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Performance analysis of SSSC based on three-level multi-bridge PWM inverter

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Abstract

This paper describes a static synchronous series compensator (SSSC) based on three-level multi-bridge pulse width modulation inverter. The dynamic characteristic of proposed SSSC was analyzed by simulation with EMTP and experiment with a scaled hardware model, assuming that the SSSC is inserted in the transmission line of one-machine-infinite-bus power system. The proposed SSSC can be directly inserted in the transmission line without coupling transformers, and has flexibility in expanding the operation voltage to increase the number of bridges in series connection.

Keywords: Flexible AC transmission system; Static synchronous compensator; Static synchronous series compensator; Gate turn-off thyristor; Pulse width modulation

1. Introduction

Flexible AC transmission system (FACTS) devices using voltage source inverter with gate turn-off thyristor (GTO) have been studied since the beginning of 1990s. Static synchronous compensator (STATCOM) is the first FACTS device to compensate the reactive power connected in parallel with the power system bus. Although static synchronous series compensator (SSSC) has the same configuration of power circuit as STATCOM, it is connected in series with the transmission line and operated with different control scheme. The function of SSSC is to control the voltage across the transmission line by injecting voltage in series with the transmission line [1,2].

The maximum sustain voltage of currently available GTO for FACTS application is about 5 kV, which is much lower than the operation voltage of power system. In order to solve this problem step-down transformers are used for properly interfacing the FACTS device with the power system, and power converters with series-connected GTO's are used. Although series connection of GTO's is proven technology, there still is restriction in maximum allowable number of units.

Multi-level inverter was proposed to increase the system operation voltage avoiding series connection of switching devices. However, multi-level inverter has complexity in the formation of output voltage and requires many back-connection diodes. In order to complement this weak point, a multi-bridge inverter with pulse amplitude modulation composed of 5 H-bridge modules per phase was proposed by Peng and Lai for STATCOM application [3,4].

In this paper an SSSC composed of six three-level half-bridge modules per phase is proposed. The operation of proposed system is verified through simulations with EMTP and experiments with scaled hardware module [5]. The advantages of proposed system over the existing one are direct insertion in the transmission line without transformers and easy expansion of the output voltage by increasing the number of modules.

2. Operation analysis

SSSC generates and injects in series with the line a balanced three-phase voltage perpendicular to the line current, whose magnitude and phase can be adjusted rapidly by using semiconductor switches. SSSC is composed of a voltage-source inverter with a dc capacitor,

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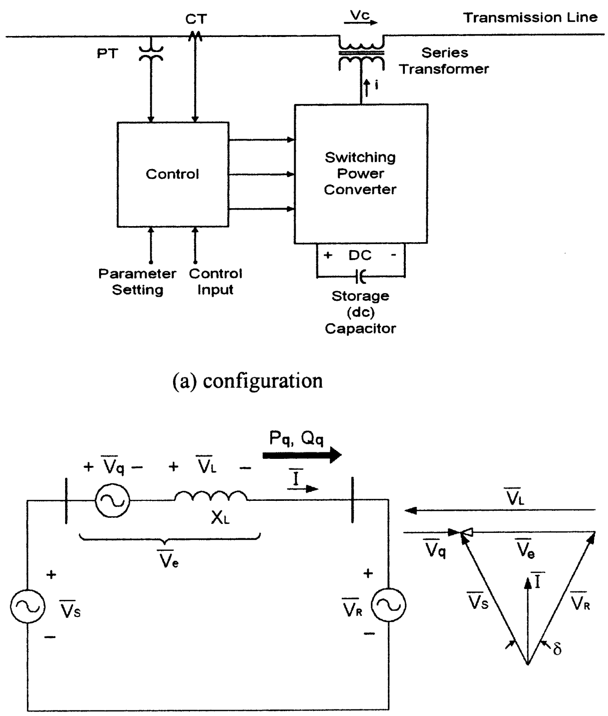


(a) configuration

(b) equivalent ciriuit

Fig. 1. Principle of SSSC operation.

coupling transformer, and control circuit as shown in Fig. 1a.

The output voltage of SSSC can be controlled by changing the firing angle. If the output voltage is lagging the line current by 90°, it supplies a capacitive reactive-power to reduce the line reactance. If leading the line current, it supplies an inductive reactive-power to increase the line reactance.

The operation of SSSC can be explained using an equivalent circuit and phasor diagram shown in Fig. 1b. SSSC is represented with an ac voltage source whose output voltage has 90° phase lead or lag to the line current. SSSC is able to emulate a line-reactance compensator by injecting ac voltage source whose magnitude and sign can be controlled. In the phasor diagram, it is assumed that the phase difference between the sending point and the receiving point is maintained as a constant value of δ.

Table 1
Switching pattern of three-level half-bridge

V1A	Switching state	Mode
$V_{dc}/2$	S1, S2: on and S3, S4: off	M1
0	S2, S3: on and S1, S4: off	M2
	S1, S4: on and S2, S3: off	M3
$-V_{dc}/2$	S3, S4: on and S1, S2: off	M4

Series compensation with SSSC is conceptually similar to that with capacitor, although its compensation characteristic is slightly different. SSSC can inject a voltage without regard to the line current.

From the phase diagram in Fig. 1b, the active power through the transmission line can be expressed by the following equation.

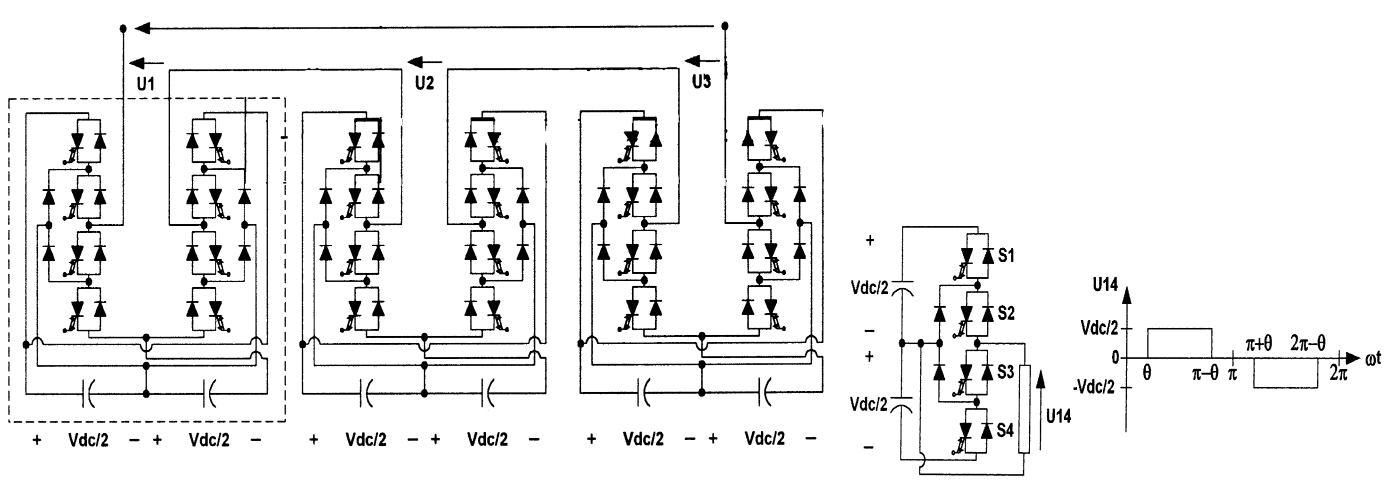
$$P_q = \frac{V^2}{X_L}\sin\delta\,\frac{1}{\left(1-\frac{V_q}{V_L}\right)} \tag{1}$$

where $V_L = IX_L$.

The voltage across transmission line of V_L can be derived by the following equation.

$$V_L = V_q + 2V\sin\frac{\delta}{2} \tag{2}$$

Inserting Eq. (2) into Eq. (1) and arranging it, the



(a)module structure

(b) switching pattern

Fig. 2. Three-level multi-bridge inverter.