

# A Control Method for Static VAR Compensator Based On Modular Multilevel Inverter

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**Abstract**—Multilevel inverters are promised to provide a better performance in high power applications such as static VAR compensators. The proposed modular inverter has advantages compared to the conventional technologies. A control system of static VAR compensator using new modular multilevel inverter is proposed in this paper. Modeling and dynamic performance of static VAR compensator based on the proposed multilevel inverter are described in this paper. The inverter switching devices are switched at the fundamental output frequency. How to control the dc capacitor voltage is described. Several simulated results are included to verify the proposed concept.

**Keywords:** Multilevel, inverter, STATCOM

## I. INTRODUCTION

Reactive power compensation plays an important role in power systems. It minimize power transmission losses, maximize power transmission capability, and stabilize the power system[1]-[3]. The compensator using state-of-the-art technology of multilevel inverter had been widely accepted to replace the conventional ones. This kind of static VAR compensator is commonly called as STATCOM. It has been shown in the literature that this kind of static VAR compensator has better performance compared to the one that is based on thyristor technology [3]-[5].

There are various inverter topologies that can be used for static VAR compensators [6]-[14]. The most promising is the one that is based on multilevel inverter systems. By using multilevel techniques, better voltage sharing among the inverter switching devices can be achieved. Moreover, better output voltage waveform can be obtained without sacrificing the system efficiency. In high-power applications, PWM operation is prohibited because of switching losses problems.

The well proven topology that has been installed around the world is the one based on series connection of several three-phase inverters[6]-[12]. The inverter itself is operated under square-wave mode and, therefore, the switching losses are minimum. The inverter outputs are connected in

series by using a special connected three-phase transformers to eliminate low-order harmonics. As the inverters are operated under square-wave mode, the only way to control the output voltage is by controlling the dc capacitor voltage. As the dc capacitance is large, a fast control response is difficult to achieve.

Another topology that has received a great interest in the recent years is the one based on cascaded inverters with separate dc sources [13]-[14]. In this topology, several single-phase full-bridge inverters are connected in series. This kind of inverter able to produce high output voltages without using transformer. The inverter is operated under quasi square-wave mode to control the output voltage. A fast response can be easily obtained as we don't need to control the dc capacitor voltage. The main problem of this STATCOM is controlling each dc capacitor voltage. Many voltage controllers must be installed with the associated complication. Moreover, the required modulation technique makes the utilization factors of each inverter are different.

In the companion paper[15], the authors have proposed a modular multilevel inverter that is suitable for high power applications. The proposed topology is also based on cascaded connection of several single-phase full-bridge inverters. In the proposed system, however, no special transformers are required. Conventional single-phase transformers are used. The proposed topology does not need separate dc sources and, therefore, no complicated dc voltage controllers are required. The use of transformer cannot be considered as a disadvantage because galvanic isolation is a must in high-voltage applications.

Static VAR Compensators (STATCOM) are connected in parallel to the system to control the reactive power. The challenge is to give a fast reactive power compensation with minimum losses and harmonics. Using the modular inverter design, it is possible to achieve those requirements. Fast reactive power can be achieved by controlling the output voltage by changing the gating signals of the

inverters. Minimum harmonics are achieved by controlling the phase differences among the inverters.

Modeling and control techniques of the proposed modular multilevel inverter system that is operated as STATCOM are proposed in this paper. Park transformation is used to simplify the control and to eliminate the steady-state errors. A ten MVAR STATCOM is designed by using the proposed topology. Simulated results are included to show the feasibility of the proposed multilevel inverter system.

## II. PROPOSED STATCOM

Fig. 1 shows the topology of the purposed STATCOM that is discussed in this paper. All single-phase inverter and transformer are identical and, therefore, can be considered as one module. A large dc electrolytic capacitor is connected in parallel on the dc side. IGBTs or IGBTs can be used as the switching devices. In practice, a small LCL filter is usually connected on the ac side to reduce high-order harmonics. In this paper, the effects of this LCL filter is neglected.

Each single-phase full-bridge inverter is operated under quasi square-wave mode as shown in Fig. 2. The rms value of the output voltage is controlled by controlling the  $\beta$  angle. It can be seen that the output voltage varies linearly to cosines of  $\beta/2$ . Instead of controlling the  $\beta$ , it is better to control the cosines of  $\beta/2$ . In order to reduce the low-order harmonics, the phase differences among the inverters must be selected appropriately. For N single-phase inverters in each phase, the phase difference is  $60/N$ . By using N single-phase inverters, the order of harmonics will be

$$h = 6N \pm 1 \quad (1)$$

By using N=5 as shown in Fig. 1, the minimum harmonic order is 29. Fig. 3 shows simulated output voltages of the proposed system.

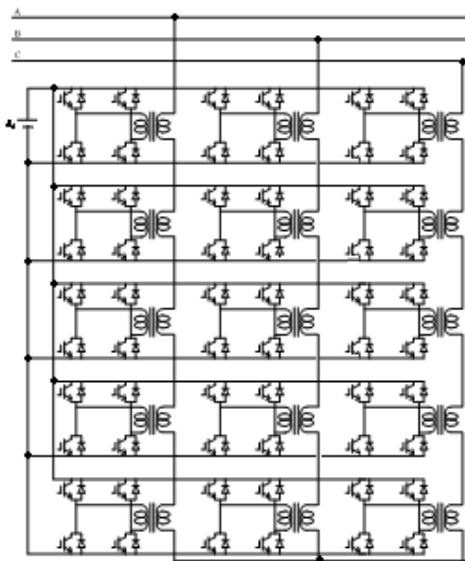


Fig.1. Proposed STATCOM system.

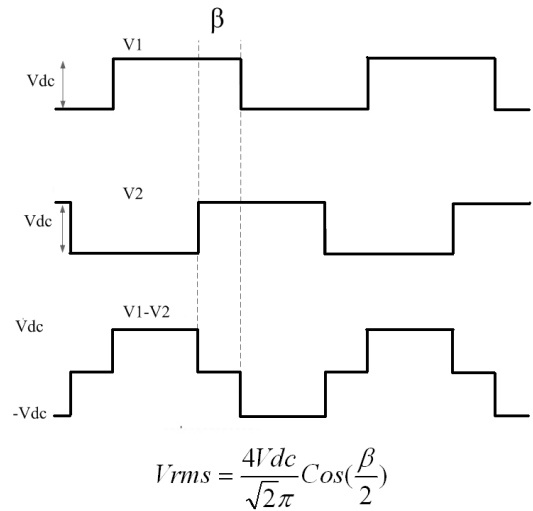


Fig. 2. Voltage control of full bridge inverter.

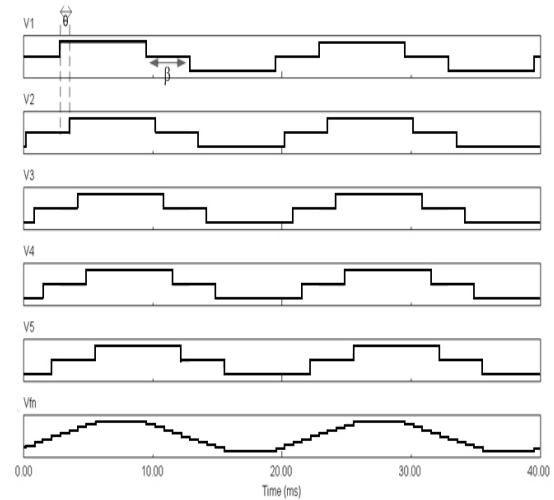


Fig. 3. STATCOM output voltages.

Based on inverter output voltages in Fig. 3, the inverter can be considered as an ideal voltage source. If the magnitude of inverter voltage is greater than the utility voltage then the STATCOM generates lagging reactive current, i.e. acting as a capacitor. On the other hand if the magnitude of inverter voltage is lower than the utility voltage then the STATCOM generates leading reactive current, i.e. acting as a reactor.

## III. DYNAMIC ANALYSIS AND CONTROL

Many approaches have been developed for modeling STATCOM system [16]. The most common method is based on averaging theory. The utility and inverter phase peak voltages can be written as follows:

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

(3)

$$\begin{bmatrix} V_{sd} \\ V_{sq} \\ V_{so} \end{bmatrix} = [M] \begin{bmatrix} V_{sa} \\ V_{sb} \\ V_{sc} \end{bmatrix} \quad (4a)$$

(4a)

$$\frac{\sqrt{2}}{\sqrt{3}} \begin{bmatrix} \cos(\omega t + \alpha) & \cos(\omega t + \alpha - 2\pi/3) & \cos(\omega t + \alpha + 2\pi/3) \\ \sin(\omega t + \alpha) & \sin(\omega t + \alpha - 2\pi/3) & \sin(\omega t + \alpha + 2\pi/3) \\ 1/\sqrt{2} & 1/\sqrt{2} & 1/\sqrt{2} \end{bmatrix} \quad (5)$$
$$L \frac{d}{dt} \begin{bmatrix} I_d \\ I_q \end{bmatrix} + \omega L \begin{bmatrix} -I_d \\ I_q \end{bmatrix} + R \begin{bmatrix} I_d \\ I_q \end{bmatrix} = \begin{bmatrix} V_{sd} - V_{id} \\ V_{sq} - V_{iq} \end{bmatrix} \quad (6)$$
$$\begin{bmatrix} V_{sd} \\ V_{sq} \end{bmatrix} = \begin{bmatrix} V_s \\ 0 \end{bmatrix} \quad (7)$$
$$\begin{bmatrix} V_{id} \\ V_{iq} \end{bmatrix} = \begin{bmatrix} V_i \sin \alpha \\ V_i \cos \alpha \end{bmatrix} \quad (8)$$

Under synchronous reference frame, the instantaneous active and reactive powers can be written as follows:

(9)

(10)

The complete block diagram of the proposed STATCOM controller is shown in Fig. 5. In this controller, we have two reference values, that are dc voltage and q-axis currents. The dc voltage reference value is compared to the actual value. The error is processed by a PI controller to generate the d-axis current reference. The actual d-axis and q-axis currents are compared to the reference values. The errors are processed by PI current controllers. Under synchronous reference frame, balanced and sinusoidal voltages and currents became dc quantities. Thus, PI current controllers result in zero steady-state errors.

The output of the current controllers are the desired d-axis and q-axis inverter output voltages. By using a look up table, the required  $\beta$  and  $\alpha$  angles are determined. For these purposes, the following expressions are used:

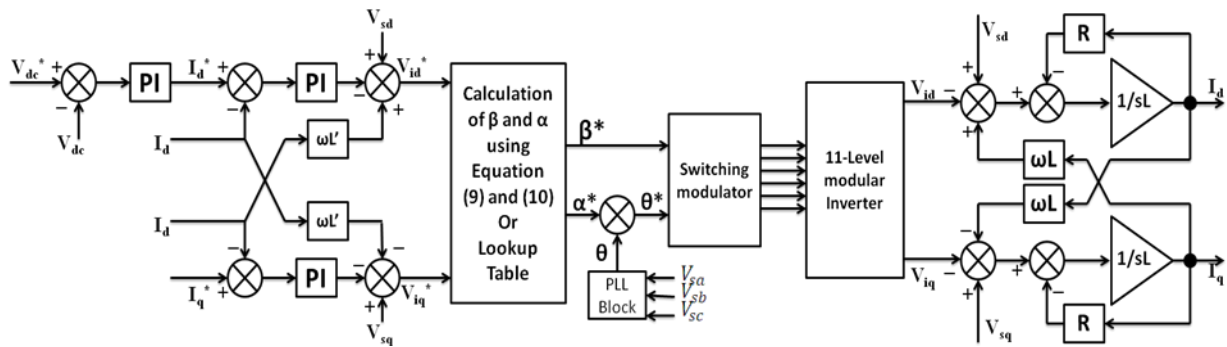
(11)

$$\alpha = \tan^{-1} \left( \frac{V_{iq}^*}{V_{id}^*} \right) \quad (12)$$

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The inverter output voltage must be synchronized to the power grid voltage. For this purpose, a phase locked loop circuit is used as shown in Fig. 5. Based on the information of  $\beta$  and  $\theta$  angles, the gating signals for the inverter can be determined.





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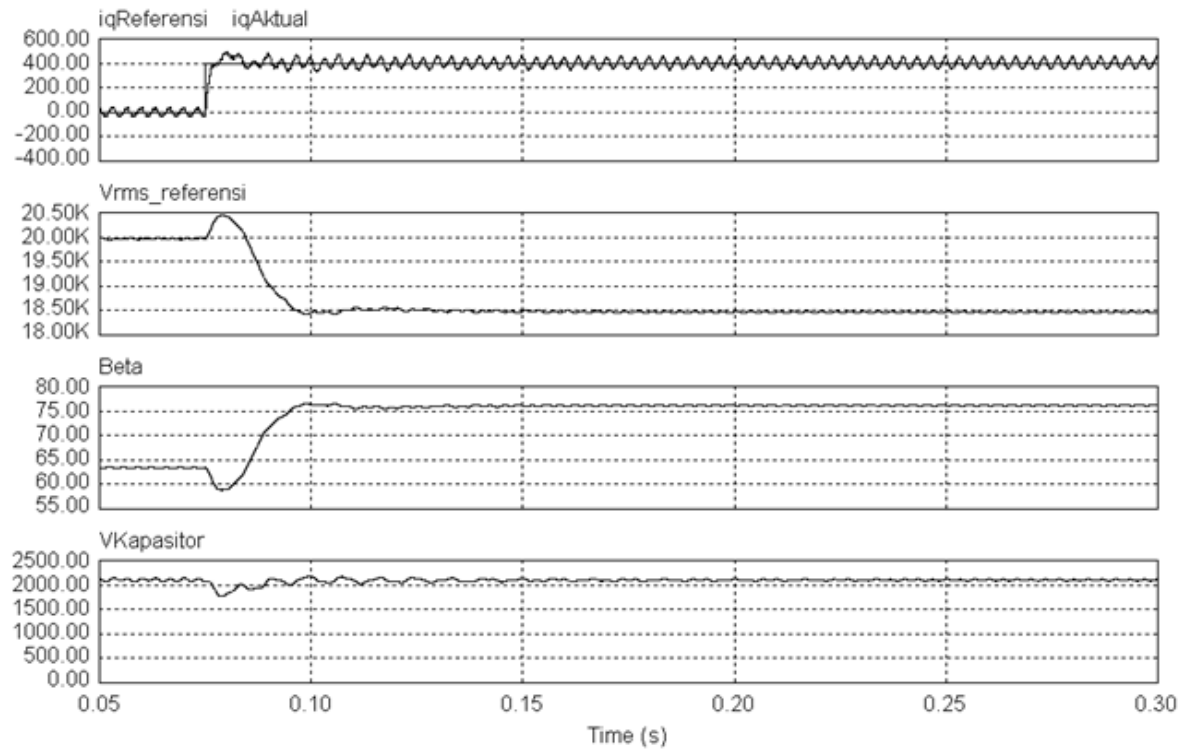


Fig. 6 Lagging operation.

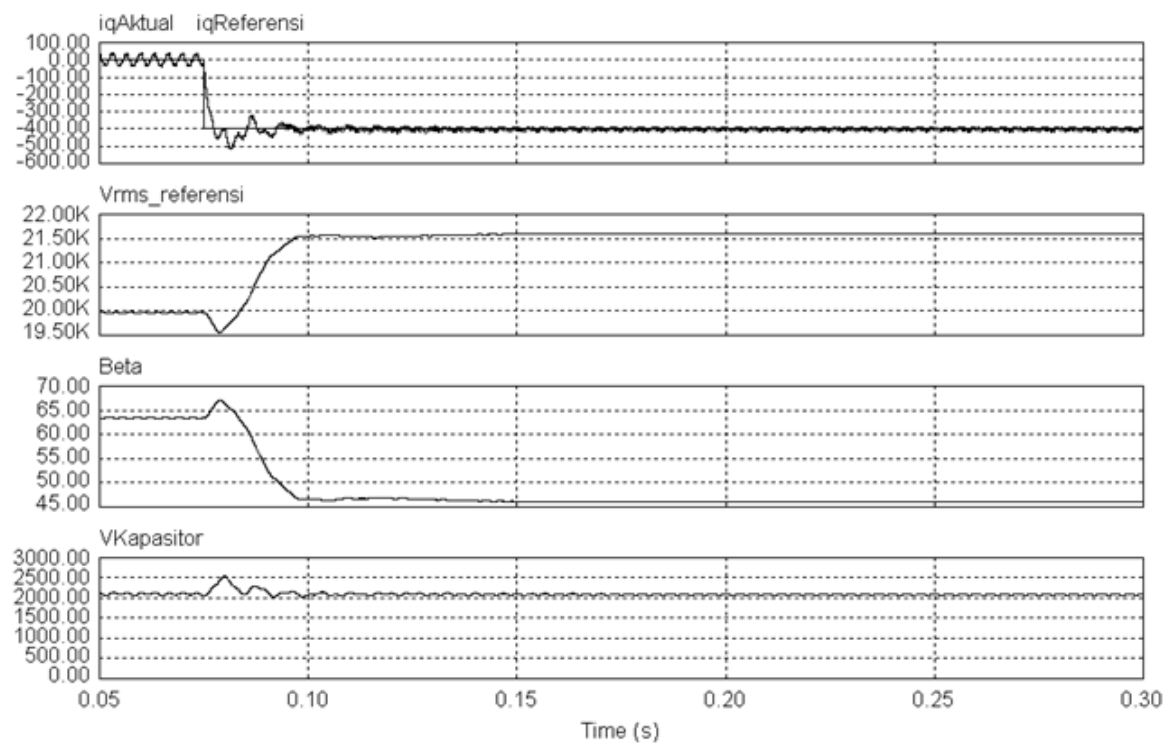


Fig. 7. Leading operation.