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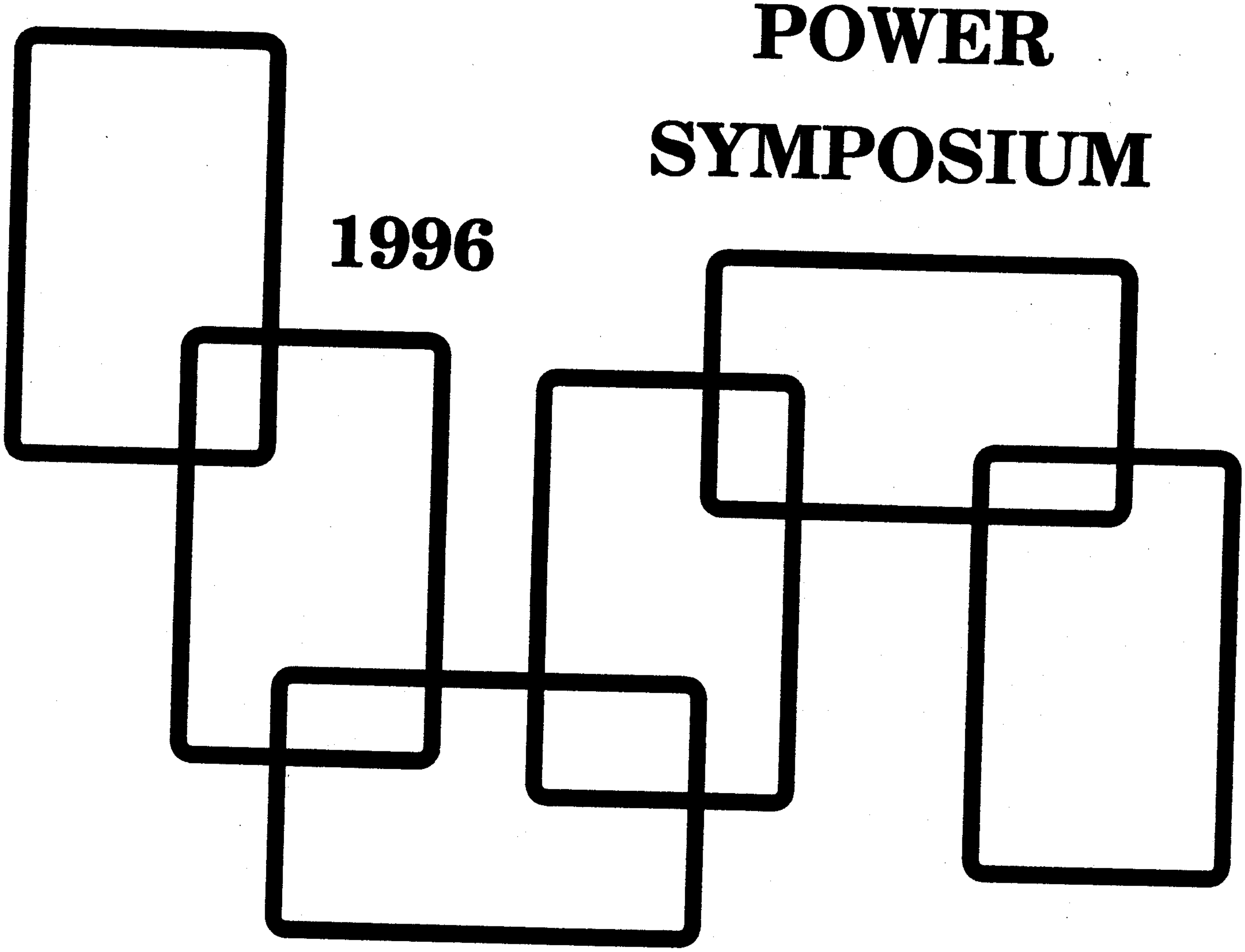

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STATIC VAR COMPENSATOR CONTROL IN MULTI-MACHINE POWER SYSTEMS USING A QUANTIZED CONTROLLER

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ABSTRACT

A quantized controller is a model-free controller which can provide nonlinear control. This paper conducts a preliminary study on using the quantized controller in the Static VAR Compensators (SVC) control to enhance damping of electromechanical power-swings. The test system used is a two area multi-machine system. A severe disturbance is introduced into a test system and the quantized controller-controlled SVC is used to damp out the oscillations. Simulation results show that the quantized controller is able to damp out the oscillations in a short period of time.

1. INTRODUCTION

Static VAR Compensators (SVC) provide rapid control of the susceptance and in turn the reactive power supplied at certain buses of an electric power system. It is an efficient and cost effective way to enhance the performance of power systems [3]. Some examples where an SVC can be applied include the stabilization of the power system following short circuits, removal of heavy-loaded transmission lines, load rejection, etc.[2][3]. Other areas include the increase of power transmission capacity, and the damping enhancement of the power-swing [2][3]. Classical lead-lag controllers with voltage regulation alone or with the addition of a supplementary control are typically used. However, in order to design the classical controllers, a complex mathematical model is needed for the power system.

A quantized controller provides a nonlinear control surface by extrapolating information from some pre-defined output patterns [4]. The control surface produced by the quantized controller can easily be implemented in a micro-controller or in a PLD using the look up table technique [4][5]. Like fuzzy controllers, the quantized controller is a model-free controller which does not require a mathematical model of the system. Efforts can be concentrated in the design of the controller instead of in finding out the model of the controlling system. Both the fuzzy and the quantized controller encode the control information in an input-output transformation or control surface and the main design effort is to find out the close-to-optimum nonlinear surface, the only difference between the two controllers being the method of transformation. There are two prominent advantages of the quantized controller. Firstly, the quantized controller can provide a generally smoother control surface than traditional fuzzy controllers [4]. Secondly, the quantized controller is easy to tune. A close to optimum control surface can be found after the tuning process [4].

This paper includes an introduction to the quantized controller, a description of the test system and the SVC control, and results from the test.

2. THE QUANTIZED CONTROLLER

The principle of the quantized controller is to extrapolate the control surface from a set of output patterns[4]. Take the two-input quantized controller used in this paper as an example; a total of 25 output patterns are used, and they are located on the corners of 16 adjacent rectangular meshes on the two dimensional input space. The location and the values of the output patterns are determined by experience and tuning of the controller. The 25 known output patterns contribute the 25 critical points on the quantized control surface.

After the determination of the output patterns, the values in between can be extrapolated by a mathematical function. The equation used for the quantized controller tested in this paper is shown in Figure 1. In Figure 1, Z1,Z2,Z3,Z4 represent the values of four neighboring output patterns, Z represents the output of the controller with the input values of X_i, and ϕ_i, and dx1, dx2, dϕ1, dϕ2 are indicators of the distance between the input values and the locations of the four output patterns. Depending on the needs of the system, some other mathematical functions can also be used in extrapolating the quantized control surface from the output patterns.

After the design of the initial quantized control surface, the control surface has to be tested and fine-tuned. The most primitive way is to do the tuning manually. Another way is to tune the controller automatically using a heuristic searching process: providing some error function to measure the performance of the quantized controller, the heuristic search changes the value of the error function. The process continues for cycles until the error function does not decrease anymore.

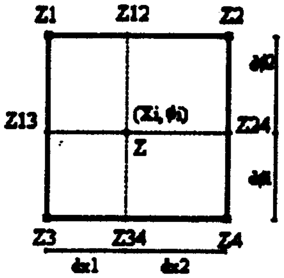


Figure 1. Variables for extrapolation

$$Z12 = \frac{Z1 \times dx2 + Z2 \times dx1}{(dx1 + dx2)} \tag{1}$$

$$Z24 = \frac{Z2 \times d\phi 1 + Z4 \times d\phi 2}{(d\phi 1 + d\phi 2)} \tag{2}$$

$$Z34 = \frac{Z3 \times dx2 + Z4 \times dx1}{(dx1 + dx2)} \tag{3}$$

$$Z13 = \frac{Z1 \times d\phi 1 + Z3 \times d\phi 2}{(d\phi 1 + d\phi 2)} \tag{4}$$

$$Z = \frac{Z12 \times d\phi 1 + Z24 \times dx1 + Z34 \times d\phi 2 + Z13 \times dx2}{(dx1 + dx2 + d\phi 1 + d\phi 2)} \tag{5}$$

3. THE TEST SYSTEM

A simple two-area multi-machine system, as shown in Figure 2, is used as the testing system for the quantized controller controlled SVC. The two-area system is similar to the one described in [1],[2].

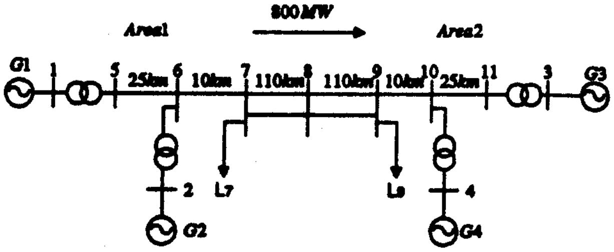
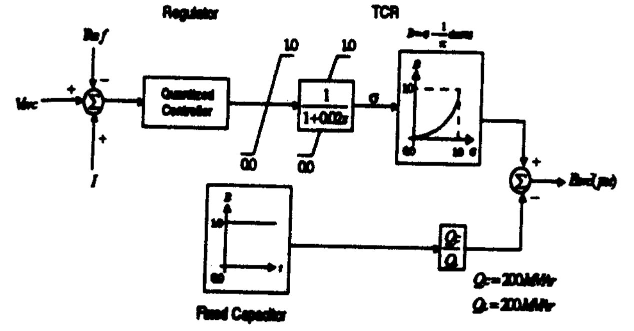


Figure 2. Diagram of the two area multi-machine test system

If a three-phase fault is placed on bus 9 of the power system, and there is a simultaneous removal of the transmission lines between bus 8 and bus 9, the system without an SVC will start to oscillate without much damping.

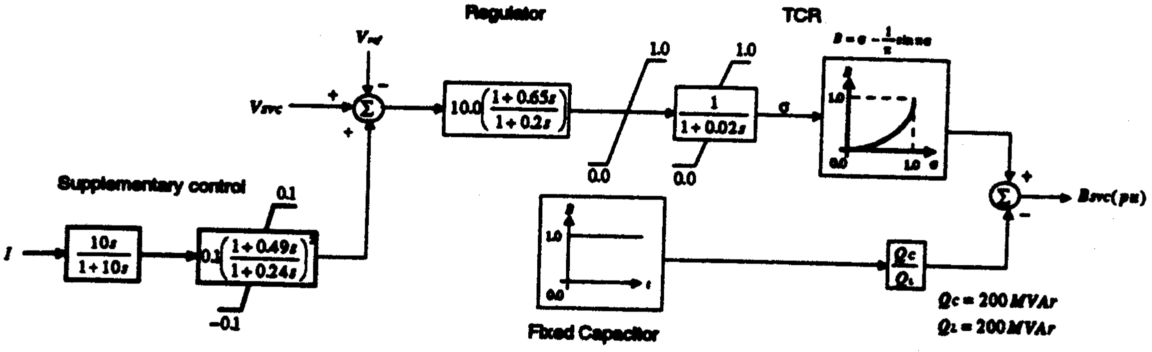
An SVC is now placed at bus 8 of the system and is composed of a fixed capacitor and a thyristor-controlled reactor (TCR). The block diagram of the SVC is shown in Figure 3. The input to the quantized controller block is the sum of the current between bus 9 to bus 10 and the voltage magnitude at bus 8 minus a reference value. The output from the quantized controller block is then fed to the TCR to control the reactance component of the SVC.



I = magnitude of line current from bus 9 to bus 10

Figure 3. Block diagram of SVC and the quantized controller

The performance of the quantized controller developed will be compared to the performance of a classical controller with lead-lag blocks, as shown in Figure 4. The classical controller is very similar to the one described in [2].



I = magnitude of line current between buses 9 and 10

Figure 4. Block diagram of SVC and the classical lead-lag blocks of the supplemental controller

4. PERFORMANCE OF THE QUANTIZED CONTROLLER

The quantized controller used in stabilizing the oscillations of the two-area system requires two input signals. The first input signal is the sum of the magnitude of line current from bus 9 to bus 10 and the voltage at bus 8 minus a reference value, and the second input signal is the change of the first input signal at a particular simulation time interval. The output of the quantized controller is the change of the reactance value going into the TCR at a particular simulation time interval. Since the robustness of the quantized controller depends on the selection of input and output signals and also the quantized control surface, different faults with different time duration are placed on the system to test the quantized controller and to fine-tune the quantized control surface. However, the Ref value has to be changed according to the line which is removed due to the fact that the value of the stabilized current from bus 9 to 10 varies with different removed lines.

The dynamic performance of the power system and the SVC are simulated using the Extended Transient-Midterm Stability Program (ETMSP) developed by Ontario Hydro for EPRI. Two sets of results are illustrated in this paper. Figure 5 shows the difference of the system response between the system without the SVC and the system with a fine-tuned quantized controller-controlled SVC after a severe disturbance. The disturbance consists of a short circuit at bus 9 for 0.01s followed by removal of one of the lines between bus 8 and bus 9.

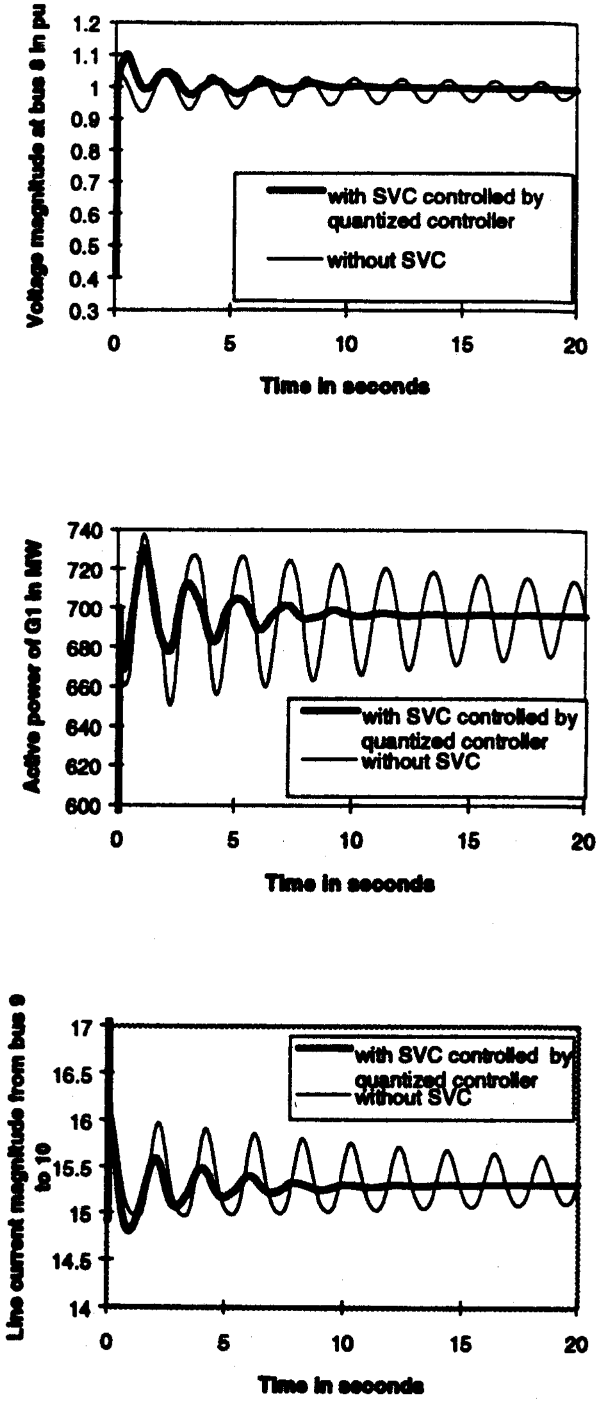


Figure 5. Response of the system with the SVC controlled by quantized controller at bus 8 and without the SVC

Figure 6 shows the comparison between the performance of the quantized controller-controlled SVC and the classical controller-controlled SVC.

The results of the performance of the quantized controller controlled SVC are promising. Figure 4 shows that the SVC is able to damp out the system oscillations smoothly in a short period of time. Figure 6 shows that the quantized controller can perform better than the classical controller.

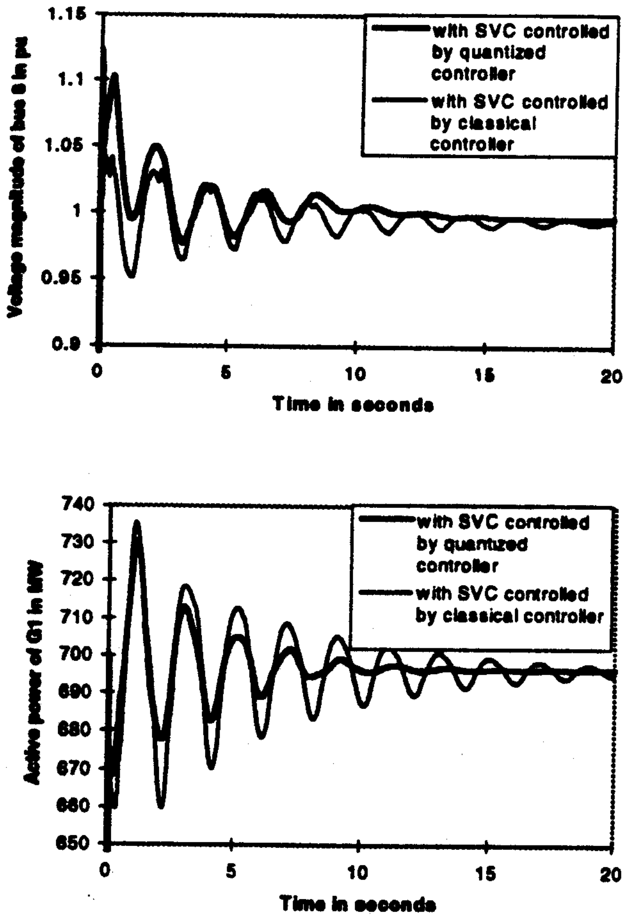


Figure 6. Comparison of the response of the system with the SVC controlled by the quantized controller at bus 8 and with the SVC controlled by a classical controller.

5. CONCLUSION

From the simulation results, the quantized controller-controlled SVC has proven to be able to damp out system oscillations smoothly and quickly. The main advantages of the quantized controller over the classical controllers is that the quantized controller is model free and it can provide a nonlinear control surface. Furthermore the output patterns and the position of the input sets of a quantized controller is easy to tune, and the resulting control surface can be implemented in a micro-controller or in a PLD. Recently, SVC are widely used in damping out power system oscillations and enhancing the stability of power systems. However, the classical controllers are usually complex and extensive time is required to determine an approximated model of the actual system. The simulation results of this paper has shown a possibility of using a model-free controller like the quantized controller in controlling the susceptance output of the SVC. However, the disadvantage of the quantized controller used in this paper is that the control surface has to change according to the specific line which is removed. Future work includes study to increase the robustness of the quantized controller by changing the input and output signals of the controller and to test the controller for more load and fault conditions.

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