Influence of the Settings of PSS2A and 2B Input Filters over the Damping of Low-frequency Power Oscillations

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***Abstract* – In the electric power system of Bulgaria power system stabilizer type PSS2A and 2B are most common. They were installed during the preparation period for connection with the European electric power system. Usually the settings of these stabilizers refer to the gain and time constants of the phase shift block. This paper proves that the settings of the input filters can influence the damping of local and mostly of inter-area oscillations, which is a real problem after the actual connection of the power systems. An algorithm for calculation of these settings is proposed and results for single-machine and multi-machine sample system are discussed.**

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

I. Introduction

In order to highlight the influence of the input filters (Fig. 1) of PSS-2A and 2B on the mechanical oscillations damping, an algorithm for calculation of their settings is developed.

The blocks with time constants from TW_1 to TW_4 form two input filters (wash-outs) – one for the power channel and one for the frequency channel. The purpose of these filters is the prevent the PSS activation in cases of normal continuous deviations of generator's active power (P) and rotor speed (ω). The blocks with time constants T_7 and T_6 shift the signal phase with lag up to 90°. The purpose of this is to obtain at the end of the power channel a signal which is proportional to the rotor speed deviation $\Delta\omega$. The electric unbalance power ΔP which enters the channel can approximately be described with the relation [2]:

$$\Delta P \approx -T_J \cdot \frac{d\Delta\omega}{dt}, \text{ т.е. } \Delta\omega \approx \frac{-\Delta P}{s \cdot T_J}, \quad (1)$$

from which for $T_7 \approx T_J$ the output signal of the block is proportional to minus $\Delta\omega$. This signal is then added to the incoming signal for ω. The resultant signal enters in the filter for torsional oscillation (ramp-tracking filter). For steam turbine generators, due to torsion forces in the shafts, rotor oscillations occur in the sub harmonic range of few tens Hz. Depending on the place of measurement of ω deviations, these oscillations superpose with the low-frequency machine's rotor oscillations (the rotor is treated as a single mass object). If these oscillations are amplified and get into the excitation, high-frequency oscillations will occur and as a result the rotor can be damaged. The filter passes only inter-area oscillations. The filter output is summed with the output of ΔP channel and as a result a signal proportional to the inter-area deviation of ω is formed. Precisely this signal is entered input of the PSS gain, i.e. the block with KS_1. This way, regardless that there is also ΔP channel, the PSS reacts to the inter-area deviation of ω.

The literature most often discusses only the filters settings for passing a certain frequency range. Here, besides this requirement, also is required that the filters output signal $\Delta\omega_e$ is in phase the $\Delta\omega$ of the unit. This is a very important requirement, especially when in PSS2A is entered only generator bus voltage frequency deviation Δf. If the output signal $\Delta\omega_e$ is not in phase with $\Delta\omega$, then a wrong phase compensation will be obtained, even though the phase shifting PSS block are tuned correctly.

II. Algorithm for Calculation of Appropriate Filter Settings

In order to meet the requirement for close phases of $\Delta\omega_e$ and $\Delta\omega$, the following optimization task is formed.

$$\min_{\mathbf{\Pi}} \gamma_f(t), \text{ for } \left| \begin{array}{l} \gamma_f(t) = (\Delta\omega_e(\mathbf{\Pi},t) - \Delta\omega(t)) - g_f(t); \\ \gamma_f(t) \le 0; \\ \mathbf{\Pi}_{Д} \le \mathbf{\Pi} \le \mathbf{\Pi}_{Г}, \end{array} \right. \quad (2)$$

where $\mathbf{\Pi}_{Д}$ and $\mathbf{\Pi}_{Г}$ are respectively the lower and upper limits of deviation the parameters to be $\mathbf{\Pi}=\{TW_1, TW_2, TW_3, TW_4, T_6, T_7, T_8, T_9, KS_2, KS_3, KS_4, M, N\}$; $\Delta\omega_e(\mathbf{\Pi},t)$ and $\Delta\omega(t)$ – respectively the change in time of the filters output signal $\Delta\omega_e$ and generators rotor speed $\Delta\omega$ caused by disturbances of the AVR - ΔU_{ref}; $g_f(t)$ – limit function which theoretically converges to zero if there is complete phase and amplitude overlapping of $\Delta\omega_e$ and $\Delta\omega$.

To solve the optimization task (2), a computing scheme is constructed in the MATLAB application Simulink, whose structure is shown in Fig. 1. The solution is carried out by the application Simulink Design Optimization (SDO).

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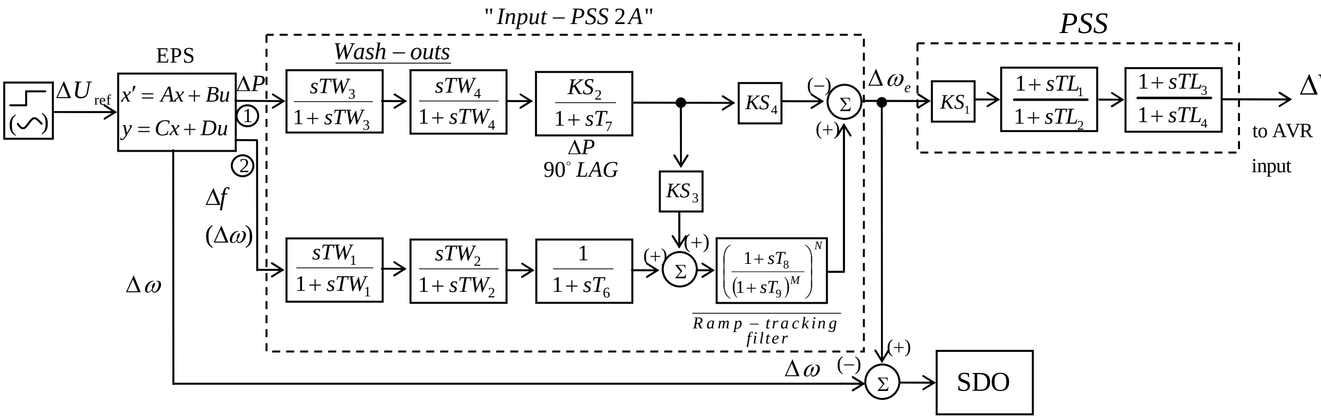

Fig. 1. Structure of the Simulink model used to calculation of PSS2A filters settings

The EPS (Electric Power System) block represents the model the electric power system in state space [1]. The disturbances are introduced through change of the reference ΔU_{ref} of the AVR in the generator whose PSS is being tuned. The disturbance can be step or if the dominant modes of mechanical oscillations for the specific generator are known the disturbance can be generated as a sum of sinusoids with the frequencies of the dominant modes. At first the limits $g_f(t)$ are set to about ± 0,005. In the process of the optimization procedure they are changed until the possibilities for their satisfaction are exhausted. As a result the quantities of **Π** which get $\Delta\omega_e$ maximally close to $\Delta\omega$ are obtained.

The stated above is basis for the formulation of the following algorithm for tuning of “Input – PSS 2A”:

1. Construction of the computing scheme (Fig. 1) in Simulink.
2. Use of SDO to solve the optimization task (2) for the smallest limits $g_f(t)$. As a result the quantities of **Π** which get $\Delta\omega_e$ as close as possible to $\Delta\omega$ are obtained.
3. The calculated **Π** settings are used to generate the frequency response characteristics of the input filters “Wash - outs” and the torsional filter “Ramp - tracking”. Their frequency bandwidths are checked if they meet the requirements. The input filters must not pass oscillations with frequencies under 0,01 Hz, i.e. they must not pass through the slow and continuous deviations in the regime parameters. The torsional filter must not pass frequencies in the 5÷50 Hz range, where the torsional oscillations are. If these requirements are fulfilled, the calculated settings are treated as final. Otherwise step 4.
4. The filters are tuned in respect to the frequency band requirements. After that step 2 is carried out again but with reduced number of parameters to be tuned **Π**={T_6, T_7, KS_2, KS_3, KS_4}. The obtained parameters settings are final.

III. Test Results

For illustration of the proposed algorithm results are shown for the calculation of the settings of “Input-PSS 2A” of generator G_1 of the tested in [1] EPS. The calculated optimal settings are: TW_1=3,66 s, TW_2=3,66 s, TW_3=2,07 s, TW_4=0 s, T_6=0 s, T_7=2,07 s, T_8=0,122 s, T_9=0,193 s, KS_2=0,16 o.e., KS_3=1,03 o.e., KS_4=1,1 o.e., N=1,M=5. In Fig. 2 are shown the frequency response of $\Delta\omega_e$ and $\Delta\omega$, and in Fig. 3 – their step response. It is clearly seen goal phase agreement of the two signals is achieved.

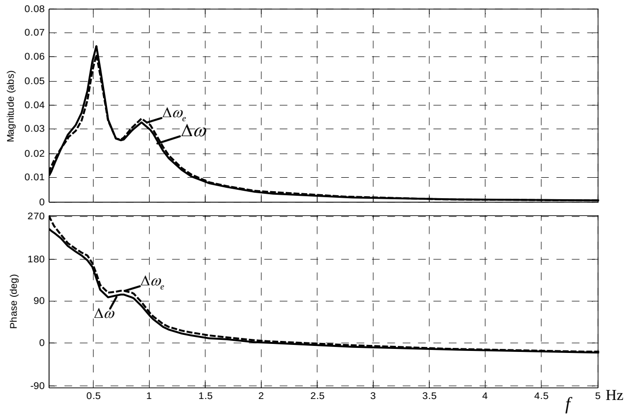

Fig. 2. Bode diagram of $\Delta\omega_e/\Delta U_{ref}$ and $\Delta\omega/\Delta U_{ref}$

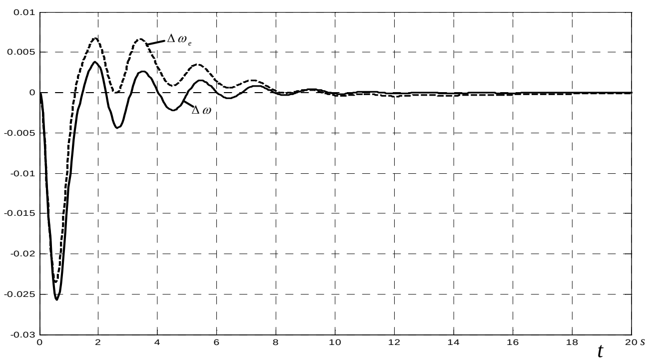

Fig. 3. $\Delta\omega_e$ and $\Delta\omega(t)$ for step change of ΔU_{ref} with 2 %

In Fig. 4, Fig. 5 and Fig. 6 are shown the frequency responses of the input filters of inputs 1 and 2 and of the torsional filter. It can clearly be seen the requirements for the pass-through frequency bands of the filters are satisfied. Therefore the calculated settings in step 2 of the algorithm are final.

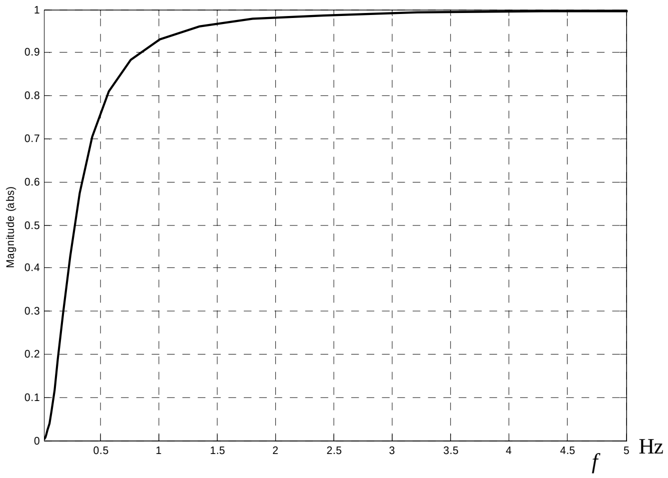

Fig. 4. Frequency response of the input filter of PSS 2A input 1

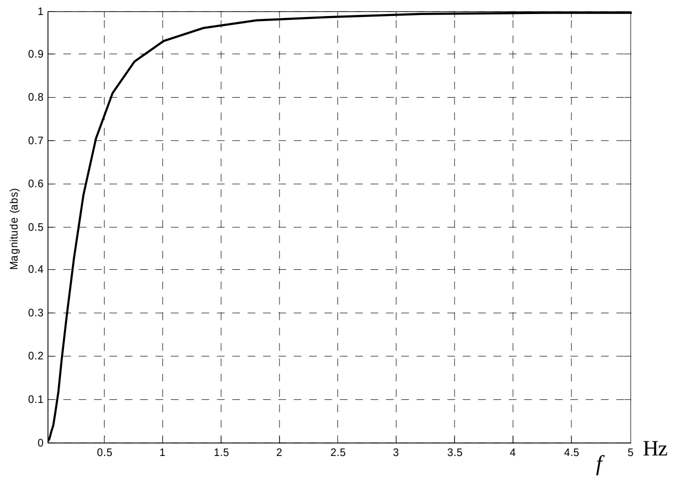

Fig. 5. Frequency response of the input filter of PSS 2A input 2

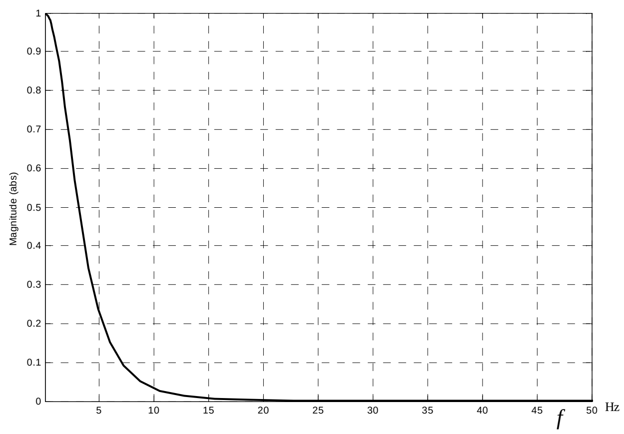

Fig. 6. Frequency response of the PSS 2A torsional filter

In Fig. 7 and 8 are shown results revealing the difference in the transient processes quality for different values of the input filters parameters. With dashed line are depicted the results for the settings: TW_1=2 s, TW_2=2 s, TW_3=2 s, TW_4=0 s, T_6=0 s, T_7=2 s, KS_2=0,18 p.u., and with solid line – the settings: TW_1=10 s, TW_2=10 s, TW_3=10 s, TW_4=0 s, T_6=0 s, T_7=10 s, KS_2=0,9 p.u.

The generalized assessment of the transient processes quality [1,3], given by the H_∞ norms for both cases, are shown in Fig. 7. They, together with the step response of the regime parameters *U*, *P* and *ω* for step change with 1% of the AVR reference (Fig. 8) shows how opening the filters for passing through frequencies under 1 Hz enables the PSS to damp them.

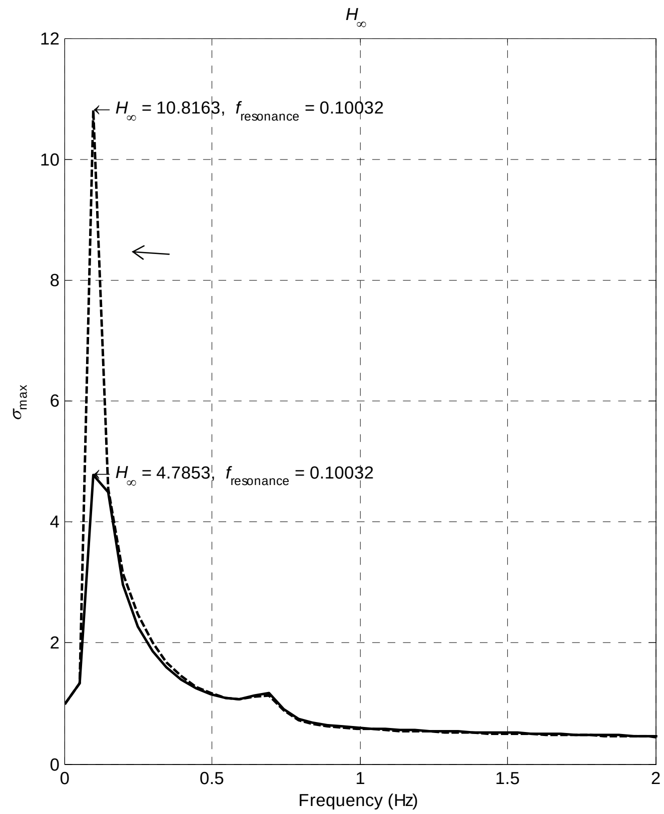

Fig. 7. Transient processes quality generalized assessment by the means of H_∞ norm

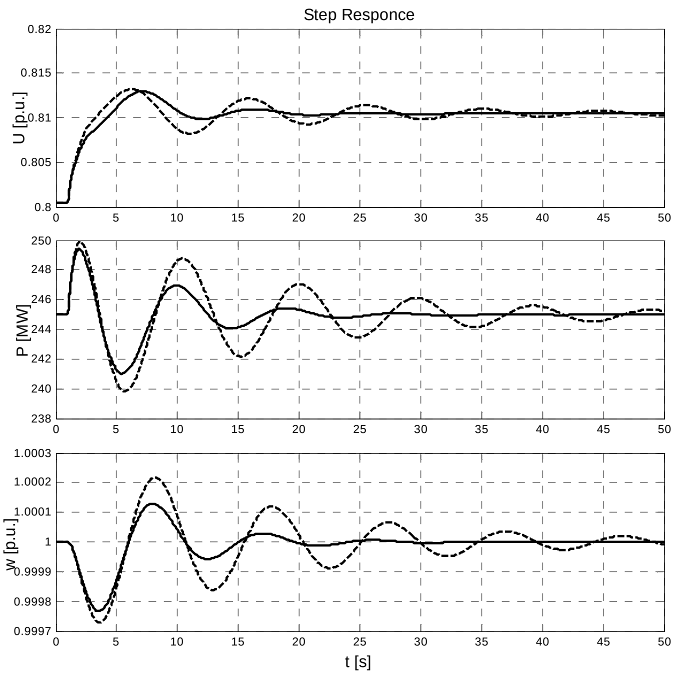

Fig. 8. Step response of the regime parameters *U*, *P* and *ω* for step change with 1% of the AVR reference

IV. Conclusion

The power system stabilizers type PSS2A and 2B successfully damp the local low-frequency electro-mechanical oscillations. The creation of large electric power systems consolidations lead to higher requirement for these devices, namely to damp successfully simultaneously the local and inter-area oscillations. Because the latter and in the frequency range under 1 Hz it is a must to tune appropriately the input filters so that they can pass them through to the PSS.

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