltage is determined in the following:

$$\text{When } V_{control} > V_{tri}, V_{ao} = V_{dc}/2 \quad (1)$$

$$\text{When } V_{control} < V_{tri}, V_{ao} = -V_{dc}/2 \quad (2)$$

The inverter output voltage has the following features:

- PWM frequency is the same as the frequency of V_{tri}.
- Amplitude is controlled by the peak value of $V_{control}$.
- Fundamental frequency is controlled by the frequency of $V_{control}$

Modulation index (m) is defined as

$$m = \frac{v_{control}}{v_{tri}} = \frac{(V_{ao})_1}{V_{dc}/2} \quad (3)$$

Where, $(V_{ao})_1$ is the fundamental frequency component of peak of V_{ao}

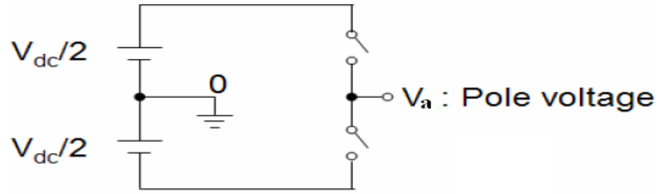

Fig.1: Circuit model of a single-phase inverter

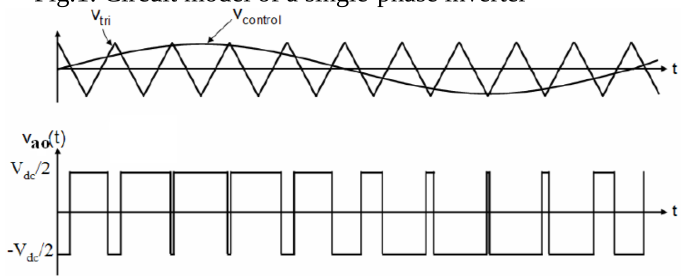

Fig.2: Pulse width modulation

The circuit model of a 3-phase voltage source PWM converter based STATCOM is given in Fig.1 It is of six power switches (IGBT based) as shown in that figure. When an upper IGBT is switched on, i.e. the output of the switches 1, 3, 5 is 1 and corresponding lower IGBT is switched off, the states of 4, 6, and 2 will be 0. Hence, there are eight possible combinations of on and off patterns of the switches and it produces eight inverter vectors (V_1 to V_0) as shown in Fig.3. Six are non-zero vectors (V_1 to V_6) and two are zero vectors (V_0 and V_7). It has been shown to generate less harmonic distortion in the output voltages and or currents applied to the phases of the load. It provides more efficient use of the DC-link voltage compared with sinusoidal pulse width modulation (SPWM) [15, 16-19] as illustrated in Fig.4.

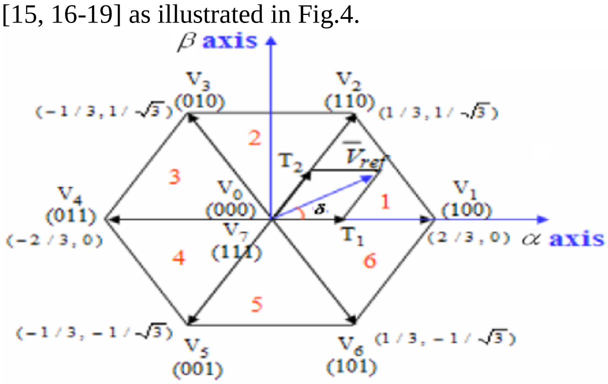

Fig.3: Basic switching vectors and sectors

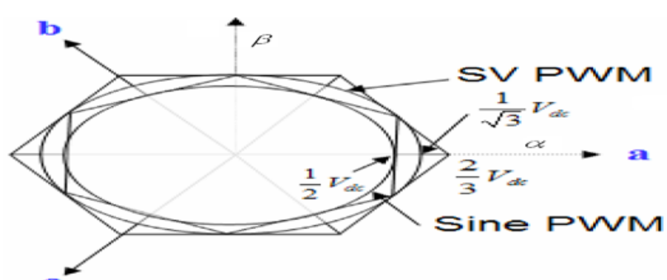

Fig.4 Locus of comparison of SVPWM over SPWM

The switching times are derived using formula

$$T_1 = \frac{\sqrt{3}.T_z.|\overline{V}_{ref}|}{V_{dc}}\left(\sin\left(\frac{\pi}{3} - \delta + \frac{n-1}{3}\pi\right)\right) \quad (4)$$

And $$T_2 = \frac{\sqrt{3}.T_z.|\overline{V}_{ref}|}{V_{dc}}\left(\sin\left(\delta - \frac{n-1}{3}\pi\right)\right) \quad (5)$$

$T_0 = T_z - T_1 - T_2$, where, n=1 through 6 (that is Sector 1 to 6) and $0 \le \delta \le 60^0$ (6)

III. MODELING AND ANALYSIS

A mathematical model is therefore developed as in [2]. After consider Fig.5. The three phase voltages in section A may be written in eq(1) and α being the phase angle between source voltage and the inverter voltage. Transforming to d-q frame using Park's transformation matrix and switching function, we obtain the state space model as shown in eq(2). where, q_c is the reactive power, X the state vector and Y the output.

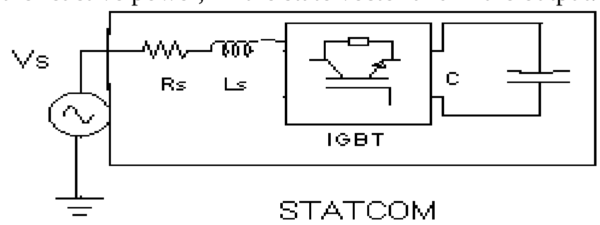

Fig.5: One line diagram of STATCOM

$$\begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} = \sqrt{\frac{2}{3}}V_S \begin{bmatrix} Sin(\omega t - \alpha) \\ Sin(\omega t - \frac{2\pi}{3} - \alpha) \\ Sin(\omega t + \frac{2\pi}{3} - \alpha \end{bmatrix} \quad (6)$$

$$\begin{bmatrix} i_q \\ i_d \\ V_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & -\omega & 0 \\ \omega & -\frac{R_s}{L_s} & -\frac{m}{L_s} \\ 0 & \frac{m}{C} & 0 \end{bmatrix} \begin{bmatrix} i_q \\ i_d \\ V_{dc} \end{bmatrix} + \frac{V_s}{L_s} \begin{bmatrix} -Sin\alpha \\ Cos\alpha \\ 0 \end{bmatrix} \quad (7)$$

$$q_c = V_s[-Cos\alpha \quad Sin\alpha \quad 0]\begin{bmatrix} i_q \\ i_d \\ V_{dc} \end{bmatrix}$$

$$X = \begin{bmatrix} i_q \\ i_d \\ v_{dc} \end{bmatrix}; Y = q_c$$

IV. STEADY STATE RESPONSE

The steady state response of the real and reactive power of the equation (7) is simulated in MATLAB for the system parameters Vs = 220 V, f = 50 Hz, R_s = 1 Ω, L_s = 5 mH, C = 500 μF, m = 1.12/√3 which is shown in Fig.2 where the real and reactive power flowing in or out of the STATCOM is linearly variation w.r.t. α. components. For a given switching frequency it is desirable that the modulation index should be in permissible limit. SPWM can be operated in under and over modulation region but it has its own known disadvantages in the overmodulation range (m ≥ 1). Also the fundamental content is maximum 78.5% at m=1 w.r.t. fundamental content of the square wave inverter but full of more harmonic. If SPWM of lower modulation index applied to the proposed system then couple inductor will be larger in size and steady state and transient response will hamper as shown in Fig.(2) Hence the model has been assumed SVPWM based switching of the inverter. As well known, the space vector modulation involves six effective voltages and two zero vectors as shown in Fig.(3) A reference voltage is composed of time-average components of two effective vectors adjacent to it and one zero vector. The modulation index can be increased up to 0.906 in under modulation where the reference voltage is subjected to trace the interior of the hexagon and it can be also increased up to 0.955 in over modulation in Mode I and up to 1.0 in Mode II. Hence the switching of inverter in SVPWM with higher modulation index decreases the size and weight of the coupling transformer and also dc capacitor. This proposed switching also impacts greatly in transient response of the reactive power in or out which is the main parameter for controlling the system voltage as shown in Fig.(4) and (5). In each case the system attains stable condition after a short transient due to higher modulation index and lower value of inductances.

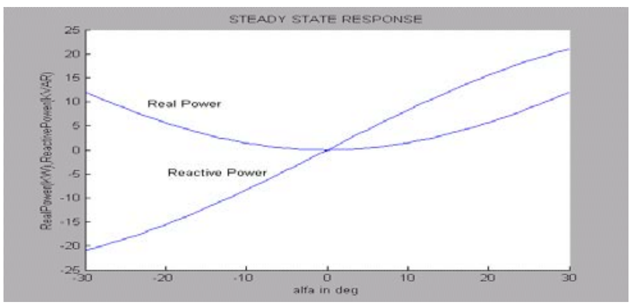

Fig.6:- Real and Reactive power on alfa

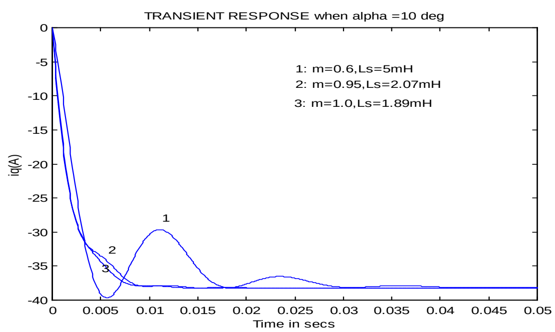

Fig. 7: Transient response of current i_q

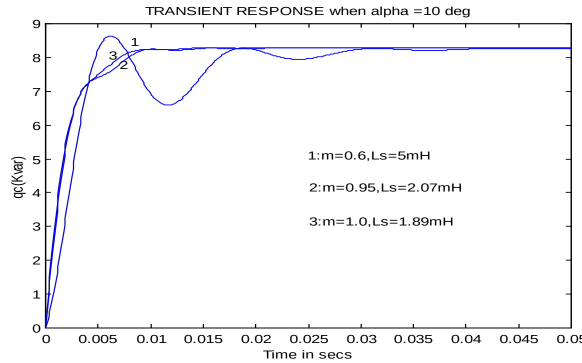

Fig. 8: Transient response of reactive power q_c

V. CLOSED LOOP CONTROL

It may be noted that the state equation (2a) and the output equation (2b) is nonlinear in alfa. To employ the closed-loop control techniques available in literature the above system is linearized about an equilibrium point (X_o, U_o), and the linearized model is given below which considers the perturbation to each state about the operating point. And Δα, a perturbation to α, is the input to the model.

$$\Delta\dot{X} = \begin{bmatrix} \Delta\dot{i}_q \\ \Delta\dot{i}_d \\ \Delta\dot{v}_{dc} \end{bmatrix} = \begin{bmatrix} -\frac{R_s}{L_s} & -\omega & 0 \\ \omega & -\frac{R_s}{L_s} & -\frac{m}{L_s} \\ 0 & \frac{m}{C} & 0 \end{bmatrix} \begin{bmatrix} \Delta i_q \\ \Delta i_d \\ \Delta v_{dc} \end{bmatrix} + \begin{bmatrix} -\frac{v_s}{L_s} \\ 0 \\ 0 \end{bmatrix} \Delta\alpha$$

$$q_c = \begin{bmatrix} -v_s & 0 & 0 \end{bmatrix} \begin{bmatrix} \Delta i_q \\ \Delta i_d \\ \Delta v_{dc} \end{bmatrix}$$

The transfer function of the above model is found out as:

$$G(s) = \frac{\Delta q_c(s)}{\Delta\alpha(s)} = \frac{\frac{V_S^2}{L_S}\left(s^2 + \frac{R_S}{L_S}s + \frac{m^2}{L_S C}\right)}{\left(s^3 + 2s^2\frac{R_S}{L_S} + \left(\omega^2 + \frac{m^2}{L_S C} + \frac{R_S^2}{L_S^2}\right)s + \frac{m^2 R_S}{L_S^2 C}\right)} \quad (8)$$

To improve the transient response of the original model of P-I controller is designed which has the following transfer function:

$$G_{PI}(s) = K\left(1 + \frac{1}{T_i s}\right) \quad (9)$$

The value of K and T_i are chosen suitably to improve the transient response of the system. The closed loop transient response shown in Fig.(9) shows a considerable lowering in the rise time of the dynamic response.

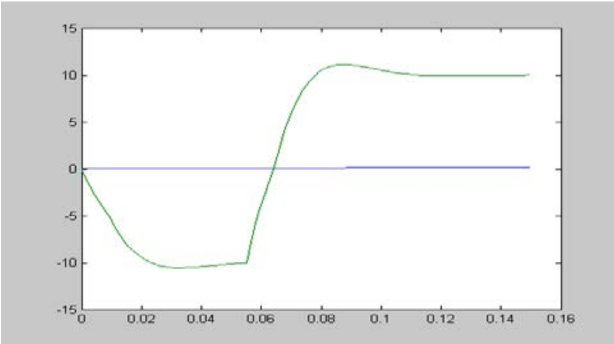

Fig.9:- Simulated reactive power response

VI.CONCLUSION

Complete analysis of the STATCOM is presented based on a state-space model. A PI controller is designed to improve the transient response. The modulation index 'm' is identified as an important parameter that can improve the dynamic response as well as lower the size of the inductor to be used in the system. A novel scheme of employing SVPWM switching of the converter is proposed which will allow use of $m \geq 1$.

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