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PSS3B SYSTEM STABILIZER PARAMETER OPTIMISATION IN MULTI-MACHINE POWER SYSTEM

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Abstract: *The paper presents the results of parameter optimisation of PSS3B dual input power system stabilizers designed for damping rotor swings of synchronous generators in the power system of a non-linear mathematical model. It is assumed that the power system consists of generator nodes and receiving nodes, all interconnected by the power system network. A generator with its excitation system and the PSS operates within the generator nodes. The generator is powered by a driving turbine with governor system. The parameters of the system stabilizers were determined by minimising the generalised quality factor in the multi-machine power system. The quality factor was calculated from deviations of the active power, rotational speed and generator voltage in individual generator nodes for transient symmetrical short-circuits in transmission lines of the system. The exemplary optimisation computations were carried out for a Cigre 7-machine power system. The presented computations were performed for systems with and without stabilizers.*

Key words: *power system, dual input PSS, PSS3B*

INTRODUCTION

System stabilizers included in excitation control systems of synchronous generators are used to damp low frequency rotors swings of synchronous generators [2]. These swings are called electromechanical swings and appear in the power system as a result of different disturbances.

Nowadays dual input system stabilizers are widely used. Their input signals are proportional to the real power (P) and angular speed (ω) of a generator (or to their deviations with respect to the steady-state values). The PSS3B stabilizer shown in Fig.1 is an example of such a dual input stabilizer [1].

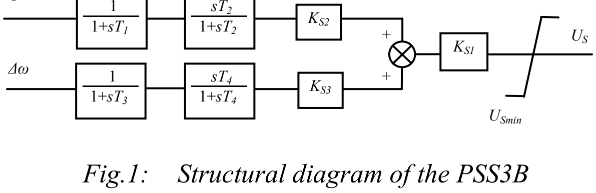


Fig.1: Structural diagram of the PSS3B

1 PSS PARAMETER OPTIMISATION FOR DIFFERENT SZSTEM LOAD CONDITION

Optimisation of the system stabilizer selected parameters can be carried out by minimising the deviations of specific quantities for different typical steady-state disturbances. As far as stabilizer application is concerned, electromechanical swings, that is the angular speed (ω) and real power (P) of the generator, are taken into account above all. Introducing system stabilizers in excitation systems should not cause deterioration of the generator terminal voltage (V_T). The damping of swings is especially important in cases of large disturbances, e.g. transient short-circuits, which can be dangerous to the system stability. A quality factor can be related to one disturbance of the selected multi-machine power system load [1, 3, 5, 8, 9]:

$$J_k(\boldsymbol{P}) = \sum_{j=1}^{N} \sum_{i=1}^{n} \left(w_p \left|\Delta P_{ij}(\boldsymbol{P})\right|\right)^2 + \left(w_\omega \left|\Delta \omega_{ij}(\boldsymbol{P})\right|\right)^2 + \left(w_V \left|\Delta V_{Tij}(\boldsymbol{P})\right|\right)^2 \quad (1)$$

where: $\boldsymbol{P}$ – vector of the optimised system stabilizer parameters for particular generating units, N - number of generating units in power system, ΔP_{ij}, $\Delta\omega_{ij}$, ΔV_{Tij} - deviations of the real power, angular speed and terminal voltage of a particular (j-th) generating unit (in p. u.) in successive (i-th) time instants w_p, w_ω, w_V – weighing coefficients.

System stabilizers should damp electromechanical swings under various loads and in different system configurations. Therefore, a generalised quality factor was introduced:

$$J = \sum_{k=1}^{K} J_k(\boldsymbol{P}), \quad (2)$$

where $K = L * M$, M – number of system load conditions, L – number of steady-state disturbances.

Determination of the system stabilizer optimal parameters can be brought to minimisation of the quality factor (2).

Appropriate selection of weighting coefficients of the minimised quality factor is of great importance. The weighting coefficients connected with the real power can be dependent on the rated apparent power generated in particular generating units [1, 3, 5]:

$$w_{pj} = \frac{n_{jm} S_{Gj}}{S_{\boldsymbol{max}}}, \quad (3)$$

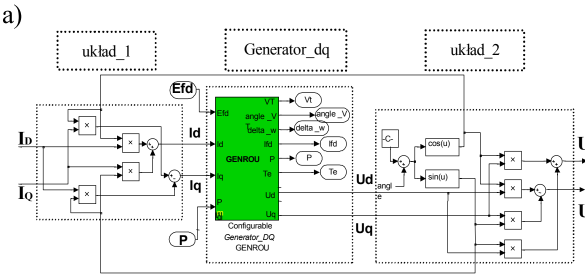
where: n_{jm} – number of generators operating in the j-th generating unit under the m-th system load condition, S_{Gj} – rated apparent power of a single synchronous generator operating in the j-th generating unit, $S_{\max}$ - rated apparent power of this unit whose apparent power generated is the highest under the particular power system load condition.

The relations between the weighting coefficients connected with different quantities are also essential. It is proposed to assume relatively large values for the weighting coefficients $w_{\omega j}$ and w_{Vj} compared to the weighting coefficients w_{pj} [1, 3, 5].

2 MATHEMATICAL MODEL OF THE SYSTEM

A mathematical model of a power system in the Matlab–Simulink environment was developed. A general model of the generating unit was realised (Fig. 2a). In this model, using the *"Configurable Subsystems"* type blocks, it is possible to create a specific model of the generating unit when choosing the specific model of: a synchronous generator, an excitation system, a turbine and a system stabilizer including PSS3B [1, 3].

a)



b)

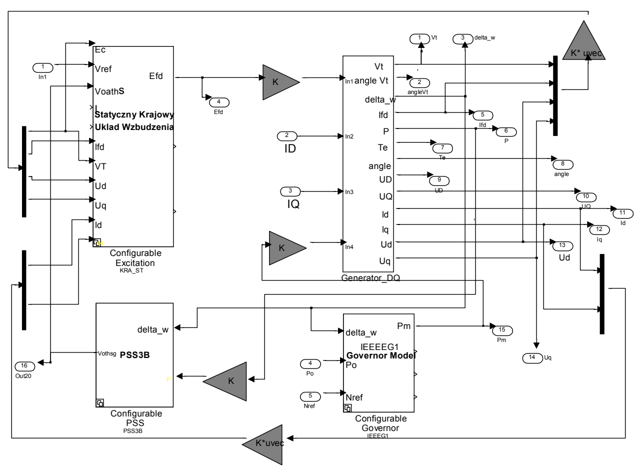


Fig. 2. Structural model of generating unit (a) and Generator_DQ system(b) in the Matlab–Simulink environment

The *Configurable Generator_dq* block in Fig. 2b represents the state and output equations of the synchronous generator determined in the cartesian coordinate system (d, q) rotating with the electrical angular speed (ω).

These equations in the coordinate system (d, q) (when neglecting transformation voltages in the armature circuits) in the network relative units are as follows [1, 3, 5]:

$$\frac{d\boldsymbol{X}_M}{dt} = \boldsymbol{M}_M \boldsymbol{X}_M + \boldsymbol{N}_m \boldsymbol{I}_m + \boldsymbol{B}_{MF} \boldsymbol{U}_{fd} + \boldsymbol{f}_{sat}(\boldsymbol{X}_M),$$
$$\frac{d\omega}{dt} = \frac{1}{T_m}(P_m/\omega - M_e), \quad \frac{d\delta}{dt} = \omega_N(\omega - 1), \quad (4)$$
$$\boldsymbol{U}_m = \boldsymbol{K}_m \boldsymbol{X}_M - \boldsymbol{Z}_m \boldsymbol{I}_m,$$

where: $\boldsymbol{X}_M$ – electromagnetic state variables of the generator linearly dependent on the fluxes linked with the rotor circuits, $\boldsymbol{U}_m = [U_d, U_q]^T$, $\boldsymbol{I}_m = [I_d, I_q]^T$ - voltages and currents of the armature in d and q axis, U_{fd}, P_m, M_e, δ, ω_N, T_m – field voltage, turbine mechanical power , electromagnetic torque, power angle, rated angular speed, electromechanical time constant, $\boldsymbol{M}_M$, $\boldsymbol{N}_M$, $\boldsymbol{K}_m$, $\boldsymbol{Z}_m$ – matrices dependent on the electromagnetic parameters of the generator model, $\boldsymbol{f}_{sat}$ – nonlinear function determining the generator magnetic circuit saturation.

Configurable Excitation, *Configurable Governor* and *Configurable PSS* blocks in Fig. 2a represent the state and output equations of the selected excitation system, turbine and system stabilizer models (in relative *regulator* units) [5]. The other (shaded) blocks in Fig. 2a include appropriate correction coefficients that allow making relations between the quantities expressed in different relative units.

The application of *network* relative units to the state equations of generators as well as transformation of currents and voltages of generator armatures to the common coordinate system (D, Q) rotating with the angular speed ω_N enables obtaining the convenient relations between the state equations of the particular generating units and the voltage-current equations of the power network. There are the following relationships between the quantities in the coordinate system (d, q) and those in the system (D, Q) [1, 3, 5]:

$$W_{(d,q)} = \boldsymbol{t}_r W_{(D,Q)}, \; W_{(D,Q)} = \boldsymbol{t}_r^{-1} W_{(d,q)}, \qquad (5)$$

where transformation matrix $\boldsymbol{t}_r = \begin{bmatrix} cos\delta_{GS} & sin\delta_{GS} \\ -sin\delta_{GS} & cos\delta_{GS} \end{bmatrix}$, W – currents and voltages of the armature in different coordinate systems, $\delta_{GS} = \delta - \delta_S$, δ_S - angle of the power system position in coordinate system (D, Q). Relationship (5) is realised in the *Generator_DQ* block.

A model of the complete power system can be created by combining models of all generating units and taking into account the voltage and current equation of a reduced power network [5]:

$$\boldsymbol{I}_{WM} = \boldsymbol{Y}_{sr}\boldsymbol{U}_{WM}, \qquad (6)$$

where: $\boldsymbol{I}_{WM}$, $\boldsymbol{U}_{WM}$ – vectors of the armature currents and voltages of all generating units in (D, Q) axis, $\boldsymbol{Y}_{sr}$ – admittance matrix representing an equivalent power network which includes only generating nodes connected by means of artificial branches.

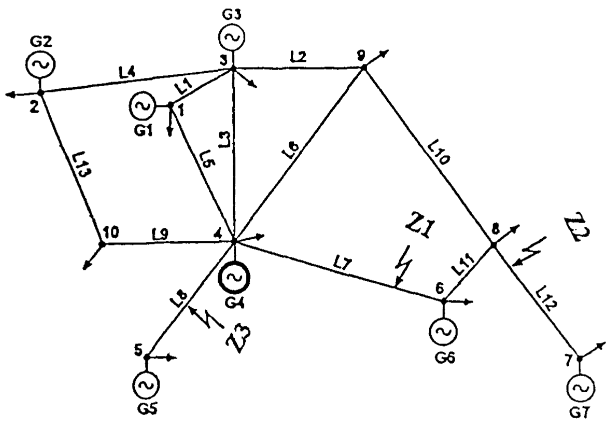


Fig. 3. Cigre power system.

Computations were carried out for a 7-machine test *Cigre* power system shown in Fig. 3. The model for the system was developed in the Matlab–Simulink environment.

It was assumed in computations that all synchronous generators were represented by a non-linear model of a GENROU turbogenerator [4, 6]. Four equivalent electric circuits in the rotor, two in the d axis (excitation circuit and one damper circuit) and two in the q axis (two damper circuits) correspond to this model. It was assumed that the excitation systems were represented by a nonlinear model of the national static excitation system [1], and the turbines by an IEEEG1 steam turbine model [4].

3 COMPUTATION RESULTS

The system stabilizer parameters were calculated in two stages. At the first stage there was analysed each of the seven generating units of the system. For each unit a set of the optimised stabilizer parameters was determined by minimising the quality factor (2) determined for the given single-machine system. A transient transmission line short-circuit was modelled (short-circuit time 0.25 s). The typical line impedances Z_e=j0.6 and Z_e=j0.3 were assumed.

The quality factor was minimised using the Newton gradient algorithm with limitations [7]. The computation results of the optimised stabilizer parameters obtained at the first stage are presented in Table 1. The other parameters were assumed to be constant K_{S1}=1, V_{Smax}=0.2, V_{Smin}=-0.066.

Generating unit	K_{S2}	K_{S3}	T_1	T_2	T_3	T_4
G1	6.0	0.300	1.00	5.0	0.052	5.0
G2	6.0	0.300	0.010	5.0	0.047	5.0
G3	3.67	0.057	0.100	4.99	0.036	0.101
G4	6.0	0.300	0.010	5.0	0.010	5.0
G5	6.0	0.282	0.100	5.0	0.071	5.0
G6	6.0	0.282	0.100	5.0	0.071	5.0
G7	6.0	0.162	0.054	5.0	0.100	5.0

Tab. 1:Computation results of stabilizer parameters (stage I)

At the second stage computations were carried out for a multi-machine system. It was assumed that the time constants were correctly determined at the first stage (in order to limit the number of optimised system stabilizer parameters at stage II). At the second stage the gains K_{S2} and K_{S3}, which are most responsible for damping electromechanical swings, were optimised for particular stabilizers.

The gain values computed at the first stage were the starting point for the second stage. In order to finally determine the quality factor (2) for the multi-machine system, there were separated three disturbances (denoted by Z1, Z2, Z3 in Fig.3). They were symmetrical short-circuits of time duration t_z=0.25 s in the transmission lines close to the generating units G7, G6, G5. The computation results of the optimised gains are given in Table 2.

Generating unit	K_{S2}	K_{S3}
G1	6.948	0.214
G2	5.929	0.235
G3	5.871	0.322
G4	2.290	0.400
G5	3.458	0.148
G6	5.990	0.409
G7	3.813	0.392

Tab. 2:Computation results of gains (stage II)

When computing the gain K_{S2} (K_{S3}) values their upper limit value was assumed to be 20 (0.5).

Fig. 4 shows the exemplary transients of the real power, armature voltage and generator angular speed in the selected generating units in the system without stabilizers and with system stabilizers of the parameters computed at the first and second stages.

From Fig. 4 it follows that the introduction of PSS3B system stabilizers of the optimised parameters resulted in damping the electromechanical swings. The generator armature voltage transients were also satisfactory.

a)

b)

c)

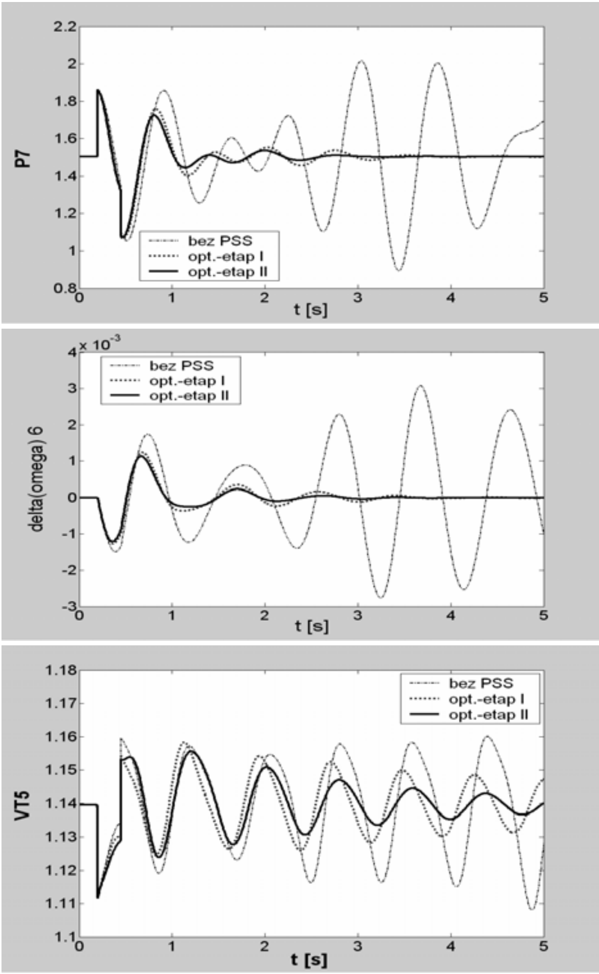


Fig.4:Transients of real power at node G7 (a) – disturbance Z2, deviations of angular speed at node G6 (b) – disturbance Z1 and generator terminal voltage at node G5 (c) – disturbance Z3

Table 3 shows the electromechanical eigenvalues of the linearised system model.

System without PSS	System with PSS – parameters optimised at stage I	System with PSS – parameters optimised at stage I and II
-0.533±j10.42	-1.24±j11.37	-1.20±j11.23
-0.716±j10.06	-1.15±j11.06	-1.45±j11.10
-0.379±j9.35	-1.08±j10.46	-1.27±j10.63
-0.229±j8.53	-1.64±j9.59	-2.30±j9.97
-0.148±j7.87	-0.41±j 8.10	-0.70±j7.92
+0.088±j6.44	-1.26±j 6.73	-1.92±j6.22

Tab. 3: Electromechanical eigenvalues of the system

Introducing the PSS resulted in moving the electromechanical eigenvalues to the left on the complex plain.

4 APPLICATION OF OPTIMISATION COMPUTATION METHOD TO POLISH POWER SYSTEM

The method presented was also used for computations of parameters of the PSS3B stabilizer installed in a 200 MW generating unit with an electro-machine excitation system in Power Plant Rybnik [10]. In that case the computations were confined to the analysis of a single-machine system: generator – infinitive bus when taking into account the generator rated load and different impedances of the transmission line. A step change of the voltage regulator voltage equal to ∓ 3 % of the steady state was assumed to be a disturbance. The computation results are given in Table 4.

Parameter	K_{S2}	K_{S3}	T_1	T_2	T_3	T_4
-	6.0	0.050	0.028	0.847	0.010	5.0

Tab. 4:Computation results of stabilizer parameters

The measurements were taken in Power Plant Rybnik thanks to the cooperation with Energotest-Gdańsk company. Fig.5 shows the active power waveforms at the step change in the regulator voltage by -3%, then by +3% of the steady state. Fig.5a refers to switching the PSS3B stabilizer off, while Fig. 5b to switching the stabilizer on (stabilizer parameters as in Table 4).

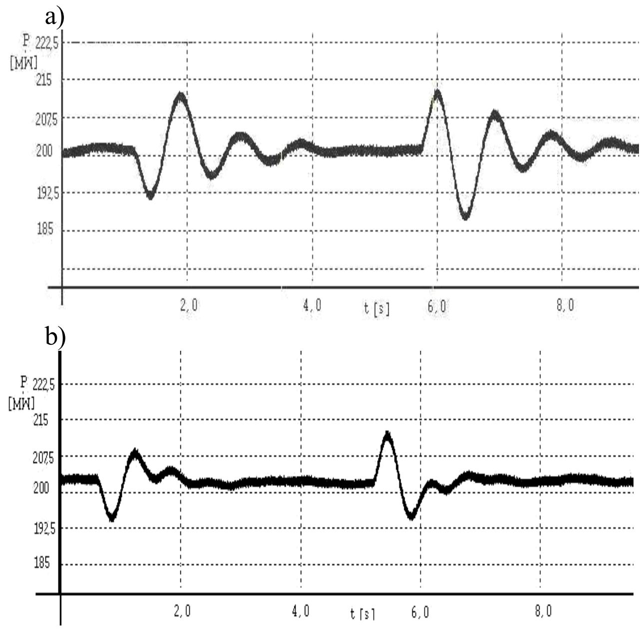


Fig.5:Active power at voltage regulator voltage step by $\mp$ 3 % recorded during measurements in Power Plant Rybnik when switching the stabilizer off (a), with the stabilizer of optimised parameters (b)

From the waveforms presented it follows that the PSS operates correctly. Introducing the PSS of appropriately selected parameters results in more efficient damping the electromechanical swings of the active power. The proposed method for system stabilizer parameter optimisation by minimisation of the quality factor (2) was positively verified when taking measurements during the power system operation.

5 CONCLUSIONS

The paper describes the method for parameter optimisation of PSS3B system stabilizers operating in a multi-machine power system. The optimal stabilizer parameters were determined in two stages. At the first stage there were computed the stabilizer parameters in particular generating units by minimising the generalised quality factor for each generating unit in a single machine system. At the second stage stabilizer gains were computed by minimising the quality factor (2) determined for a multi-machine system. The presented computations show that the dual input PSS3B system stabilizer of correctly adjusted parameters damps well electromechanical swings that appear in power systems during large disturbances without causing deterioration of the generator terminal voltage

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