3-레벨 인버터를 사용한 무효전력 보상기의 모델링, 해석 및 제어기 설계

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MODELING, ANALYSIS AND CONTROL OF STATIC VAR COMPENSATOR USING THREE-LEVEL INVERTER

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Abstract: A new static var compensator(SVC) system using three-level inverter is proposed for high voltage and high power applications. A general and simple model for the overall system is obtained using circuit DQ-transform and DC and AC analyses are achieved to characterize the open-loop system. Using the proposed model, a new control method which controls both the phase angle and modulation index of switching pattern simultaneously is suggested to provide fast response of SVC system without using independent voltage source. Finally, predicted results are verified by computer simulation.

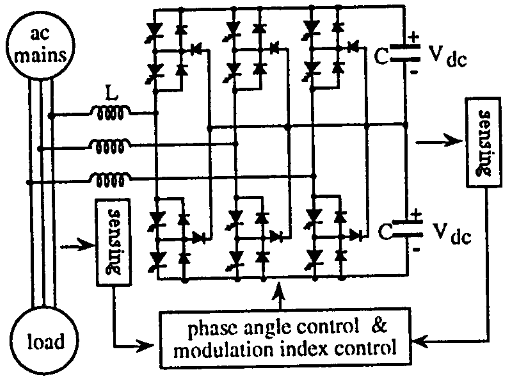


Fig. 1 SVC using 3-level inverter

I. INTRODUCTION

The advantages of introducing force-commutated inverters in reactive power compensation have been confirmed by many researchers. So far, SVC's using 2-level inverter have been proposed[1][2]. Due to the rating restriction of the switching devices in the inverter, it is difficult to apply SVC using 2-level inverter for high voltage and high power[3]. To overcome this disadvantage, SVC system using 3-level inverter instead of 2-level inverter is chosen as shown in Fig. 1 in this paper, because 3-level inverter has lower voltage stress and lower harmonic components and can be operated at lower switching frequency[3].

II. PRINCIPLE OF OPERATION

The operating principle of the SVC system can be explained by considering a voltage source connected to the AC mains through a reactor and a resistor representing the total loss in the inverter as shown in Fig. 2. Fig. 2(b) shows the phasor diagram for leading power factor and Fig. 2(c) for lagging power factor. Fast dynamic response irrespective of dc capacitor in the inverter can be achieved by controlling the phase angle(α) and the modulation

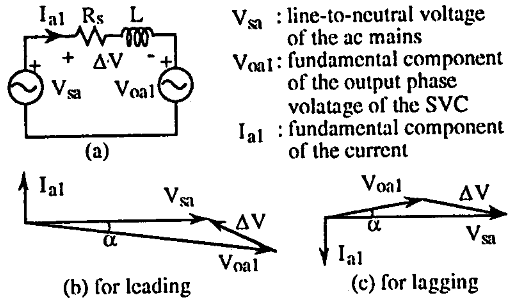


Fig. 2 single-phase equivalent circuit

index(MI) of switching pattern simultaneously. More detailed operation is described by analyzing the equivalent circuit obtained in later section.

III. MODELING

The main circuit of SVC shown in Fig. 3 is modeled in this section. Equivalent circuit is obtained by circuit DQ-transform method[4]. The voltage source, DQ-transform matrix(K) and switching function matrix(S) are given as follows:

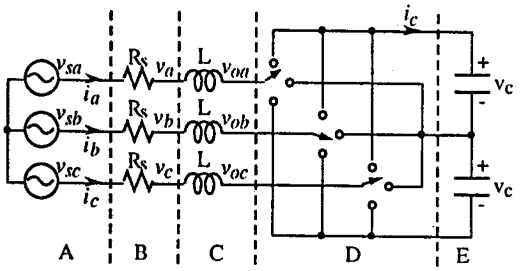


Fig. 3 Main circuit of SVC

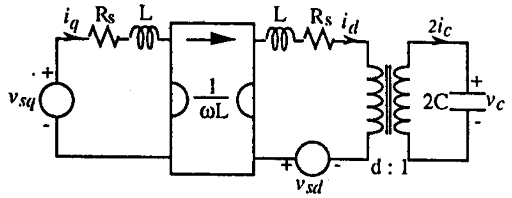


Fig. 4 The equivalent circuit

$$v_{s,abc}=\begin{bmatrix} v_{sa} \\ v_{sb} \\ v_{sc} \end{bmatrix}=\sqrt{\frac{2}{3}}\,V_s\begin{bmatrix} \sin(\omega t) \\ \sin(\omega t-2\pi/3) \\ \sin(\omega t+2\pi/3) \end{bmatrix}, \quad (1)$$

$$K=\sqrt{\frac{2}{3}}\begin{bmatrix} \cos(\omega t+\alpha) & \cos(\omega t+\alpha-2\pi/3) & \cos(\omega t+\alpha+2\pi/3) \\ \sin(\omega t+\alpha) & \sin(\omega t+\alpha-2\pi/3) & \sin(\omega t+\alpha+2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix},$$

$$K^{-1}=K^{T} \quad (2)$$

$$S=\begin{bmatrix} S_a \\ S_b \\ S_c \end{bmatrix}=\sqrt{\frac{2}{3}}\,d\begin{bmatrix} \sin(\omega t+\alpha) \\ \sin(\omega t+\alpha-2\pi/3) \\ \sin(\omega t+\alpha+2\pi/3) \end{bmatrix}. \quad (3)$$

Because the original system is too complex to transform, it is partitioned to several basic sub-circuits as shown in Fig. 3. DQ-transform of a variable in the abc-axis is as below:

$$x_{qdo}=K\,x_{abc}\,.$$

The equivalent circuit obtained by DQ-transform is shown in Fig. 4. The DQ-transformed v_{sq} and v_{sd} is as follows:

$$v_{sq}=-V_s\sin\alpha\,,\quad v_{sd}=V_s\cos\alpha\,.$$

IV. ANALYSIS

A. DC Analysis

The DC analysis can be done the steady-state circuit as shown in Fig. 5 obtained from Fig. 4 by shorting the inductors and opening the capacitor. For given α and D, we obtain

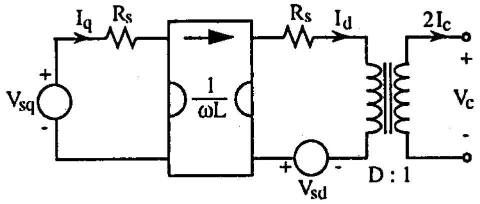


Fig. 5 The equivalent circuit for DC

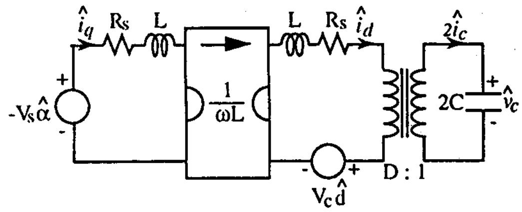


Fig. 6 The equivalent circuit for small signal

$$V_c=\frac{1}{D}\left(V_{sd}+\frac{\omega L}{R_s}V_{sd}\right), \quad (4)$$

$$I_q=V_{sq}/R_s\,,\quad I_d=0\,. \quad (5)$$

B. AC Analysis

To know the dynamic characteristics of SVC system, the small signal analysis is to be done. For a given operating point, small signal equivalent circuit is derived based on the following assumptions:

i) the second order terms (products of variations) are negligible,

ii) the phase angle(α) of switching pattern is small.

With the above assumptions, the small signal equivalent circuit is derived as shown in Fig. 6 from Fig. 4.

From the small signal equivalent circuit shown in Fig. 6, the important transfer functions of the SVC system are given as follows:

$$\frac{\hat{v}_c(s)}{\hat{d}(s)}=-\frac{DV_c(Ls+R_s)}{A(s)} \quad (6)$$

$$\frac{\hat{v}_c(s)}{\hat{\alpha}(s)}=-\frac{DV_s\omega L}{A(s)} \quad (7)$$

$$\frac{\hat{i}_q(s)}{\hat{d}(s)}=\frac{2V_c\omega LCs}{A(s)} \quad (8)$$

where

$$A(s)=2CL^2s^3+4LCR_s\,s^2+\left[2C\left\{R_s^2+(\omega L)^2\right\}+D^2L\right]s+D^2R_s \quad (9)$$

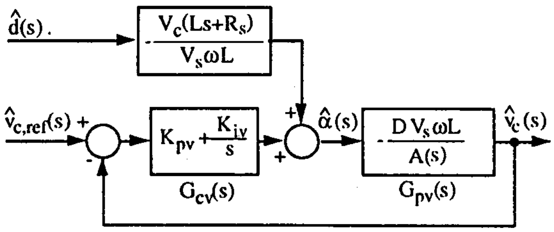
V. CONTROLLER DESIGN

To achieve fast dynamic responseit is required that the capacitor voltage v_c should be kept constant by controlling the phase angle(α) while compensating the load reactive power by controlling the modulation index of switching function simultaneously. From (6) and (7) to make the dc capacitor voltage constant,

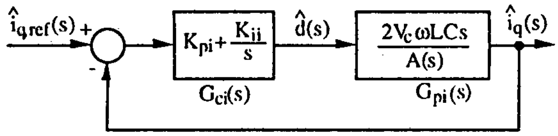
$$\hat{\alpha}(s) = -\frac{V_c(Ls + R_s)}{V_s \omega L}\hat{d}(s) . \qquad (10)$$

The authors propose the PI and feedforward control methods which are shown as follows:

i) phase angle(α) control for keeping constant capacitor voltage,



ii) modulation index(MI) control for compensating load vars simultaneously:



The parameters K_{pv}, K_{iv}, K_{pi} and K_{ii} can be determined by using root-locus technique.

VI. SIMULATION RESULTS

To check the validity of the proposed control method, computer simulation is done using the system parameters given by

L=5mH, R_s=1Ω, C=2000μF, V_s=220V

with the control parameters given by

$K_{pv}=-7\times10^{-3}$, $K_{iv}=-0.45$, $K_{pi}=1\times10^{-4}$, $K_{ii}=0.95$

By the proposed control method, the capacitor voltage is fixed(V_c=225V). Fig. 7 shows the transient response of the total SVC system for a step change in the load power factor. The transient process is completed within one cycle.

VII. CONCLUSION

In this paper, a new static var compensator(SVC) using three-level inverter is proposed. The general and simple model is obtained and analyzed. Using this model, a new control method which controls the phase angle and modulation index simultaneously in the switching pattern is suggested to achieve fast response of SVC system without using additional voltage source.

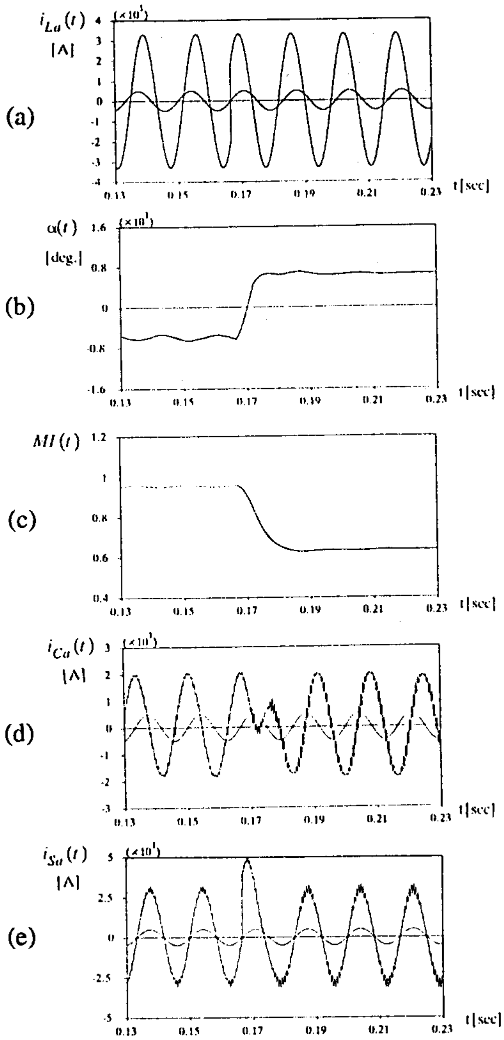


Fig. 7 Response for step change of load current: (a)load current, (b)phase angle, (c)MI, (d)SVC current, (e)sourse current.

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