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Analysis of PSVR Transient Voltage Stability Based on RTDS

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Abstract. Power system voltage regulator (PSVR) is a kind of high-voltage side bus voltage control method, which maintains the high-voltage side bus voltage of the power plant at a high level, increases the reactive power limit of the generator, and improves the voltage stability of the power system. In this paper, a PSVR model with gain reduction is introduced. With PCS-9410 excitation regulator, the semi-physical simulation system is constituted on RTDS. By setting a three-phase ground short-circuit on the high-voltage side transmission line, the time domain dynamic response of automatic voltage regulator (AVR) and PSVR is compared and analyzed in synchronous generator and synchronous condenser mode respectively, simulation results show that PSVR with gain reduction can increase the reactive power response speed of the excitation system in two modes.

1. Introduction

Due to the interconnection of cross-region power grids, the voltage stability problem of power system has become increasingly prominent, and thus has received extensive attention from the power industry. Different from the conventional generator terminal voltage control mode, the high-voltage side voltage control is aimed at controlling the voltage of a certain point outside the generator end such as the high-voltage bus or the step-up transformer to achieve the purpose of improving the stability of the power system.

Currently, there are three main high-voltage side voltage control methods: advanced high-side voltage control regulator (HSVC) [1-3], line drop compensation (LDC) [4] and PSVR [5,6]. HSVC controls the high-voltage side voltage of the step-up transformer to be constant by introducing compensation for reactive current in the conventional excitation system, and does not require high-voltage side feedback signal. Similar to HSVC, LDC uses stator current to compensate for line voltage drop. PSVR introduces the high-voltage side voltage of the generator to participate in the control of the AVR. To control the voltage at a certain point outside the generator end, the reactance of the step-up transformer can be compensated, and the high-voltage side bus voltage of the power plant is maintained at a high level. In literature [7], the parameters tuning method of PSVR and its effect on system reactive power is discussed. Unlike [5,6], the gain reduction loop is not included in this PSVR model. In order to verify the application effect of PSVR, Chen X *et al.* implemented this PSVR model in the EXC9000 excitation regulator of Guangzhou Qingtian Industrial Co. Ltd. and conducted a field trial [8]. In [9], Chen X *et al.* analyzed the improvement of PSVR's voltage stability in Zhejiang power



system quantitatively. However, the PSVR model is the same as [7]-[8] and does not include a gain reduction loop.

With the development of HVDC transmission systems, large-capacity synchronous condenser has received wide attention again because of its good dynamic voltage support capability [10-12]. Wang Y *et al.* study the application of new generation large capacity synchronous condenser in HVDC transmission system receiving end, and point out that it has the advantages of strong voltage support capability and fast transient response speed in the event of grid fault [10]. In [11], Cui T *et al.* verify that after the 300 MVar synchronous condensers are installed in Hunan power grid, the voltage stability level of Hunan power grid could be effectively improved. Wu K *et al.* discuss the coordinated control strategy for synchronous condenser and reactive power in DC converter station and propose that PSVR is a potential control method [12].

In this paper, research is mainly focused on a PSVR model with gain reduction. With the PCS-9410 excitation regulator of NARI-Relays Electric Co. Ltd., the closed-loop semi-physical simulation model is built on the RTDS platform. The time domain simulations of AVR and PSVR are carried out in synchronous generator and synchronous condenser mode respectively. It shows that PSVR with gain reduction can increase the reactive power response speed of the excitation system in both modes.

2. PSVR semi-physical simulation model based on RTDS

2.1. PSVR model without gain reduction loop

The conventional AVR excitation control mode adjusts the voltage deviation of the generator as the feedback, and maintains the generator terminal voltage U_g as a given value. The PSVR control mode introduces the high-voltage side voltage U_s to participate in the AVR control, which takes the voltage at a certain point outside the machine as the target. Therefore, the high-voltage side bus voltage of the power plant is maintained at a high level.

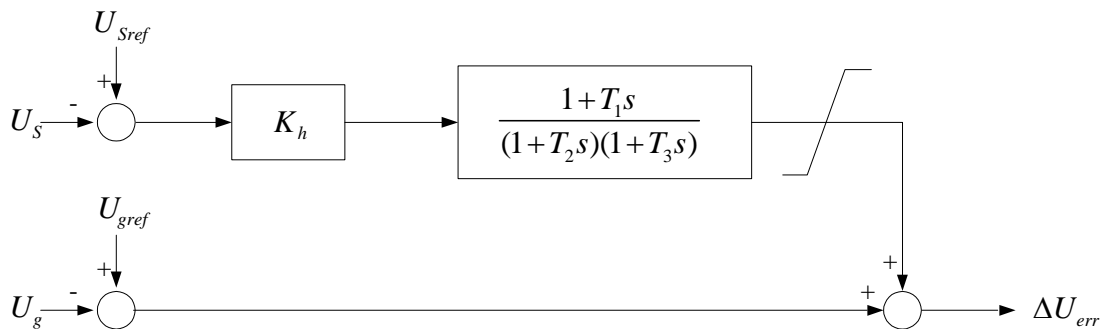


Figure 1. PSVR model without gain reduction loop.

The PSVR model without gain reduction loop is shown in figure 1, which takes the difference between U_{sref} and U_s as input signal, and consists of amplification, phase compensation and output limit:

$$\Delta U_{err} = (U_{gref} - U_g) + K_h (U_{sref} - U_s) \frac{1 + T_1 s}{(1 + T_2 s)(1 + T_3 s)} \quad (1)$$

Where U_{gref} is generator terminal voltage reference value, U_{sref} is high-voltage side voltage reference value, K_h is system voltage gain, $T_1 \sim T_3$ are time constants.

2.2. PSVR model with gain reduction

PSVR is an additional control of AVR and takes the high-voltage bus voltage of power plant as the target. The mathematical model in PCS-9410 excitation regulator is shown in figure 2. K_H is system voltage gain, T_{s1} is system voltage differentiation time constant, and T_{s2} is system voltage integral time

constant. A gain reduction loop ($1-\beta$, $\beta \leq 1$) is provided in this model to improve the ability of suppressing power oscillations.

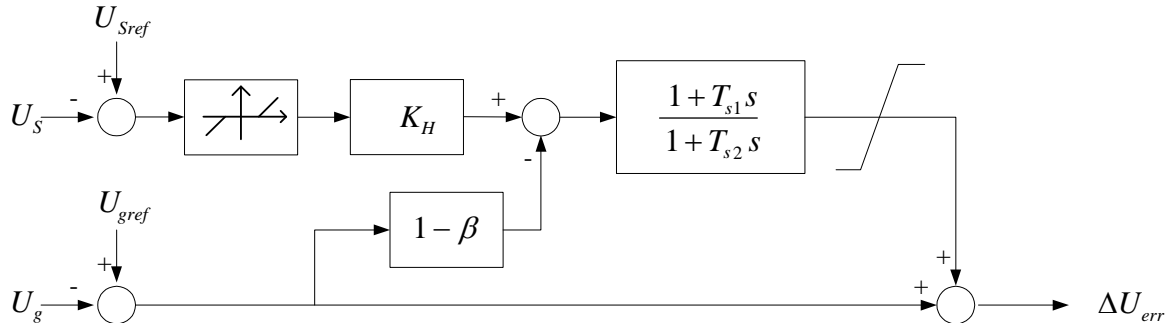


Figure 2. PSVR model in PCS-9410 excitation regulator.

In figure 2, the system voltage deviation passes through the dead zone. When the deviation is less than the set threshold and lasting for 10s, the system voltage calculation branch output is set to 0, and the model becomes figure 3.

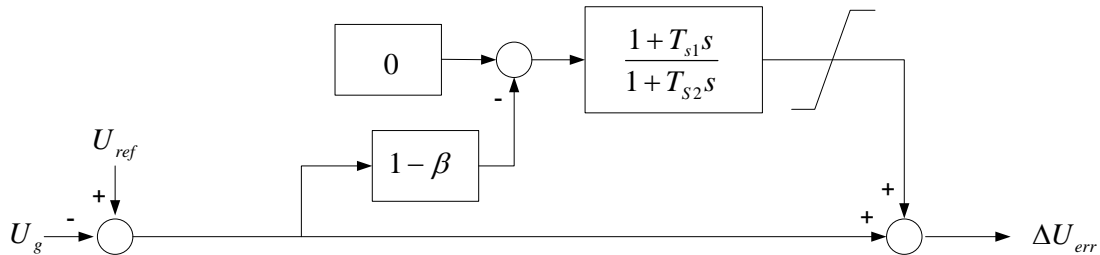


Figure 3. PSVR dead zone in PCS-9410 excitation regulator.

2.3. Simulation Model

In order to test the effect of PSVR, the simulation model established on RTDS platform is shown in figure 4. In the single machine infinite system model, the primary equipment such as generator and transformer, and the governor system are realized with digital simulation model [13]. By connecting RTDS analog input/output interface card with PCS-9410 excitation regulator, the closed-loop semi-physical simulation system is constituted. U_g and I_g are generator terminal voltage and terminal current, U_s is high-voltage side bus voltage, U_z is trigger pulse synchronization voltage for rectifier, I_f is excitation current, and U_c is excitation control voltage from the PCS-9410 regulator.

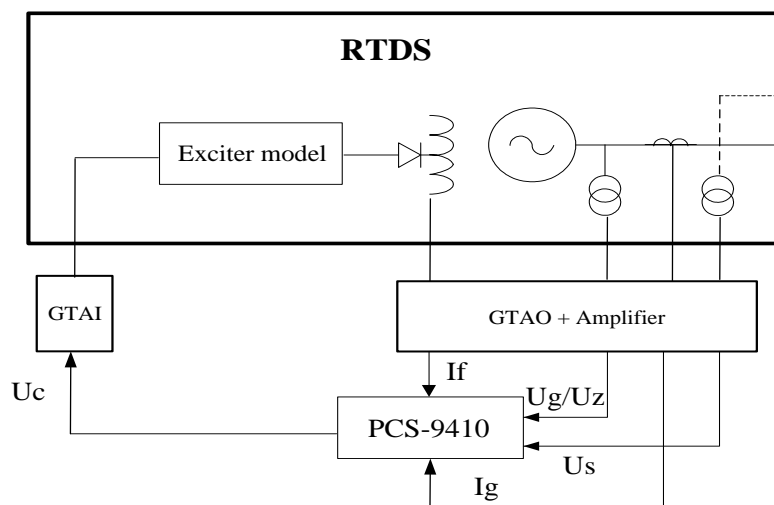


Figure 4. Excitation system semi-physical simulation model based on RTDS.

3. PSVR transient voltage stability analysis

In the simulation model, the rated power of the generator is 300MW, and the rated voltage is 20kV. Boosted by the step-up transformer, the generator is connected to the infinity system via the double-circuit line. The simulation model can simulate the real operating condition of the generator. Firstly, the generator is dragged to the rated speed by the governor system; secondly, the excitation regulator is used to start the excitation and establish rated terminal voltage; finally, the synchronous logic of the digital simulation model is used to realize the grid connection. Set a three-phase ground short-circuit fault on Line1 and cut off Line1 after 50ms, as shown in figure 5. In this transient process, the terminal voltage and electromagnetic power fluctuate drastically, and the system reactive power is seriously lacking.

Select a set of typical parameters for PSVR: the gains $K_H = 0.5$, $\beta = 0.9$ and phase compensation time constants $T_{s1} = 1$, $T_{s2} = 5$.



Figure 5. Fault location of the simulation model.

The semi-physical simulation system can give the generator active power in governor system, and adjust the reactive power by the excitation regulator. In synchronous generator mode, perform the fault and the dynamic response of AVR and PSVR are shown in figure 6. It can be seen from figure 6 that after the PSVR is put into operation, the generator is more sensitive to the transient voltage changes of the system. Compared with the AVR, the terminal voltage responding speed of the generator is faster during system voltage drop and system voltage recovery. Therefore, the transient stability of the power system has been improved with PSVR on.

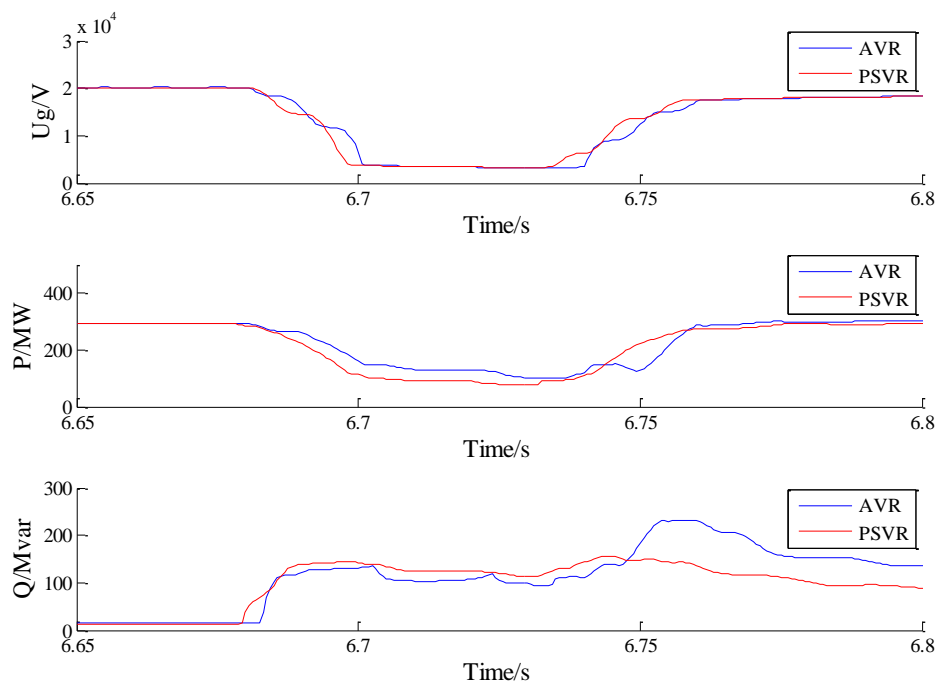


Figure 6. Dynamic response of AVR and PSVR in synchronous generator mode@ Three-phase ground short-circuit.

In synchronous condenser mode, perform the fault again and the dynamic response of AVR and PSVR are shown in figure 7. As can be seen from figure 7, the synchronous condenser responds faster to system-side voltage drops and provides greater reactive power support with PSVR on. Compared with the AVR, PSVR increases the sensitivity of the synchronous condenser to grid voltage changes.

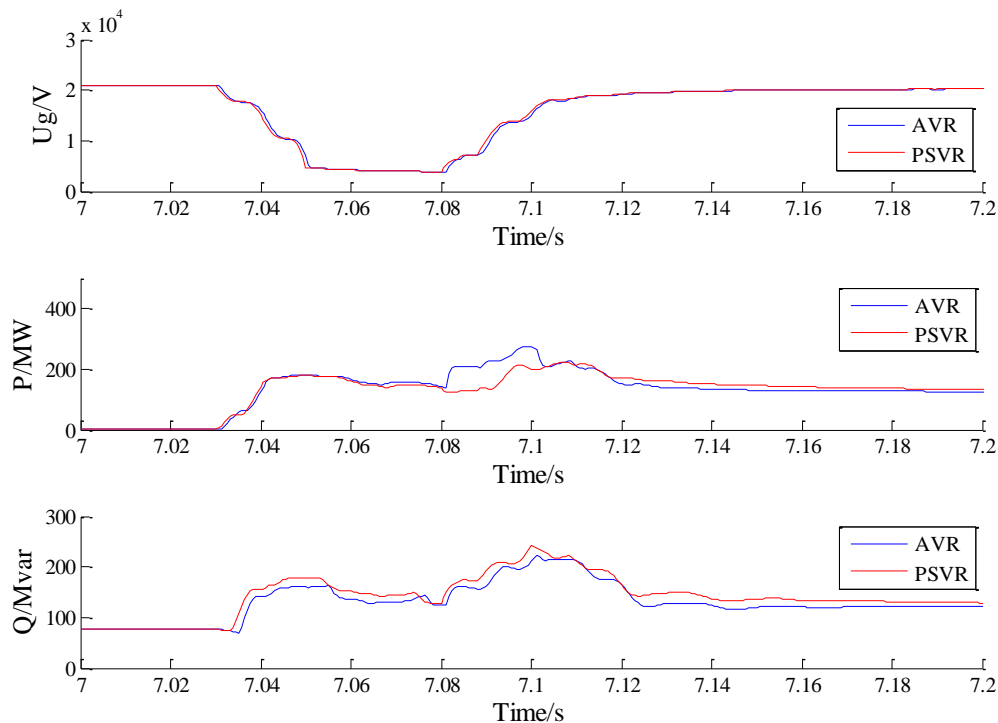


Figure 7. Dynamic response of AVR and PSVR in synchronous condenser mode@ Three-phase ground short-circuit.

4. Conclusions

In this paper, a PSVR model with gain reduction is investigated to evaluate the transient voltage stability. The semi-physical simulation model of excitation system is established on RTDS real-time digital simulation platform. By performing three-phase ground short-circuit fault on high-voltage side transmission line, the dynamic response of AVR and PSVR is compared and analyzed in synchronous generator and synchronous condenser mode respectively. The results show that PSVR can improve the transient stability of the power system. In the future, we will focus on parameters optimization tuning of the PSVR with gain reduction and its effect on small disturbance stability.

Acknowledgments

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