# STATIC VAR COMPENSATOR CONTROL USING A QUANTIZED CONTROLLER FOR A TWO AREA MULTI-MACHINE SYSTEM

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This is an extended summary of the actual paper

## ABSTRACT

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

## I. INTRODUCTION

A quantized controller provides a nonlinear control surface by extrapolating information from the pre-defined output patterns. 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. Like fuzzy controllers, quantized controller is a model-free controller which does not require a well defined 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 inputs-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 is the method of transformation. There are two prominent advantages of the quantized controller. Firstly, the quantized controller can provide a smoother control surface than tradition fuzzy controllers []. Secondly, the quantized controller is easy to tune. A close to optimum control surface can be found after the tuning process [].

Static VAR Compensators (SVC) provides rapid control of the susceptance and in turn the reactive power supplied at a certain bus of an electric power system. It is an efficient and cost effective way to enhance the performance of power systems []. One area of power system which apply SVC includes the stabilization of the power system following short circuits, removal of heavy-loaded transmission lines, load rejection, etc.[] Other areas includes the increase of power transmission capacity, and the damping enhancement of power-swing [][]. Traditional PID controllers with voltage regulation alone or with the addition of a supplementary control is always used []. However, in order to design the PID controllers, a complex linearized mathematical model is needed for the power system.

This summary includes an introduction to the quantized controller, a description of the test system and the SVC control, and results for the performance of the quantized controller controlled SVC.

## II. THE QUANTIZED CONTROLLER

The design of a quantized controller can be separated into three parts: exemplary output patterns, extrapolating the quantized control surface, and the tuning process:

### A. Exemplary Output Patterns

After the selection of the input and output signals to the controller, the domain of the input and output variables are separated into segments. Considering a quantized controller for the backing up truck problem as described in [], the inputs to the controller are the x-coordinate and the ϕ angle from the position of the ramp and the output of the controller is the steering angle of the truck. The x-coordinate is divided into 5 segments and the ϕ angle is divided into 7 segments as shown in Figure 1. The choice of the position of the input sets are important to the quantized controller and can be determined by some experimentation. The output values for these 48 input sets form 48 output patterns which can be determined by experience. The 48 known output patterns contribute the critical points on the quantized control surface.

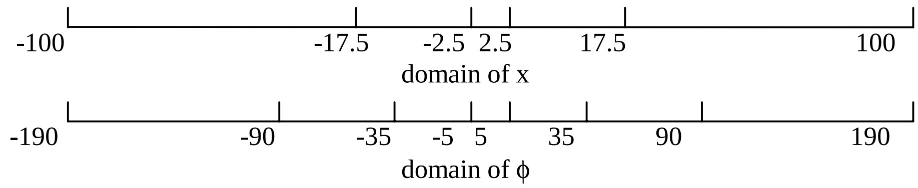
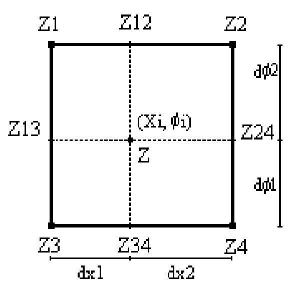



**Figure 1**. Boundary points of the input variables segments used to form the 48 input sets. (six boundary points for input x, and eight for the input ϕ).

### B. Extrapolating the quantized control surface from the output patterns

In order to extrapolate the values in between the output patterns, a mathematical function is needed. As shown in Figure 2, Z1, Z2, Z3, and Z4 represents four neighboring output patterns, values in between can be extrapolated by the following function:




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

$$Z24 = \frac{Z2 \times d\phi1 + Z4 \times d\phi2}{(d\phi1 + d\phi2)} \qquad (2)$$

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

$$Z13 = \frac{Z1 \times d\phi1 + Z3 \times d\phi2}{(d\phi1 + d\phi2)} \qquad (4)$$

**Figure 2.** Variables for extrapolation

$$Z = \frac{Z12 \times d\phi1 + Z24 \times dx1 + Z34 \times d\phi2 + Z13 \times dx2}{(dx1 + dx2 + d\phi1 + d\phi2)} \qquad (5)$$

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.

### C. Tuning Process

Some tuning process is needed to fine-tune the initial quantized control surface. The most primitive way is to do the tuning manually. Another way is to use computers: providing some error function to measure the performance of the quantized controller, the heuristic search process can be used which changes one output patterns at a time with an objective to decrease the value of the error function. The process continues for cycles until the error function does not decrease anymore.

## III. THE TESTING SYSTEM

A simple two-area multi-machine system, as shown in Figure 3, is used as the testing system for the quantized controller controlled SVC. The two-area system is similar to the one described in [].

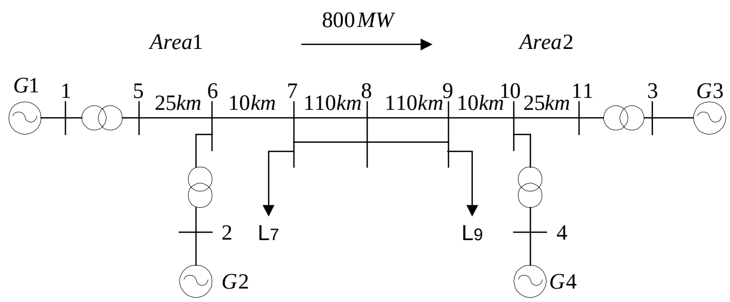



**Figure 3.** Diagram of the two area multi-machine test system

The detailed information for the two area system is listed below:

$X_d = 1.8$ $X_q = 1.7$ $X_l = 0.2$ $X_d' = 0.3$ $X_q' = 0.55$
$X_d'' = 0.25$ $X_q'' = 0.25$ $R_a = 0.0025$ $T_{d0}' = 8.0$ s $T_{q0}' = 0.4$ s
$T_{d0}'' = 0.03$ s $T_{q0}'' = 0.05$ s $A_{sat} = 0.015$ $B_{sat} = 9.6$ $\psi_L = 0.9$
$\psi_M = 1.2$
$H = 6.5$ (for G1and G2) $H = 6.175$ (for G3 and G4) $K_D = 0$

Impedance of each step-up transformer is 0+j0.016 per unit on 900 MVA and 20/230 kV base

Line parameters on 100 MVA, 230 kV base are:
$r = 0.0001$ pu/km $x_L = 0.001$ pu/km $b_C = 0.00175$ pu/km

Data for the generating units are:

| | | | |
|---|---|---|---|
| G1: | $P = 700$ MW, | $Q = 205$ MVAr, | $E_t = 1.03\angle 18.8^{o}$ |
| G2: | $P = 700$ MW, | $Q = 291.9$ MVAr, | $E_t = 1.01\angle 9.0^{o}$ |
| G3: | $P = 723$ MW, | $Q = 233$ MVAr, | $E_t = 1.03\angle -6.8^{o}$ |
| G4: | $P = 700$ MW, | $Q = 348$ MVAr, | $E_t = 1.01\angle -17.2^{o}$ |

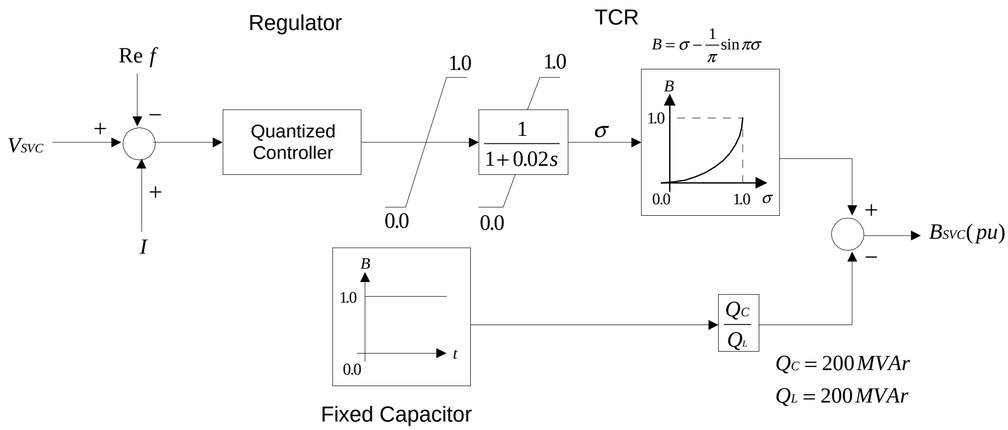
Data for the loads are:

| | | |
|---|---|---|
| $L_7$: | $P_L = 967$ MW, | $Q_L = 100$ MVAr, |
| $L_9$: | $P_L = 1767$ MW, | $Q_L = 100$ MVAr, |

The Thyristor exciter with a high transient gain are used for all four generators:
$K_A = 200.0$ $T_R = 0.01$

A three-phase fault is placed on bus 9 of the power system for a duration of 0.01s and 0.05s respectively. Then one of the transmission lines between bus 8 and bus 9 is removed. Figure 5 and Figure 6 shows that the system without SVC starts to oscillate without much damping.

The SVC is placed at bus 8 of the power system and is composed of a fixed capacitor and a thyristor-controlled reactor (TCR). The block diagram of the SVC is shown in Figure 4. 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 4.** Block diagram of SVC and the quantized controller

## IV. PERFORMANCE OF THE QUANTIZED CONTROLLER

The quantized controller used in stabilizing the oscillations of the testing two-area system requires two input signals -- which is not shown in the block diagram. 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 controling signal 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, therefore different faults with different time duration is placed on the system to test the quantized controller and to fine-tune the quantized control surface. The tuning process is done manually for the simple quantized controller used in this paper. The detail description of the final tuned control surface of the quantized controller will be included in the final paper. However, the Ref value has to be changed according to the fault due to the fact that the value of the stabilized current from bus 9 to 10 varies with the faults.

The power system and the quantized controller controlled SVC are simulated using the Extended Transient-Midterm Stability Program (ETMSP) developed by Ontario Hydro. Two sets of results are illustrated in this paper. Figure 5 and Figure 6 show the difference of the system response between the system without a SVC and the system with a fine-tuned quantized controller controlled SVC after a severe disturbance.

The results of the performance of the quantized controller controlled SVC are promising. The SVC is able to damp out the system oscillations smoothly in a short period of time.

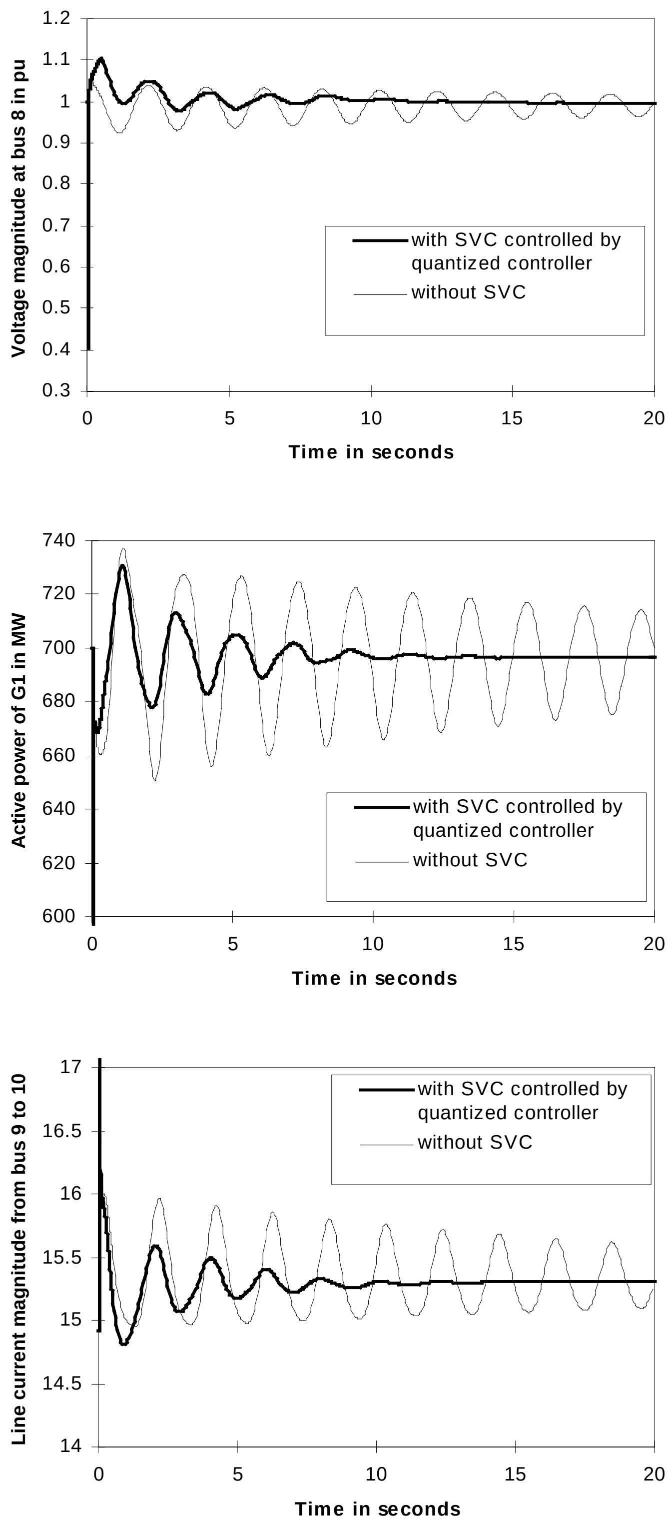



**Figure 5.** Response of the system with the SVC controlled by quantized controller at bus 8 and without the SVC to a severe disturbance which consists of a short circuit at bus 9 for 0.01s followed by a removal of one of the lines between bus 8 and bus 9

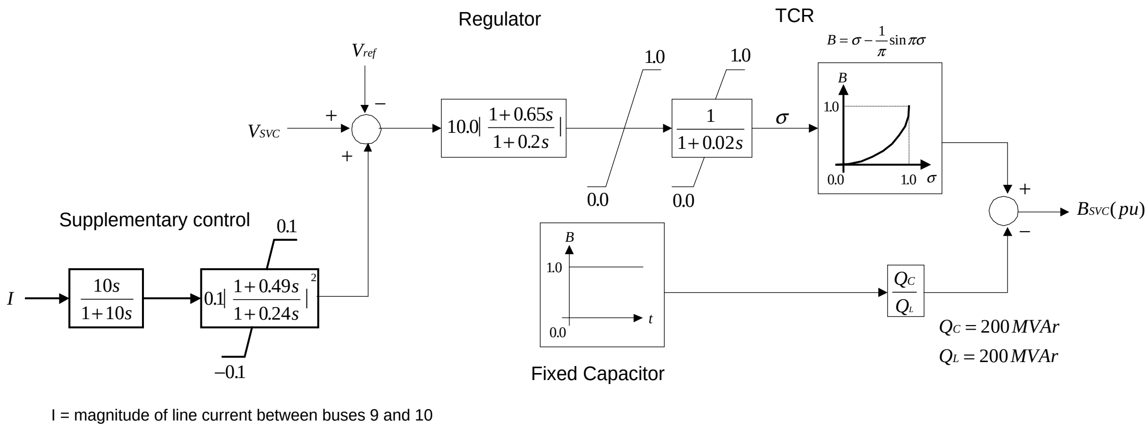
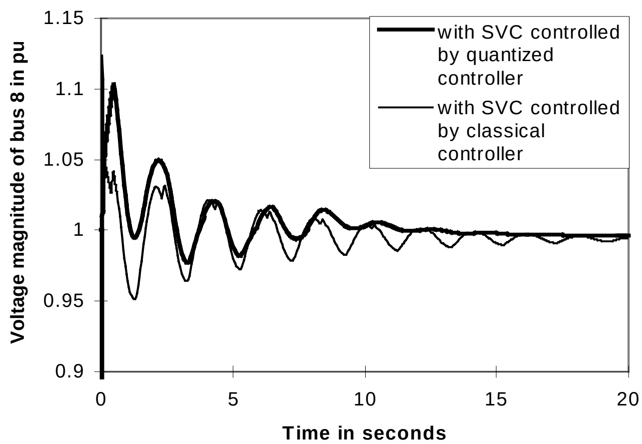



**Figure 5.** Block diagram of SVC and the classical lead-lag blocks controller



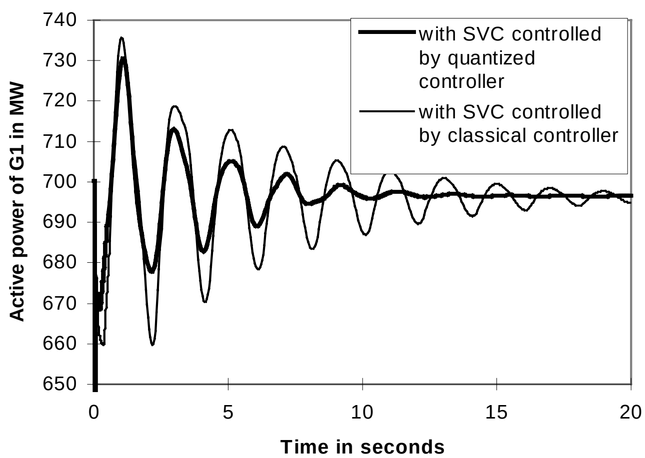




**Figure 6.** Comparison of the response of the system with the SVC controlled by quantized controller at bus 8 and with SVC controlled by classical controller at bus 8 to a severe disturbance which consists of a short circuit at bus 9 for 0.01s followed by a removal of one of the lines between bus 8 and bus 9

## V. CONCLUSION

From the simulation results, the quantized controller controled SVC has proven to be able to damp out system oscillations smoothly. The main advantages of the quantized controller over tradition controller -- one which requires a mathematical model are that the quantized controller is model free and it can provide a nonlinear control surface. Furthermore the output patterns and the postition 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 the power system. However, the traditional controller is usually complex and lots of time in 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. 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.

## VI. REFERENCES

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Name of the book which the system is found

Name of the tutorial about SVC

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