Impact of the Power System Stabilizer on Transient Stability of the Power System

Blagoja Stevanoski[1] and Natasa Mojsoska[2]

Abstract – **Stable operation of the power system is one of the key factors for reliable and quality power supply. Major disruptions in the system operation mode (short circuits, outages of large generating units, transmission lines, etc.) cause significant changes in the parameters of state of the electricity system. The response of the system in such cases is an emergence of electromechanical oscillations in synchronous generators reflected in the fluctuation of the regime parameters (rotational speed, active and reactive power, voltage, power output, etc.). Oscillations can reach an amount that can compromise the stable operation of the synchronous generator and the power system in general. One way to suppress oscillations is to use a stabilizer of the power system as an integral part of the excitation systems of generators. The task of the power oscillation stabilizer is to produce a torque damping component of the electromagnetic torque through the excitation systems. This paper presents the theoretical basics of contemporary power system stabilizers, and on concrete example analyzes its impact on transient stability in a case of a close short-circuit near TPP Bitola.**

Keywords – **Synchronous generator, excitation system, power system stabilizer, transient stability.**

I. Introduction

The power system is a complex non-linear system that is constantly exposed to various types of disruptions (load changes, outputs of production units, short-circuit, changes in a topology of the network, etc.). Stability of a power system is its ability to return to a running equilibrium state after an occurrence of a disturbance, while the regime parameters of the system remain within the limits that provide a complete integrity of the power system. Important variables at power system equilibrium are rotor (power) angle, nodal voltages and frequency. Rotor angle stability is the ability of interconnected synchronous machines to remain in synchronism in case of transient disturbance [1].

The stability problem involves the study of electromechanical oscillations inherent in power systems. Electromechanical oscillations are a consequence of the physical nature of a synchronous generator connected to a power system. Such a system contains multiple energy accumulators (rotating masses, inductive excitation coils, etc.) which react with electromechanical oscillations to the smallest deviation from the equilibrium state. Oscillations are superposed on stationary variables and in the worst case can endanger the stability of the synchronous generator.

Electromechanical oscillations can be divided into local and systemic oscillations. The connection of new generating units to the power system through relatively long transmission lines creates favorable conditions for the occurrence of local electromechanical oscillations of the generators in relation to the power system. When connecting and unifying smaller power systems at the regional level in a single state system or connecting multiple systems, the occurrence of electromechanical oscillations is much more complicated and falls within the category of systemic oscillations. Such oscillations are a consequence of various factors: relatively long transmission lines between the power system, the current state and system configuration (character and location of consumers and production units, occurrence of various interruptions and outages of generators, inclusion and exclusion of large consumers, poor synchronization with network connectivity, etc.).

Due to competitive energy market, in order to transmit as much power as possible, the energy system is used up to its limits of stability. This leads sometimes to stability problems like power oscillations. In the synchronous generator, the damping field and damper windings provide to the rotor oscillations is weakened due to excitation control system action. The reason for this is the appearance of additional currents in the rotor circuits induced by the voltage regulation which oppose the currents induced by the rotor speed deviations [2]. Therefore, an additional stabilizing signal is needed and the device used for this purpose is known as the power system stabilizer (PSS). This is one of the most cost-effective methods of enhancing power system stability. PSS uses auxiliary stabilizing signals to control the excitation system. Based on the operation of the automatic voltage regulator (AVR) commonly used input signals to the power system stabilizer are shaft speed, power or terminal frequency. The stabilizer introduces an additional electric torque corresponding to the deviation of the speed by increasing the damping of system oscillations and improving the stability of the power system.

II. Excitation Systems and Power System Stabilizer

Excitation systems are one of the most important parts of the synchronous generators that are intended to provide direct current to the generator field winding. Additionally, excitation systems are also responsible for control and protection functions of the power system. Its dynamic performance has a direct impact on generator stability and reliability [1], [2].

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Fig. 2.1 shows the general structure of voltage regulator for synchronous generator, which includes a circle for regulating the excitation current and a predetermined circle for regulating the voltage of the generator. Reactive power regulator and power system stabilizer is used according to the request of the power system. Terminal voltage controller is proportional-integral (PI) type and is superior to excitation current controller which is proportional (P) type. Output of voltage regulator is a reference value of excitation current. Based on measured values of terminal voltage and currents, active and reactive power of synchronous generator are determined [3],[4].

A power system stabilizer is a device which provides additional supplementary control loops to the automatic voltage regulator system of a generator unit. Task of the power system stabilizer is to generate a stabilizing signal which creates a damping component of electromagnetic torque during transient process, acting through the excitation system. The output signal from the stabilizer is introduced into the summator before the voltage regulator. The stabilizer has to perform phase compensation between an input of excitation system and electromagnetic torque. The usual input signal used in classical stabilizers is the active power of the generator or the frequency at the place of the connection of the generator to the power system. The damp component of the torque is in phase with the change in a rotational speed of the generator. On that way, it can be used as an additional stabilization signal [1].

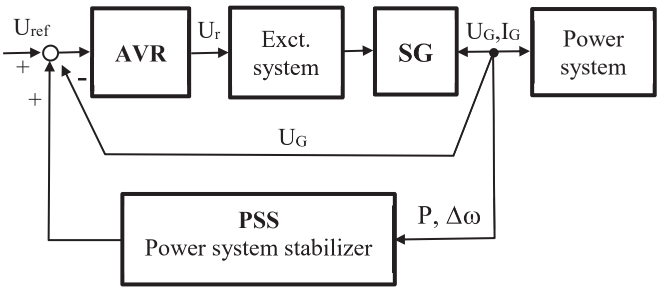


Fig. 2.1 Conventional structure of the system for managing the excitement of the synchronous generator

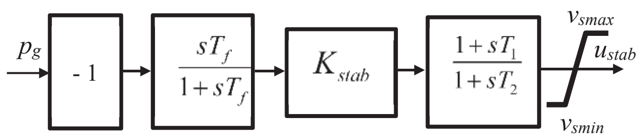
Power Stabilizer (PSS) is a feedback link controller that is part of the synchronous generator control system. Its main function is to damp the oscillations of the rotor of the generator in an interval of about 0,1 ÷ 2.5 Hz as if electromechanical oscillations. For this purpose, PSS should produce such a component of an electromagnetic torque that is opposite to the mechanical torque. Such a component should be in phase with the deviation of the rotor speed.

The input signal in the PSS is measured at the generator connection and determines the type of controller structure. Different types of stabilizing circuits are designed. In Fig. 2.1 shows the structure of the dual input power stabilizer known as PSS2B (according to the IEEE standard 421.5.2005). PSS2B uses the deviation of the speed and the active power to determine the stabilizing signal.

In Fig. 2.2 shows the structure of the PSS1A type stabilizer (according to IEEE). A washout filter with a time constant T_f allows crossing the signal of the active power deviation of the generator without changes. In this way, a change of amount of active power does not affect the voltage of the generator. This block allows the stabilizer to operate only in case of transient changes in the active power signal. The value of the appropriate time constant should be large enough so that the signal of a deviation can be crossing without changing the frequency range of interest. In the case of a local oscillation of the generator in a frequency range of 1 ÷ 3 Hz, the time constant of the derivative block T_f in the amount of 1s may be satisfactory, while in the case of interconnection in a frequency range of 0,1 ÷ 0,6 Hz. The desired value of the time constant T_f is about 10s.

The amplification K_{stab} determines the size of the damping that is introduced by acting on the stabilizer. Damping of the oscillation is increased by increasing the amplification to a certain limit when the increase in amplification causes a decrease in the oscillation of the generator [5]. The phase compensation block compensates the phase lag between the input in the excitation system and the electromagnetic torque. To achieve the appropriate phase compensation, it is possible to use two or three blocks of first-order or a second-order block with complex solutions. The output signal from the stabilizer has a positive (V_{smax}) and negative (V_{smin}) limit. The positive limit can be set (according to the IEEE) to the amount of 0,2 p.u. in order to ensure the efficiency of the stabilizer during large scales, and the negative limit set to the amount of 0,1 p.u. is considered satisfactory. This ensures sufficient bandwidth of the stabilizer.

Fig. 2.2 Structure of the stabilizer type PSS1A (according to IEEE)



From the stabilizer is required damping of oscillations that are of a local character and an inter-area character. Depending on a type of oscillation, the stabilizer performs phase compensation in a certain frequency range. The phase characteristic to be compensated, changes with the change in the state of the system, so the setting of the stabilizer for one condition does not mean a satisfactory setup for another state of the system.

III. Case Study

The current characteristic of Macedonian electric power system is domination of thermal power plants (TPP), which produce about 80% of total electricity demand. TPP Bitola is the biggest and most essential in the country. It has three units with installed capacity of 233 MW per unit or total 700 MW. This potential allows the plant to participate with more than 70% in total electricity production in the Macedonian power system. TPP Bitola is linked to the power system through substation 400/110 kV Bitola 2 that is the most important in Macedonia.

Impact of a power system stabilizer is examined on synchronous generator installed in unit “Bitola 1”. Generator’s main parameters under observation are excitation voltage (E_{fd}), active power (P) and terminal voltage (U). During the test three phase short circuit and transmission line outage are simulated. The generator and the network are modelled in Neplan 5.5.3 software.

A. Power system stabilizer modelling

Static excitation system DIREMK - Koncar is installed at the generators in TPP Bitola [6]. Control of the excitation system is based on microprocessor twin-channel voltage regulator. Fig. 3.1 is a block diagram of the stabilizer of electromechanical oscillation which is an integral part of the voltage digital controller. The stabilizer corresponds to the type PSS2B (according to the IEEE Std. 421.5 classification). A combined stabilizer is used in two quantities: active power and frequency. The stabilizer has the same standard transmission function for both channels, but with different parameters:

$$F(p) = K_{ss} \frac{pT_D}{(1+pT_F)(1+pT_D)} \quad (1)$$

where:

K_{ss} – gain the stabilizer per channel,
T_F – time constant of the stabilizer (filter)
T_D - time constant of the stabilizer (derivative)

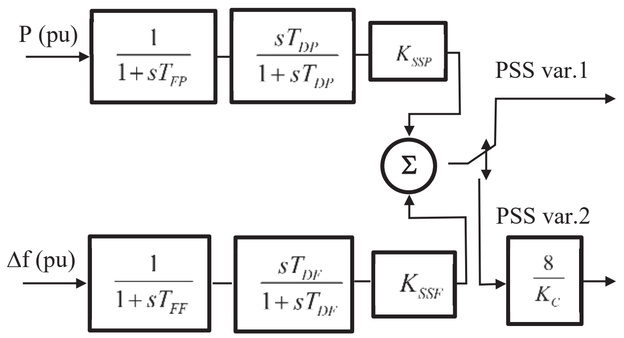


Fig. 3.1 Block scheme of the power system stabilizer (Koncar)

The input signals (active power and frequency) are filtered with given time constants. The filtered signals are further multiplied according to the amplification of the individual channels depending on whether the signals are entered in the summator before the PI - regulator (index 1) or after it (index 2). The output of the stabilizer is an output as PSS1 in the case when the stabilizer signal is kept in a summator before the voltage regulator and as PSS2 when the stabilizer signal is added to the output signal from the voltage regulator. With the help of logical parameters, the active power channel, or the channel in frequency, can be separately activated.

B. Excitation System Response to a Short Circuit with and without PSS

This test was performed in order to show excitation system reaction on large network disturbance. Three phase short circuit at 110 kV bus bar of SS Bitola 2 is simulated. Short circuit appears on 0,1s, duration of the test is 5s and short circuit time is chosen 0,2s as typical short circuit length in power system. Fig. 3.2 shows excitation voltage changes, terminal voltage and active power fluctuation without PSS and Fig. 3.3 shows the same parameters with PSS as a part of the excitation system.

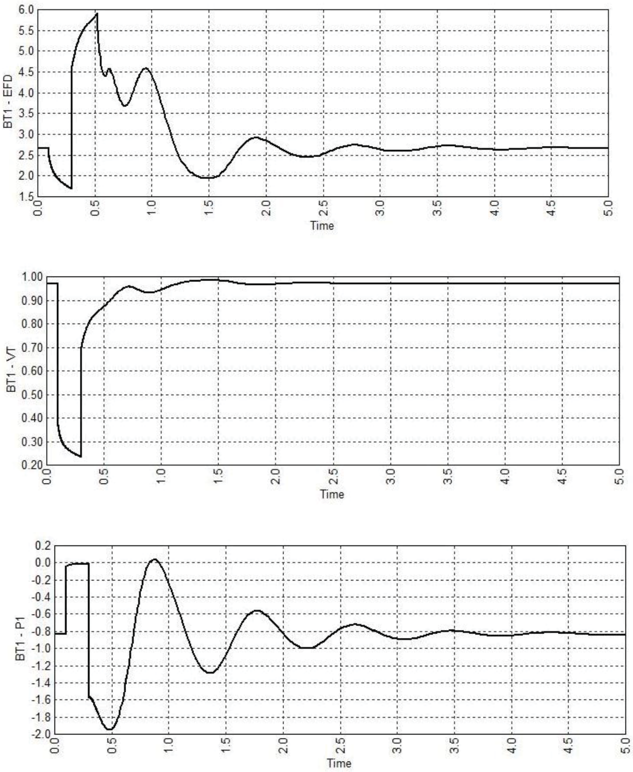


Fig. 3.2 Excitation voltage, terminal voltage and active power (PSS - off)

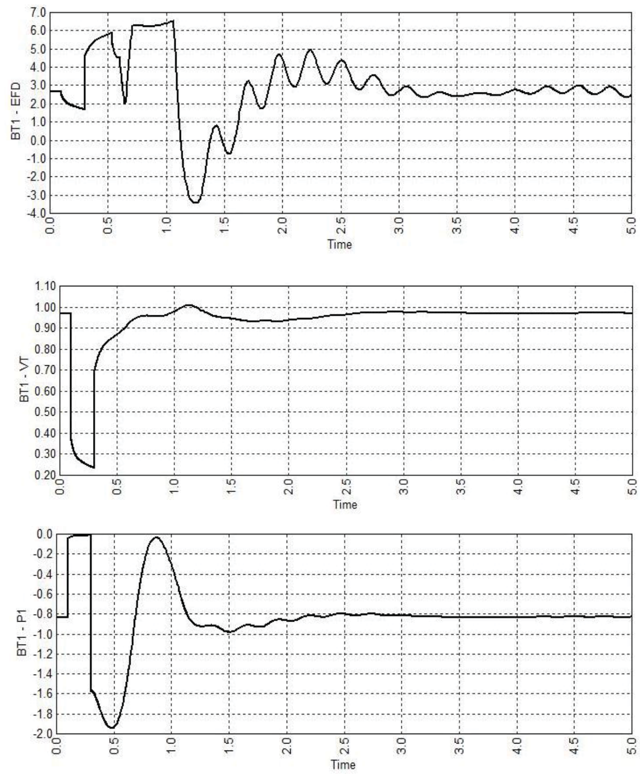


Fig. 3. 3 Excitation voltage, terminal voltage and active power (PSS - on)

C. Excitation System Response to a Transmission Line Outage with and without PSS

This test examines excitation system response during transmission 400 kV line outage. The line connects TPP Bitola with the main consumption center, the capital city Skopje. Time duration of line outage is 0,3s simulating auto reclosing of transmission line. Fig. 3.4 and 3.5 show system parameters changes without and with PSS.

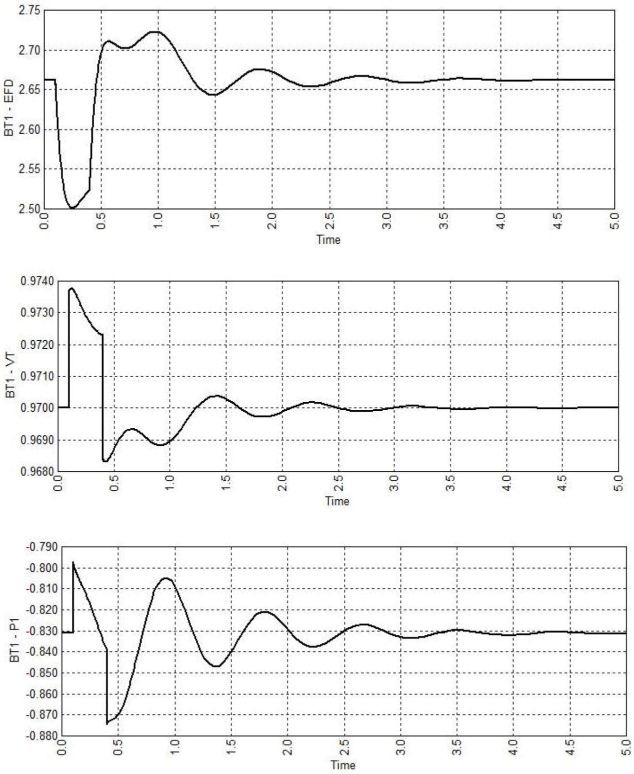
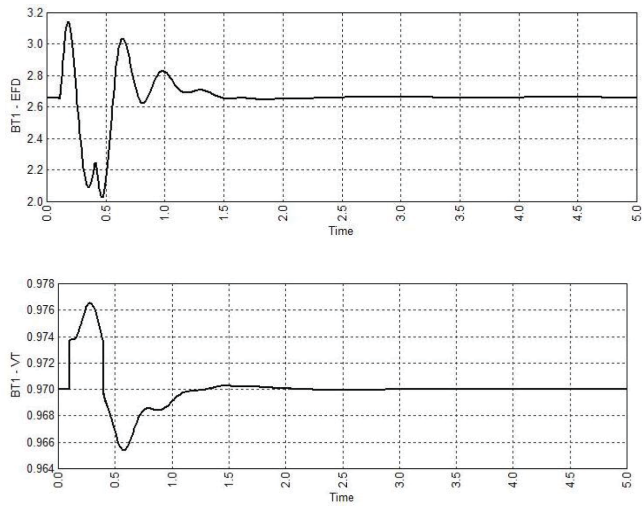


Fig. 3.4 Excitation voltage, terminal voltage and active power (PSS - off)



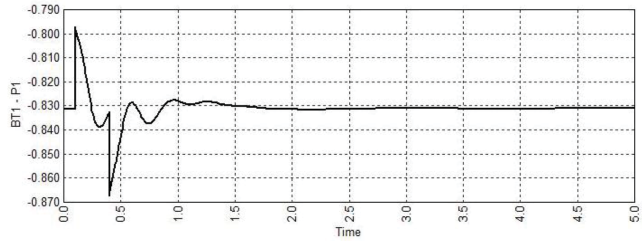


Fig. 3.5 Excitation voltage, terminal voltage and active power (PSS - on)

IV. Conclusion

The aim of the work was to investigate behavior of synchronous generator excitation system at TPP Bitola in different conditions and impact of its power system stabilizer on excitation system response. The test was performed with real system parameters of Macedonian power system modelled by Neplan 5.5.3 software. Based on the performed analysis, and the simulations results it is possible to conclude that a stabilizer of electromechanical oscillations can reduce the oscillation, especially active power fluctuation, in given operation range. To provide effective damping and ensure the stability, the PSS should be properly chosen and carefully tuned.

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