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POWER FLOW IMPROVEMENT IN TRANSMISSION LINE USING A SERIES VECTORIAL COMPENSATOR (SVEC)

NÂNG CAO KHẢ NĂNG TRUYỀN TẢI CÔNG SUẤT CHO HỆ THỐNG ĐIỆN SỬ DỤNG THIẾT BỊ BÙ NỐI TIẾP VECTƠ (SVEC)

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ABSTRACT

This paper shows the comparative power flow improvement in transmission line power system results using a Series Vectorial Compensator (SVeC). The proposed SVeC is one of the Flexible AC Transmission System (FACTS) devices that uses AC capacitor instead of DC capacitor. An equivalent Synchronous Generator (SG) based on Single Machine connected to Infinite Bus (SMIB) through transmission line model is studied to present for the transmission line power system. A Proportional Integral Derivative (PID) controller for SVeC is designed by applying try and error method to supply the damping characteristic to the studied power system. To clearly compare the damping contributed by the control device, time domain approach based on nonlinear model simulation is presented. The simulation results are performed in Matlab software environment. It can be concluded from the simulation results that the proposed SVeC joined with the designed damping controller shown better damping characteristics to the studied SMIB system under severe operating condition.

***Keywords**: Single-machine infinite-bus system; Series vectorial compensator; Damping controller; Power flow; Stability.*

TÓM TẮT

Bài báo trình bày kết quả so sánh của việc nâng cao khả năng truyền công suất trong hệ thống truyền tải sử dụng thiết bị bù nối tiếp vectơ (SVeC). Thiết bị SVeC đề xuất là một trong những thiết bị truyền tải xoay chiều linh hoạt (SVeC) sử dụng tụ bù xoay chiều thay vì 1 chiều như các thiết bị FACTS khác. Mô hình tương đương của máy phát điện đồng bộ (SG) dựa trên mô hình 1 máy phát nối với bus vô hạn (SMIB) thông qua đường dây truyền tải được sử dụng để mô tả hệ thống truyền tải điện. Bộ điều khiển PID cho SVeC cũng được thiết kế bằng phương pháp thử và sai để cung cấp độ giảm chấn cho hệ thống nghiên cứu. Để dễ dàng so sánh sự tác động của thiết bị đề xuất, các kết quả mô phỏng trong miền thời gian dựa vào mô hình phi tuyến được thực hiện. Các kết quả mô phỏng mà được thực hiện dựa trên phần mềm Matlab. Có thể kết luận từ kết quả mô phỏng rằng, thiết bị bù SVeC đề xuất kết hợp với bộ điều khiển thiết kế cho thấy có đặc tính giảm dao động tốt hơn trong hệ thống SMIB nghiên cứu trong điều kiện vận hành nghiên trọng.

***Từ khóa:** Hệ 1 máy điện nối lưới vô hạn; Thiết bị bù nối tiếp vectơ; Bộ điều khiển giảm dao động; Dòng công suất; Ổn định.*

1. INTRODUCTION

Flexible AC Transmission System (FACTS) devices have become more popular in the world due to high-speed response to effectively control power flow and voltage of power systems. Beside, FACTS devices can effectively enhance the stability of power systems in the existing transmission networks [1-4]. Among various types of FACTS devices, almost based on voltage-sourced converters (VSCs) using

DC capacitor to store the energy that provide a potentially attractive solution to control power flow in modern electric networks. However, one of the drawbacks of these devices is using DC capacitors which are quite vulnerable to high temperatures. To overcome this restriction, a new Series Vectorial Compensator (SVeC) device that using the direct AC/AC power conversion principle without large DC-link energy storage components is introduced. This device with a simpler pulse width modulation (PWM) controller is utilized to control active power in a transmission line [5]. A comparative dynamic performance of SVeC and thyristor controlled series capacitor (TCSC), SVeC and SSSC are presented in [6] and [7], respectively. In [8], many specifications of SVeC such as transformer rating, capacitor, converter, power loss, and estimating power circuit cost are compared with SSSC to demonstrate the superior specifications of SVeC.

This present paper focuses on design PID damping controller for SVeC to improve the damping of a power system. The organization of this paper is as follow. Section 2 introduces the configuration of the studied system. Section 3 shows the comparative transient responses of the studied system with the proposed SVeC and it designed damping controllers. Finally, specific important conclusions of this paper are drawn in Section 4.

2. THE STUDIED SYSTEM

Figure 1 shows the configuration of the studied system. The SG-based SMIB system has an equivalent SG of 160-MVA is connected to an infinite bus (or a large power grid) through transmission line and a step-up transformer [9-10]. The proposed 50-MVAR SVeC is connected in series with transmission line and located near the Point of Common Coupling (PCC). The utilized mathematical models of the studied system are described as follow.

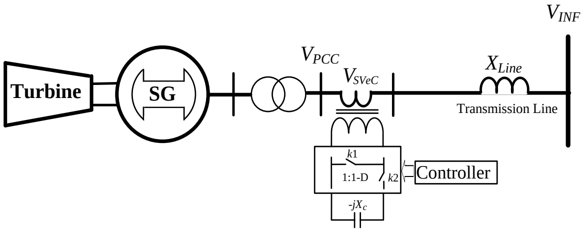


Fig. 1. *Single line diagram of the studied system*

2.1. Synchronous Generator (SG) Model

The SG model used in this paper is taken into account the sub-transient effects.

The complete d- and q-axis equivalent circuits and the corresponding equations of a SG can be referred to [9] in which, the block diagram is shown in Figure 2.

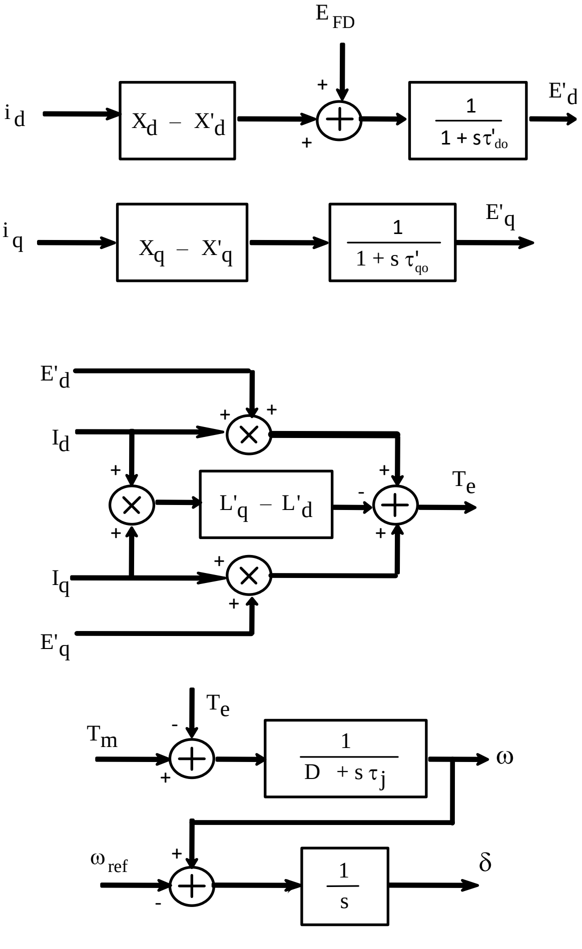


Fig. 2. *Control scheme of the SG.*

The excitation system in this model is the fast static exciter IEEE type ST1A [11] as shown in Figure 3 which is including the automatic voltage regulator (AVR) and the power system stabilizer (PSS).

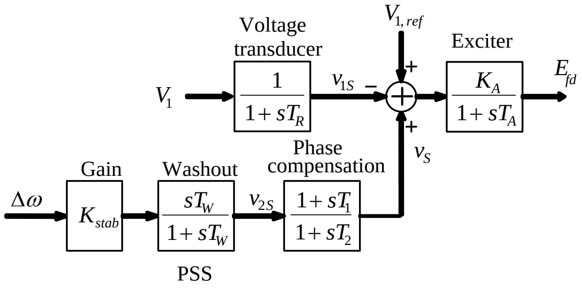


Fig. 3. *Fast static exciter and PSS model.*

The mechanical input torque of the SG is a single reheat tandem compound steam turbine model presented in Figure 4 while the speed governor model for the steam turbine is also utilized in Figure 5 [9].

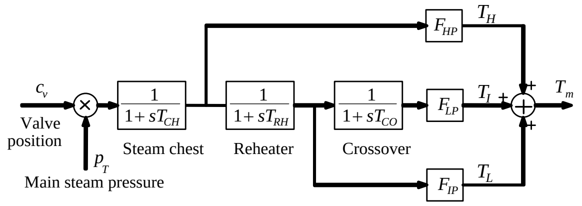


Fig. 4. *Single reheat tandem compound steam turbine model*

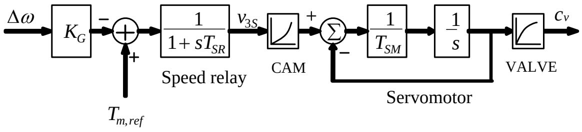


Fig. 5. *Speed governor model for steam turbine*

2.2. SVeC Model

The single line schematic diagram of the power circuit of the studied SVeC is also plotted in Figure 1. This device includes a series injection transformer connected to a AC capacitor bank through a pulse width modulation (PWM) AC controller. As shown in Figure 1, there are two switches. When the switch *k*1 is closed, the transformer terminal is shorted to isolating the compensation capacitors from the transmission line the. On the contrary, when switch *k*2 is closed, the compensation capacitors are effectively connected in series with the transmission line.

The net amount of reactive compensation of SVeC is determined by the total switching period. The duty ratio (*D*) of the converter is defined as the ratio of the on-period of switch *k*2 with respect to the total switching period [7].

The external of the SVeC is represented by the reactance (X_{SVeC}) and the voltage source (V_S) in series with the transmission line. The main purpose of using SVeC is to provide a variable reactance X_{SVeC} in series with the transmission line. This reactance is adjusted through variations of the duty cycle (*D*) of the controller.

By means of varying its equivalent reactance of the transmission line, the power flow of this line is controllable. The equivalent series reactance can be defined as:

$$X_{SVeC} = -n^2(1-D)^2 X_C \tag{1}$$

where

n is the turn ratio of the coupling transformer,

D is duty cycle,

X_C is the reactance of the capacitor bank.

The value of the voltage source in series with transmission line with line current I_{TL} can be described by

$$V_s = n^2(1-D)^2 X_C I_{TL} \tag{2}$$

Also in [7], power flow between the sending end V_1 and the receiving end V_2 can be calculated as follows

$$P_{12} = \frac{V_1 V_2}{X_{Line} - n^2(1-D)^2 X_c}\sin(\theta_1 - \theta_2) \tag{3}$$

where X_{Line} is the reactance of the transmission line.

In order to improve oscillations of the system by mean of controlling active power flow of transmission line, the control block diagram of the controller of this device is shown in Figure 6.

In Fig. 8, P_{REF} is determined by the percentage of compensation level of SVeC with the active power transmitted in the transmission line. In this paper, the percentage of compensation is chosen as 30%. The auxiliary signal, i.e., power oscillation damping (V_{Ctrl}), is the output signal of the PID controller which will be designed to damp out oscillations of the studied system.

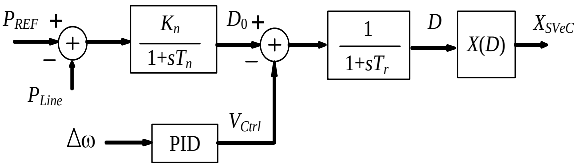


***Fig. 6.** Control block diagram of the SVeC*

The parameters of the PID controller is estimated by using try and error method based on the results from auto tune function in Matlab software.

3. SIMULATION RESULTS

This section presents the time domain simulation results of the studied system under severe operating condition to compare the damping characteristics contributed by the proposed SVeC joined with the designed damping controller.

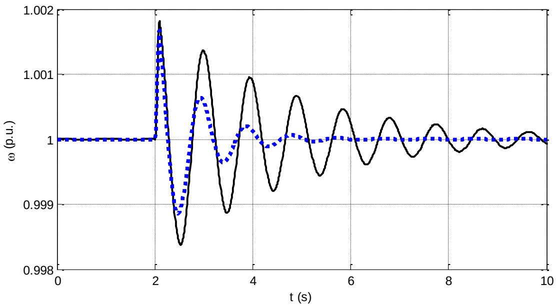
The simulation results in this section are performed in MATLAB software.

For easier comparing the effective of the proposed SVeC, the following transient responses of the studied system without SVeC (black lines), with the proposed SVeC and its designed damping controller (blue dotted lines) will be plotted.

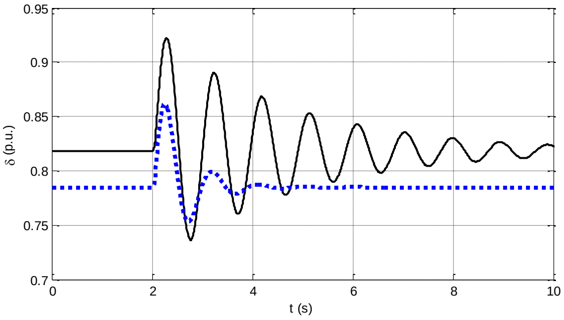
The case studied is a severe three-phase short-circuit fault happened at the infinite bus at t = 2 s and is cleared after 5 cycles.

Figure 7 presents the response of rotor speed, the toque angle, the voltage at PCC, active and reactive power in transmission line of the studied system respectively.

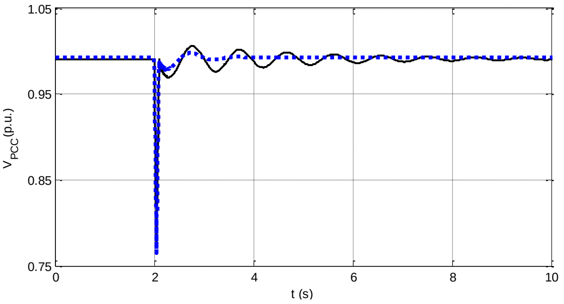
It is clearly observed from simulation results that the proposed SVeC with its designed PID damping controller can offer the better damping characteristics to the studied system.



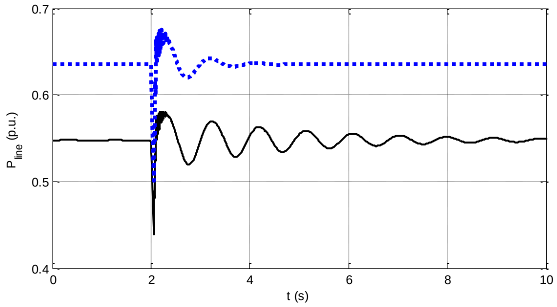
a. Rotor speed of SG



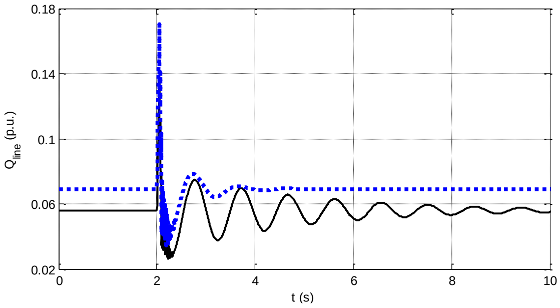
b. Torque angle



c. Voltage at PCC



d. Active power in transmission line



e. Reactive power in transmission line

***Fig. 7.** Simulation results*

4. CONCLUSION

This paper has shown the comparative damping improvement of a SMIB system using SVeC. The PID damping controller has been designed for the proposed SVeC. Time domain simulation results of the studied system subject to a three-phase short-circuit fault at the infinite bus have been systematically performed to compare the effectiveness of the proposed SVeC joined with the designed damping controller. It can be concluded from the simulation results that the proposed SVeC joined with the designed PID damping controller has better damping characteristics to improve the performance of the studied SMIB system under different operating conditions.

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