Damping Low-frequency Oscillations by Three-channel Power System Stabilizer PSS4B

Nikolay Nikolaev[1], Yulian Rangelov[2], Konstantin Gerasimov[3]

***Abstract* – It is a well-known fact the power oscillations in electric power systems consist of many frequencies. The classic type power system stabilizers PSS2A and 2B each have one phase shift block and thus their optimal settings are around a certain frequency meaning that they cannot damp the local and the inter-area oscillation at the same time. In regard to this issue the multiband power system stabilizers, like PSS4B, were developed. This paper reviews the capabilities of the modern three-channel PSS. A comparative analysis in cases with PSS2A either PSS4B is made and graphical results are present.**

***Keywords* – Power system stabilizer, input filters, multiband power system stabilizers, electric power system.**

I. INTRODUCTION

Because the automatic voltage regulator (AVR) takes into account only the generator terminal voltage, it is possible that they have bad influence on the generator damping. This drawback can be compensated if other input quantities are considered. This approach can not only neutralize this negative AVR influence but even increase the synchronous generator damping coefficient and therefore improve the stability. This is the main idea of the power system stabilizer. Additional signals can be obtained from quantities for instance the change in the rotor speed ($\Delta\omega$), in the generator voltage frequency (Δf), or in the electrical power (ΔP_E) [2,4,5,6].

The block diagram of the main PSS elements is shown in Fig. 1. Special sensors for speed, frequency or power transform the measured quantities into controlling voltage. After that its phase is shifted in such a way that it can appropriately compensate the time delay of the generator and the excitation system. The obtained signal is amplified to the required level and is being limited by the end module, if it is necessary.

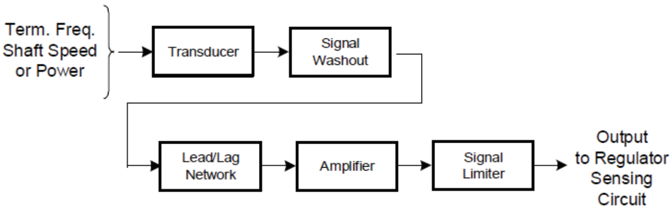

Fig. 1. Main PSS blocks

System stabilizers of type PSS4B are structurally based on three separate frequency bands – for mode oscillations with low, medium and high frequencies.

The low frequency band usually is specific for global system oscillations, the medium frequency band – for inter-area oscillations, and the high frequency band – for local oscillations. Each of the three channels is consisted of differential filter, amplifier and limiter. Their outputs are summed and are entered into the end limiter V_{STMIN}/V_{STMAX}, forming the final output signal V_{ST} of the stabilizer. Its structural scheme is shown in Fig. 2.

PSS4B measures the speed deviation in two different ways. $\Delta\omega_{L-I}$ acts as input signal in the low and medium frequency channels while $\Delta\omega_H$ is entered into the high frequency channel. The equivalent model of those two speed sensors is shown in Fig. 3. Additional notch filters with transfer function $N_i(s)$ for regulating the level, can be used for the torsional modes of the steam turbine generators. They are described with the following equation [5,6]:

$$N_i(s) = \frac{s^2 + \omega_{ni}^2}{s^2 + B_{wi}.s + \omega_{ni}^2} \tag{1}$$

where ω_{ni} is the frequency of the filter, and B_{wi} is its frequency band at 3 dB.

Although the parameters of the differential filters can be tuned in different ways, a simple method for tuning is based on three symmetrical band filters, correspondently set to frequencies F_L, F_I and F_H. The time constants and gains of the separate channels are obtained from equations (2), (3), (4) and the equation (5) for low frequency band [7]. It is necessary that only six parameters are known – F_L, F_I, F_H, K_L, K_I, K_H.

$$T_{L2} = T_{L7} = \frac{1}{2\pi F_L \sqrt{R}} \tag{2}$$

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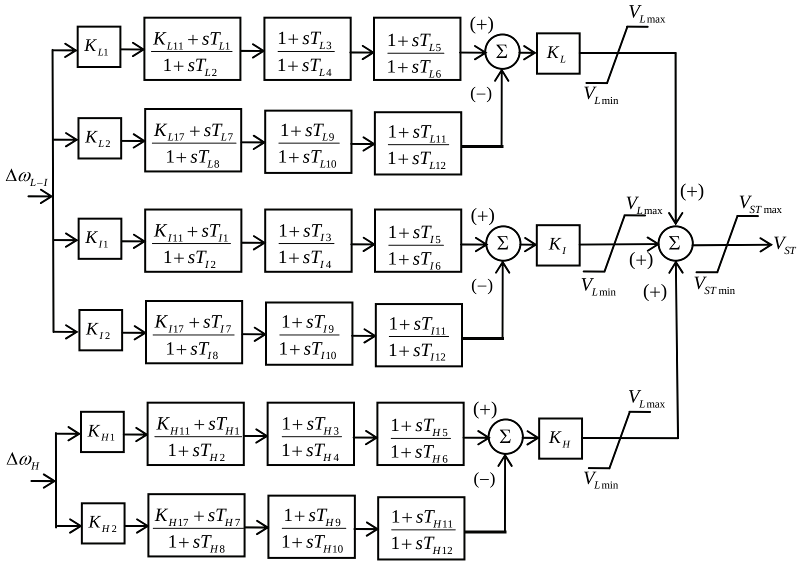

Fig. 2. Block diagram of PSS4B

$$T_{L1} = T_{L2} / R \tag{3}$$

$$T_{L8} = T_{L7} \cdot R \tag{4}$$

$$K_{L1} = K_{L2} = (R^2 + R) / (R^2 - 2R + 1) \tag{5}$$

where R is a constant. Such relations are also valid for the other two channels. A total of 24 parameters are selected.

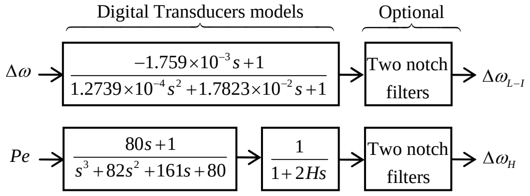

Fig. 3. Block diagram of the sensors for change of the speed

II. PROBLEM FORMULATION

In Fig. 4 is shown the structure of the analyzed united electric power system (EPS) [2,8]. The first EPS is represented in more details with two zones, and the second – generalized. The connection between the two zones is made by long 400 kV power line (W5). The task is to analyze and compare the electromechanical oscillations of G4 without PSS, with PSS2A and with PSS4B.

The data for the steady state and the circuit parameters are as follows:

1) Generators (G_1 - G_4): $U_{н}$=15,75 kV; $P_{н}$=280 MW; x_d=2,19; x_q=2,1; x'_d=0,34; x'_q=0,54; x''_d=0,25; x''_q=0,25; x_l=0,2; r_a=0,003; T'_{d0}=4,54s; T'_{q0}=0,38s; T''_{d0}=0,031s; T''_{q0}=0,068s; T_J=11,12s. Generator G_5: $U_{н}$=400 kV; $P_{н}$=2000 MW; x''_d=0,05; r_a=0; T_J=6s; D=1.

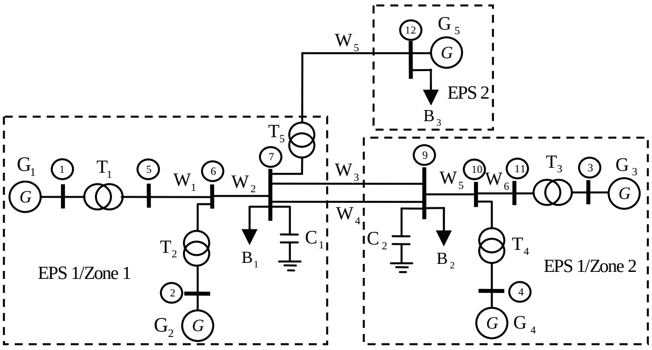

Fig. 4. Structure of the analyzed united EPS

2) Power lines

TABLE I. POWER LINES' PARAMETERS

Nodes	$U_{н}$, kV	R, p.u.	X, p.u.	B, p.u.
5-6; 10-11	400	0,0025	0,025	0,04375
6-7; 9-10	400	0,001	0,01	0,0175
2x(7-9)	400	0,037	0,37	0,385
7-12	400	0,0025	0,25	0,044

3) Transformers

TABLE II. TRANSFORMERS' PARAMETERS

Nodes	$U_{н1}$, kV	$U_{н2}$, kV	$S_{н}$, MVA	R, p.u.	X, p.u.
5-1; 6-2; 10-4; 11-3	400	15,75	295	0	0,13

4) Excitation system with regulator type UNITROL from ABB (Fig. 5): T_r=0,02s; T_S=0,003s; K_R=350; T_{c2}=1s; T_{b2}=1s; T_{c1}=5s; T_{b1}=6,6s.

5) PSS – IEEE PSS2A (Fig. 6): TW_1=TW_2=TW_3=2s; TW_4=0s; T_6=0s; T_7=2s; KS_2=0,18; KS_3=KS_4=1; T_8=0,5s; T_9=0,1s; N=1; M=5; KS_1=10; T_{L1}=0,2s; T_{L2}=0,03s; T_{L3}=0,1s; T_{L4}=0,02s;

6) PSS - IEEE PSS4B:
K_{L1}=7,7; K_{L2}=0; K_{L11}=0; K_{L17}=0; T_{L1}=5s; T_{L2}=5s; T_{L3}=0,36s; T_{L4}=1,57s; T_{L5}=0,37s; T_{L2}=1,21s; K_{L}=11,14s;
K_{I1}=6,5; K_{I2}=0; K_{I11}=0; K_{I17}=0; T_{I1}=0,4s; T_{I2}=0,4s; T_{I3}=0,19s; T_{I4}=0,38s; T_{I5}=0,1s; T_{I2}=0,09s; K_{I}=25,6;
K_{L1}=10,5; K_{L2}=0; K_{L11}=0; K_{L17}=0; T_{L1}=0,03s; T_{L2}=0,03s; T_{L3}=0,096s; T_{L4}=0,021s; T_{L5}=0,09s; T_{L2}=0,01s; K_{L}=49,2.

Regime parameters of the analyzed EPS

1) Complex loads and capacitive power of the shunt condensers: P_{B1}=320 MW; Q_{B1}=133 MVAr; Q_{C1}=60 MVAr; P_{B2}=600 MW; Q_{B2}=133 MVAr; Q_{C2}=50 MVAr.

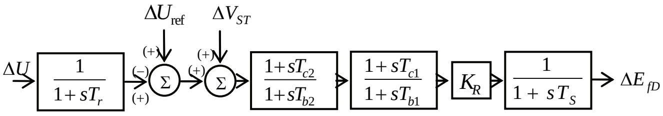

Fig. 5. AVR type UNITROL

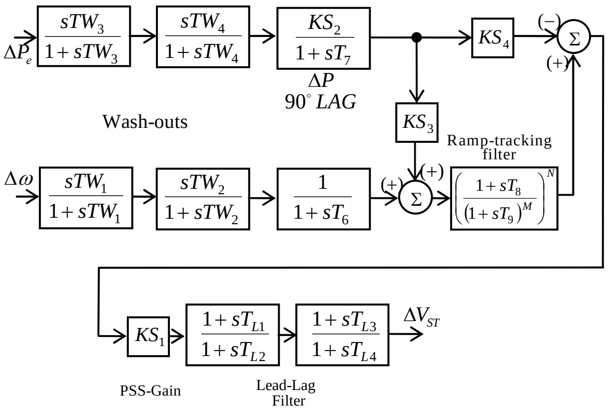

Fig. 6. System stabilizers type PSS2A

2) Generator regime

TABLE III. GENERATOR REGIME PARAMETERS

Generators	*P*, MW	*Q*, MVAr	*U*, p.u.
G_1	245,00	77,479	1,03
G_2	245,00	29,644	1,01
G_3	719	74,224	1,03
G_4	700	65,590	1,01
G_5	-50,452	24,304	1,00

III. RESULTS

In order to assess the PSS effect, the specialized software tool NASAVR [1,2] is used. It is developed by a team from department Electric Power Engineering in Technical University of Varna. NASAVR operates in the MATLAB and Simulink environment and is capable of tuning automatic voltage regulators and power system stabilizers of synchronous generators in large electric power unions considering the influence of the specific generator unit parameters and of the EPS, to which it is connected.

In Fig. 7 is shown the generalized assessment for the transient processes quality by the means of the H_∞ norm for the three different cases.

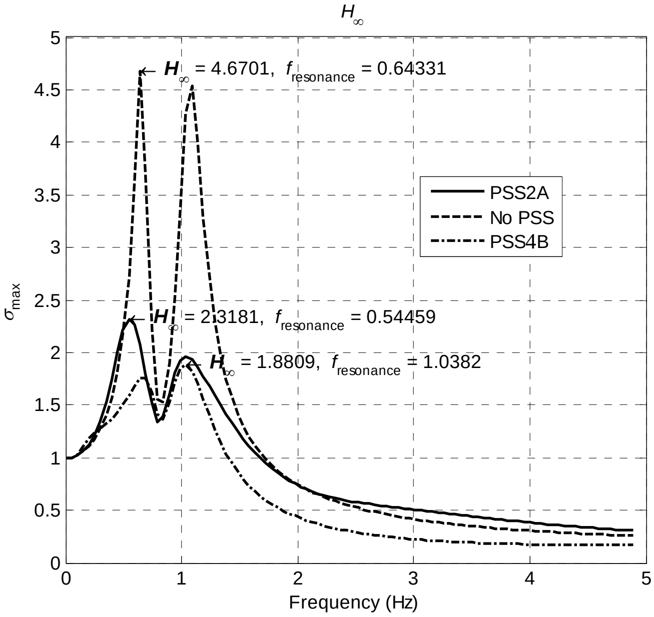

Fig. 7. Generalized assessment of the transient processes quality - H_∞

The analyzed system is constructed in such a way so that distinct oscillations between the generators in the separate zones are observed with frequency around 0,63 Hz. An oscillation with frequency of around 1 Hz (the local mode) is also observed. The installation of PSS leads to successful damping of those oscillations and PSS4B copes equally well with the local and the inter-area oscillations because of its specific design. Another important aspect is that its settings can be optimized for damping inter-area oscillations without worsening its influence on the local oscillations. For PSS2A this is possible but only to a certain extent.

Fig. 8 shows the frequency response of the change of the voltage, the active power and the rotor angular speed for unit step disturbance of the AVR reference. As expected, good damping of the electromechanical oscillations is observed in case of PSS presence.

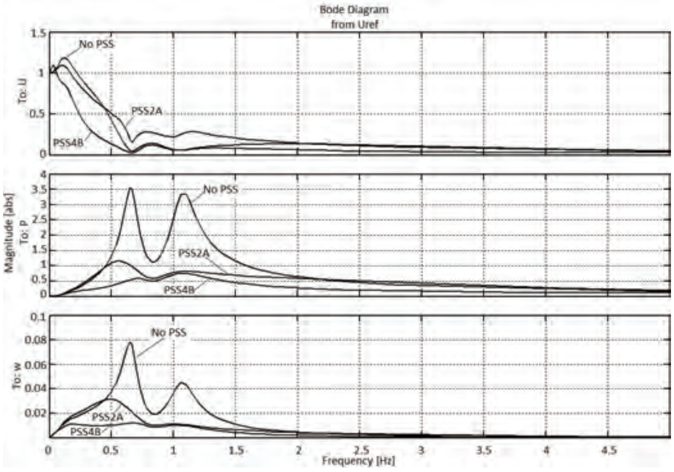

Fig. 8. Frequency response of the change of *U*, *P* and *ω* for unit step disturbance in the AVR reference

The step response, shown in Fig. 9, demonstrates the transient processes progress in time of U, P and ω for change of the AVR reference (ΔU_{ref}) with one percent.

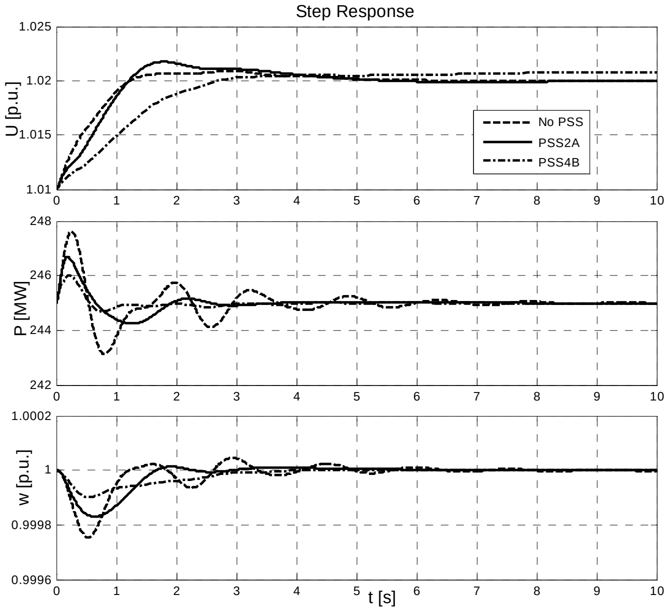

Fig. 9. Step response of U, P and ω for ΔU_{ref} =1%

The clearly expressed oscillations of the regime parameters of the generator without PSS are successfully damped when system stabilizer is activated. The best results are obtained with the use of PSS4B.

IV. CONCLUSION

From the conducted comparative analysis the following conclusions can be made:

1. The use of modern system stabilizers significantly improves the transient processes quality at normal parallel operation of the generators in EPS and even makes them obligatory for generating units with bigger power;
2. The creation of large electric power system unions favors the occurrence of low frequency inter-area and inter-zone oscillations, which can be successfully damped with PSS4B without decrease of the local oscillations damping in the specific machine;
3. In all conducted tests PSS4B behaves better and is far more flexible in terms of tuning;
4. The use of special software for modal analysis of the processes in EPS and for PSS tuning enables the accurate determination of problematic synchronous generators in EPS and appropriate tuning of their stabilizers.

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