Journal of Electrical Engineering, Vol. 76, No. 3, 2025, pp. 232-240

Robust power system stabilizer tuning using genetic algorithm

Martin Ernek, Marián Tárník, Adrián Ilka, Róbert Málík

Significant changes in the energy sector are currently taking place, with conventional power sources being replaced by renewable energy sources. This trend leads to the reduction of the power system inertia and consequently weakens its dynamic stability. The damping of oscillations in the power system is significantly influenced by the excitation of synchronous generators, with the power system stabilizer (PSS) playing a crucial role. In this article a power system stabilizer design is offered that could meet any requirements formulated as the objective function. The proposed design of PSS also ensures robustness properties such as changes in the generator's operating point and variations of the rotating system inertia. The PSS parameters are obtained through the minimization problem, and the genetic algorithm is used to perform this task. This design procedure could be used to obtain parameters for any structure of the power system stabilizer and in the example section it is used to design PSS2a to prove this concept.

Keywords: power system stabilizer, power system oscillations, robust control

1 Introduction

The importance of power system oscillations damping has been recognized for decades. Oscillations themselves are dangerous from many perspectives, such as causing overcurrent in transmission systems, mechanical resonances in machines, and potential frequency instabilities. In recent years, large oscillations within the ENTSO-E transmission system have been observed that partially disrupted its operation [1, 2]. These oscillation events resulted in the search for new methods for setting power system stabilizers to dampen inter-area oscillations while ensuring the damping of the synchronous generators local mode oscillations [3-5]. The local mode oscillations are damped by Power System Stabilizers (PSS) present in the excitation systems of synchronous generators. Power system stabilizers are often tuned based on the requirements of local transmission system operators and modern optimization algorithms are used to find their optimal parameters [6-9]. Stochastic Fractal Search Optimization algorithm has been used to tune parameters of the dual-input power system stabilizer IEEE PSS3B in article [6]. The main benefit of this approach is that this algorithm reached the optimal settings of the PSS parameters in a minimum number of iterations. Another approach that has been used was Teaching Learning-Based Optimization (TLBO) combined with a genetic algorithm to find the parameters of a system stabilizer with speed feedback [8]. The comparative study of the determination of PSS parameters using a genetic algorithm and particle swarm optimization (PSO) has been published by [9]. The optimization and simulation results showed in this article that the optimization by the genetic algorithm had been very effective compared to particle swarm optimization.

The contribution of our work is to improve the robustness of the PSS parameter design by considering the impact of the operation range and the uncertainty of the generator parameter on oscillation dynamics behaviour. The design optimization algorithm will be selected using the genetic algorithm approach based on knowledge from the referenced articles. The example, which demonstrates the effectiveness of the designed method, used the methodology from the Technical conditions of SEPS, a. s. [10], the transmission system operator of Slovakia, to construct the objective function for the genetic algorithm.

The structure of the paper is as follows. After the introduction, the power system model is described in the second section. The third section presents the genetic algorithm used to search for PSS parameters. The final section demonstrates the proposed design concept through a simulation example where the objective function has been based on the Technical conditions of SEPS, a. s. [10].

2 Power system model

The design of the power system stabilizer parameters will be carried out on a simplified model of a synchronous generator operating with the grid shown in Fig. 1. Although this model is simplified and does not allow for the analysis of inter-generator oscillations, it is used by multiple authors. The model consists of the following basic components:

Faculty of Electrical Engineering and Information Technology, Slovak University of Technology in Bratislava, 81219 Bratislava, Slovakia
martin.ernek@stuba.sk

https://doi.org/10.2478/jee-2025-0024, Print (till 2015) ISSN 1335-3632, On-line ISSN 1339-309X

- Synchronous generator connected through an equivalent impedance to an infinite bus.
- Steam turbine and governor model TGOV5 according to standard [11].
- Excitation system AC7c and PSS2a power system stabilizer [12].

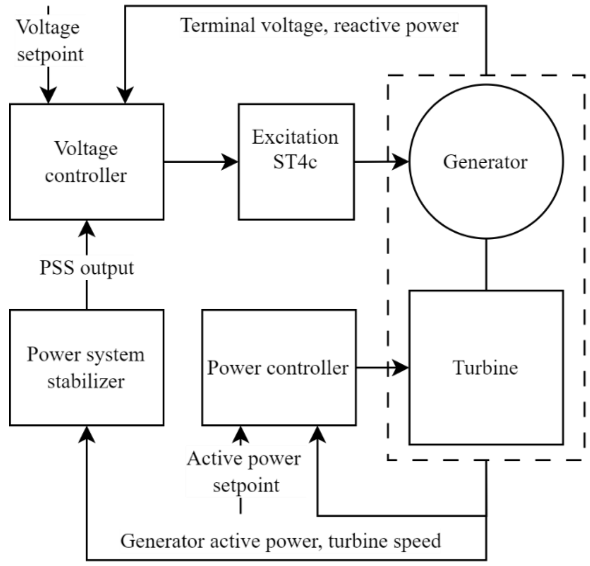

Fig. 1. Generator model

The main objective of this paper is the design of the power system stabilizer, and for this purpose, it is necessary to also consider the linear model of the generator. This model is valid only in a limited certain operating range and is obtained through the linearization process and by neglecting certain properties of the nonlinear model. The simplifications of the linear model must closely relate to its intended use, that is, in this case, the design of the power system stabilizer.

The Heffron-Phillips model [13] is often used for such analysis and simulation tasks, along with a simple first-order transfer function model of the excitation system [14]. However, the simplifications of the generator model to 3rd order linear model are not always suitable for the design of PSS for several reasons:

- The 3rd order model does not account for the influence of higher frequencies, as it considers only a single differential equation for the internal voltage in the q-axis e_q'. Power system stabilizer settings may amplify frequencies in the range of 6-8 Hz, which this model does not cover. Such amplification of oscillations in this frequency region could be problematic, as this region contains the generator torsional oscillations.
- The model does not consider the detailed dynamics of the excitation system, for example the feedback from the excitation current in the exciter model.
- The model omits the turbine and turbine governor, which affect the lower-frequency range, where an improperly designed system stabilizer may amplify inter-area oscillations.

A more complex linear model must be derived that includes the influences of the variables mentioned above for the PSS design. The complete model created for this purpose is shown in Fig. 2 and can be decomposed into three main subsystems:

- The synchronous generator and excitation subsystem contains a 6th-order linear model of the generator connected to the infinite bus and a linearized model of excitation and voltage controller.
- The turbine and its governor subsystem contain the simplified turbine model and its governor. This model could be further expanded by primary frequency control.
- The designed power system stabilizer (PSS) subsystem.

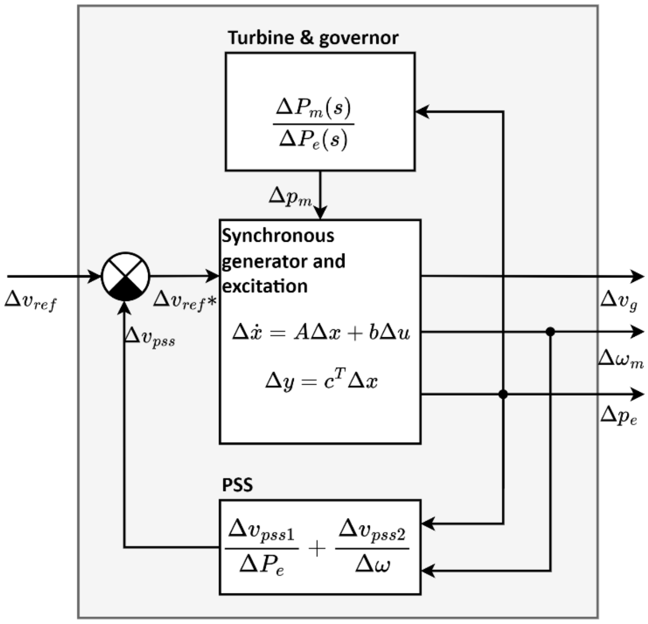

Fig. 2. Linear model and subsystems

The role of the power system stabilizer is to damp the oscillations throughout the operating range of the generator, defined by the *PQ* diagram. The design of the power system stabilizer must consider the uncertainty of the operating point at which the generator may be located. The uncertainty of the generator's operating point (steady-state) has a significant impact on the generator's transient and frequency response.

The impact of the operating point on the qualitative characteristics of voltage control can be analysed by simulation experiments, where the generator's operating point is always set to a defined steady-state condition. This analysis was performed on the generator modelled in the example section. In this analysis, the required active power of the generator is maintained near the maximum turbine power at 0.8 p.u.

In terms of transient properties, the shape of the transient response of all variables significantly changes with the generator's operating point when there is a step change in the voltage reference. These changes are documented in Fig. 3 and are particularly noticeable in terms of overshoot and the settling time of the generator's stator voltage. There is also a noticeable change in the oscillation frequency and amplitude in the transient response of the active power shown in Fig. 4.

By comparing the qualitative indicators obtained through simulations, it can be concluded that as the reactive load of the generator increases, the overshoot of the generator terminal voltage decreases, along with the amplitude of active power oscillations. The settling time of the terminal voltage decreases with the absolute value of reactive power.

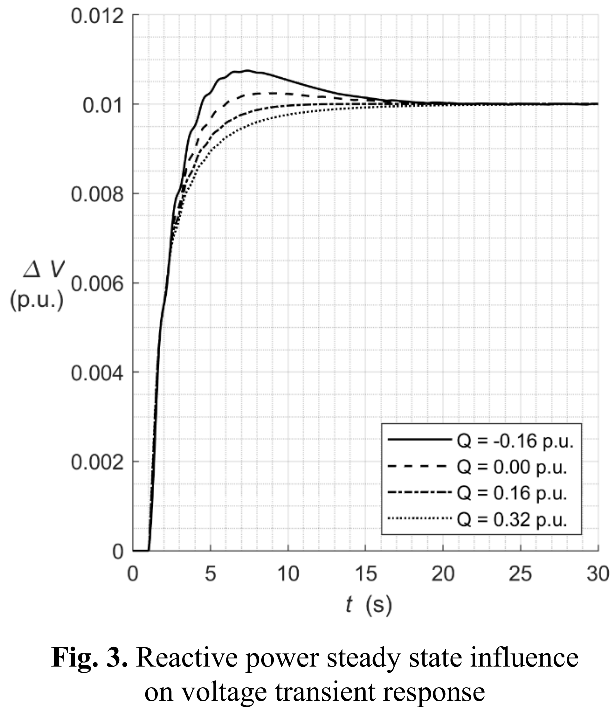

Fig. 3. Reactive power steady state influence on voltage transient response

From the perspective of the amplitude-frequency response of the active power of the generator, a similar simulation analysis can be performed. Depending on the steady-state value of the reactive power, the maximum gain between the active power and the reference of the generator terminal voltage $A_{pe}=|P_e(j\omega)|/|v_{ref}(j\omega)|$ and the frequency f_r of its peak is determined. The frequency response of the generator's active power, obtained while assessing the dependence of qualitative indicators on the initial value of the generator's reactive power, are shown in Fig. 5.

The amplitude of the active power gain with respect to the desired generator voltage decreases with the magnitude of reactive power. The resonance frequency of the generator's natural oscillations slightly increases with the reactive power initial value.

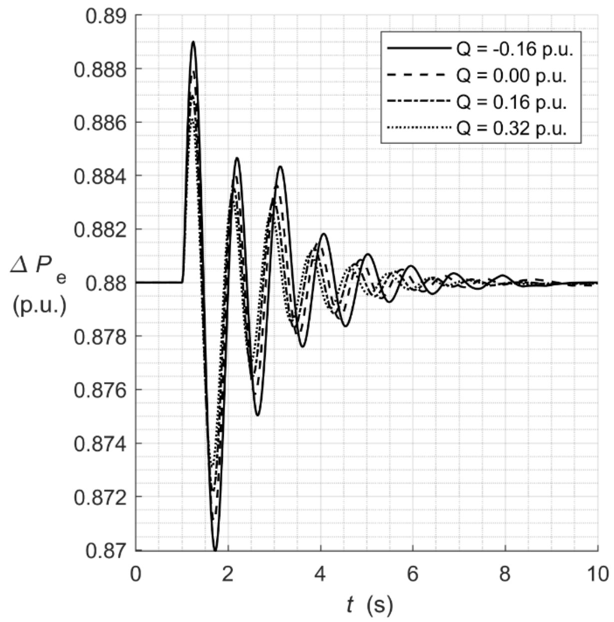

Fig. 4. Reactive power steady state influence on active power transient response

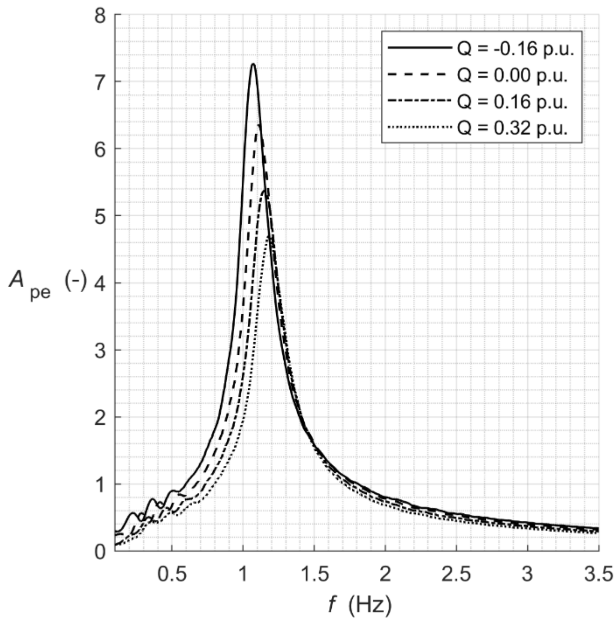

Fig. 5. Reactive power steady state influence on active power frequency response

3 Genetic algorithm

The design of the power system stabilizer parameters is typically carried out using two approaches. The first approach involves approximating the generator, excitation system and network model using a linear model and then determining the unknown parameters of the stabilizer through a selected control method. The second approach designs the unknown parameters of the PSS structure using a genetic algorithm on a nonlinear simulation model [15, 16]. Genetic algorithms have been used successfully in the past to find optimal solutions in the field of power system engineering [17, 18]. A prerequisite for a successful design in both approaches is knowledge of the simulation models' parameters. The simulation model should be validated through measurements prior to the design process. In both approaches, the design conditions of the PSS parameters can be adjusted, thereby ensuring different qualitative control properties.

The main disadvantage of both approaches is that the parameter design is typically performed for only one operating point of the generator. Although it is possible to design PSS parameters for multiple models at different operating points, it is not always possible to guarantee the fulfilment of the required qualitative criteria across the entire operational range. Additionally, this design may not ensure robustness against variations in generator and excitation parameters or account for inaccuracies in the knowledge of the generator model parameters. Further challenges and limitations in PSS parameters design include requirements from the power plant operator, oscillation damping requirements from the transmission system operator, and, in most cases, the already implemented turbine control system. The solution to this problem is to use the linear model with parametric uncertainty described in Section 2, that should be adjusted to meet the real plant properties. In this case, it would be quite complex to define the uncertainty in additive or multiplicative forms, so the design will be based on parametric uncertainty.

The parametric uncertainty model should be used to calculate the frequency response for the highest gain at the specified frequency defined by the uncertainty. This response is known as the worst-case scenario frequency response and should be obtained from this model to compute the value of the objective function in each iteration. The objective function could also be defined by other quality parameters, e.g., overshoot and settling time of voltage control. It is advisable to use the linear model at Q=0 p.u. as the nominal model of the uncertain system. The optimization algorithm should calculate the value of the objective function only if the stability conditions of the nominal model are met. The selection of individual components of the objective function should be made based on the capabilities of the uncertainty model and the technical and operational requirements. The selected objective function should be evaluated from the responses obtained from the uncertainty model and minimized by the genetic algorithm.

The genetic algorithm in Fig. 6, proposed in this paper, works as follows:

- Select the first random population within the specified lower and upper bounds. Then calculate the fitness of the population.
- In each iteration, the algorithm selects three working populations. The first working population is the best population. The second is obtained through tournament selection of the old population and is crossed with a randomly selected population. The last working population is obtained by tournament selection and then modified by multiplicative and additive mutations.
- The new population is formed based on the best population from the previous iteration, the crossed population, and the mutated population.
- The optimization ends when the maximum iteration number has been reached.

The proposed methodology to obtain the PSS parameters is based on the following steps:

1. Design linear model with synchronous generator, excitation and turbine by linearization of their nonlinear models.
2. Select uncertain parameters (recommended are the operating point of reactive power and generator inertia).
3. Obtain the objective function by formulating the local transmission system operator policy and the demands of the power plant operator.
4. Use the proposed genetic algorithm to minimize the objective function obtained.
5. Verify the designed parameters on the nonlinear model.

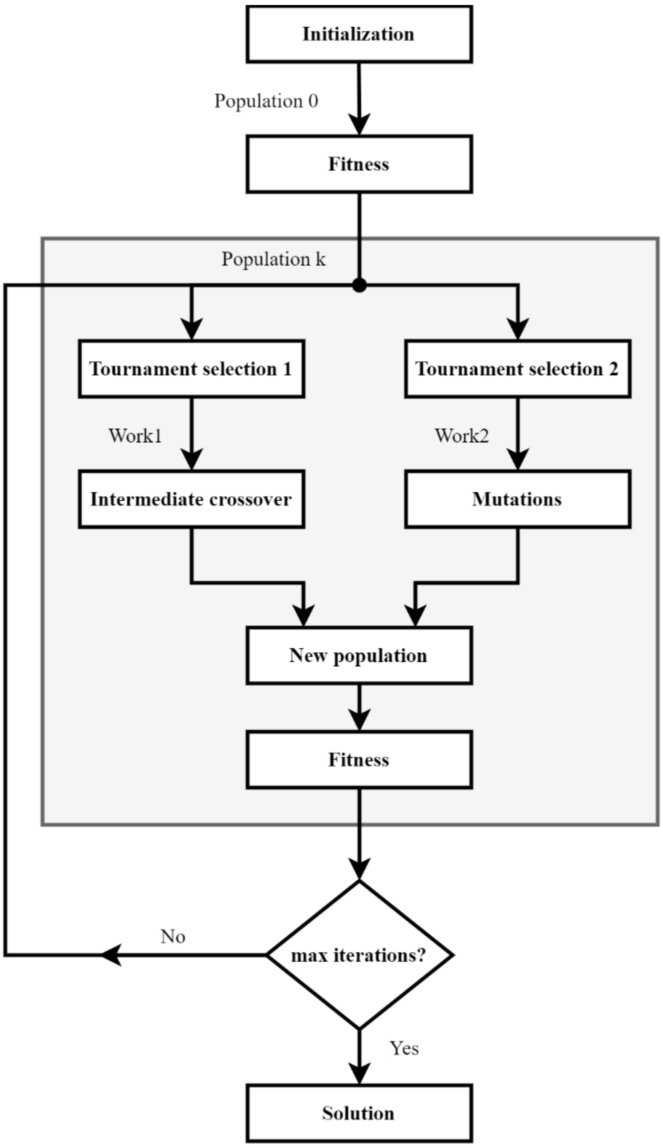

Fig. 6. Genetic algorithm

4 Simulation example

The task of this example is to design the PSS2a parameters that meets the requirements in the technical conditions of SEPS, a. s. [10]. The generator and excitation parameters of this example are noted in the Appendix. The technical conditions suggest that the amplitude of the active power frequency response should be less than 1 and the active power oscillation index should be less than 0.5. The PSS influence must not significantly reduce the stator voltage settling time. Although it is not that hard to obtain the voltage controller settings that ensure the metric of transient response, the amplitude of the frequency response is a different chapter. The oscillation index of active power is computed as:

$$\kappa = \frac{A_2 - A_3}{A_1 - A_2} \qquad (1)$$

Here, A_1, A_2, and A_3 are the first three consecutive amplitudes (first maximum, first minimum and second maximum) of the active power transient response to a step change in the reference voltage.

Based on these requirements from the transmission system operator, quality indicators can be defined which will need to be minimized. The first design condition is the damping of active power oscillations in the specified frequency range of 0.2-3.5 Hz. However, the operation of the PSS must not interfere with voltage regulation, leading to the second design condition. The third design condition is related to the oscillation index of the active power. From these design conditions, the following objective function J could be formulated as:

$$J = w_\mathrm{p}||A_\mathrm{Pe}||_\infty + w_u t_u + w_\kappa \kappa \qquad (2)$$

Here, w_p, w_u and w_κ are the weights of the individual components of the objective function, A_{pe} is the response to the amplitude frequency of the active power, t_u is the settling time of the terminal voltage after a step change in the reference value v_{ref} by 0.01 p.u. and κ is the oscillation index of the active power transient response. The design has been carried out on the following uncertainty conditions:

- The first uncertainty, from the perspective of the steady state of the generator, is its reactive power. The generator's reactive power operating range is $Q\in(-0.16, 0.32)$ p.u. The parameters of the nominal model are determined for the steady state of the reactive power Q = 0 p.u.
- The inertia of the generator and turbine can change over time, for example, by turbine blade wear. Similarly, when designing the power system stabilizer, it is necessary to consider whether the inertia of the generator is accurately identified. The chosen inertia value also affects the gain K_{s2} of the power system stabilizer. Therefore, the second uncertainty is selected as the inertia of the system $H_u\in(0.95\,H_n,\ 1.05\,H_n)$. The gain K_{s2} of PSS2a has a fixed value according to the identified value of the inertia parameter. The nominal value of H_n is chosen as the generator parameter H.

In the simulation example, we further focus on the impact of selecting the weight w_u of the voltage settling time on the resulting qualitative indicators. For the selected weight values, 10 runs of the genetic algorithm will be performed. For each run, the following data have been recorded: the found minimum, the amplitude of the frequency characteristic of active power, the oscillation index, and the settling time. The data resulting from the different voltage weights w_u=0.05, 0.1 and 0.5 are recorded in Tabs. 1 to 3.

Table 1. Genetic algorithm results for w_u=0.05

Run	Minimum	A_{Pe}	κ	t_u
1	9.3	0.8	0.33	12.88
2	9.95	0.84	0.34	16.61
3	10.19	0.88	0.36	12.6
4	7.66	0.6	0.35	19.59
5	11	0.96	0.34	14.59
6	9.9	0.82	0.34	20.4
7	9.77	0.84	0.36	12.8
8	12.35	1.09	0.41	12.96
9	9.53	0.82	0.34	11.81
10	10.58	0.91	0.39	14.51

Table 2. Genetic algorithm results for w_u=0.1

Run	Minimum	A_{Pe}	κ	t_u
1	11.22	0.91	0.36	13.82
2	11.17	0.93	0.37	11.69
3	10.23	0.84	0.33	11.65
4	10.11	0.83	0.36	11.12
5	10.37	0.8	0.35	16.96
6	10.57	0.85	0.32	14.34
7	9.73	0.81	0.36	9.38
8	10.75	0.89	0.35	11.57
9	12.05	1	0.38	12.69
10	9.67	0.81	0.34	8.51

Table 3. Genetic algorithm results for w_u=0.5

Run	Minimum	A_{Pe}	κ	t_u
1	20.75	1.46	0.42	10.74
2	13.85	0.91	0.3	8.25
3	24.15	1.85	0.41	9.67
4	14.1	0.84	0.35	10.05
5	13.56	0.81	0.36	9.47
6	14.36	0.86	0.4	9.93
7	16.42	1.16	0.42	8.04
8	12.9	0.79	0.33	8.57
9	17.21	1.22	0.38	8.58
10	15.02	1.02	0.36	8.14

The PSS2a parameters obtained from the experiment with weight w_u=0.5 and *run*=8, by the genetic algorithm, have been verified on the simulation model. The worst-case scenarios of the amplitude frequency response of active power with and without PSS are shown in Fig. 7. The PSS2a parameters have been successfully designed by a genetic algorithm damping the largest peak of amplitude in the frequency response from 10.84 to 0.79. The Transient Response of active power, documented in Fig. 8, has also been damped by the influence of PSS and brought the oscillation index from 0.67 to 0.33. The voltage settling time has been affected by PSS and has been extended from 5.4 s to 8.57 s.

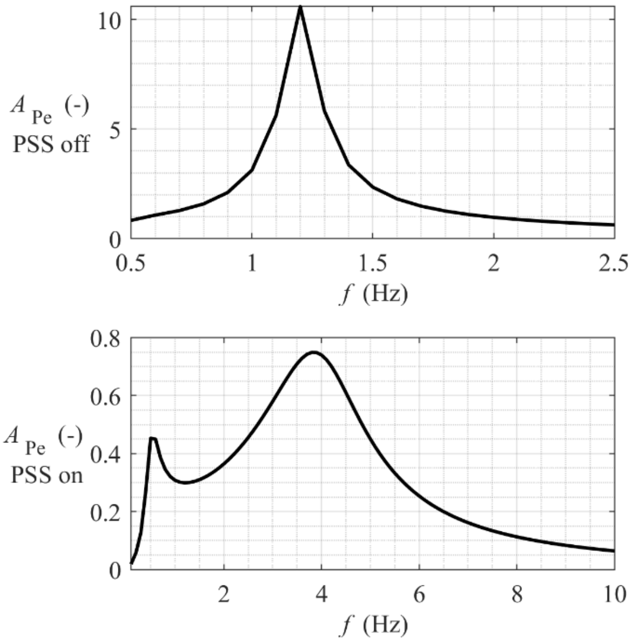

Fig. 7. Frequency response of the active power for PSS turned on and off for the worst-case

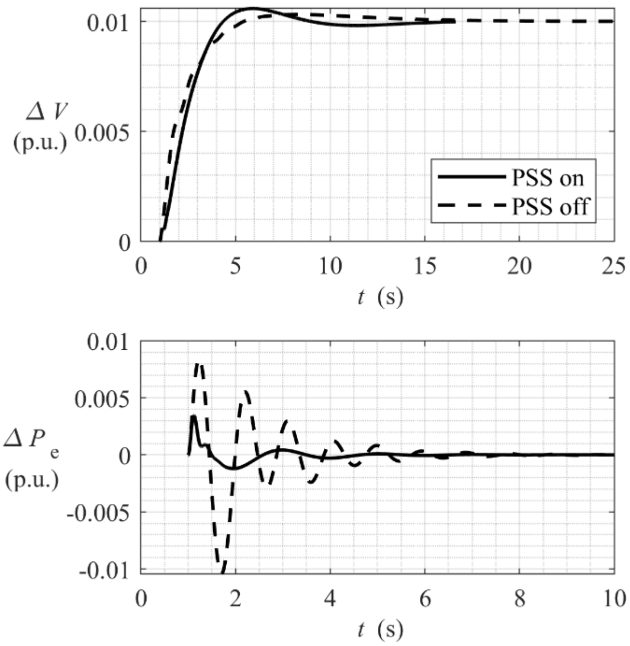

Fig. 8. Transient response of voltage and active power on voltage reference step change for PSS turned on and off for the nominal model

5 Conclusion

The design of a power system stabilizer (PSS) must consider various uncertainties, including changes in the operating point and system parameters. This article has highlighted the importance of considering these uncertainties, particularly in the context of the reactive power and inertia of the generator, which significantly influence the stability and dynamic behaviour of the system.

To ensure robustness, the PSS parameters were optimized using advanced control techniques, including genetic algorithms. The optimization process was constrained by multiple design conditions, such as minimizing power oscillations, maintaining voltage regulation performance, and preventing the amplification of generator active power oscillations. The proposed approach improves the damping characteristics of the power system while ensuring that the stability requirements are met under a wide range of operating conditions.

The simulation results confirm that the PSS parameter should be designed using the proposed methodology and genetic algorithm. Furthermore, the selected optimization criteria ensure that the PSS maintains effective performance throughout the entire *PQ* diagram of the generator. The proposed method offers a systematic and adaptable approach to PSS tuning, improving the stability of the power system in practical applications.

Future work could explore additional uncertainties, including network variations and load fluctuations, to further enhance the robustness of the stabilizer. Experimental validation in a real power system could also provide valuable insight into the practical implementation of the proposed design methodology.

Acknowledgement

The research is supported by the grant VEGA 1/0229/24 granted by the Ministry of education, science, development, and sport of the Slovak republic. This work was also supported by the Slovak Research and Development Agency under the contract No. APVV-22-0169.

References

[1] ENTSO-E System Protection and Dynamics Working Group, *Analysis of CE interarea oscillations – December 1st*, 2016, tech. rep., ENTSO-E, 2017.

[2] ENTSO-E System Protection and Dynamics Working Group, *Oscillation event 03.12.2017*, technical report, ENTSO-E, 2018.

[3] M. S. Rawat and R. Sharma, "The effective role of PSS in damping inter area mode of oscillation using Matlab/ Simulink", *2011 International Conference on Computational Intelligence and Communication Networks*, pp. 732–736, 2011.

[4] A. Ajamal, M. Elthalathiny, and K. Ellithy, "PSSs design based on PMUs signals to enhance the stability of inter-area oscillations of interconnected power systems", *2015 IEEE Power and Energy Conference at Illinois (PECI)*, pp. 1–5, 2015.

[5] L. Kumar and N. Kishor, "PSS design and its performance investigation on the subsystem where the inter-area mode is most dominant", *2019 IEEE Region 10 Symposium (TENSYMP)*, pp. 190–195, 2019.

[6] B. Elrachid, R. Hammoud, B. Oussama, and H. Meriem, "Parameter tuning of power systems stabilizer using stochastic fractal search optimization", *2022 19th International Multi-Conference on Systems, Signals & Devices(SSD)*, pp. 1853–1857, 2022.

[7] N. S. Ab Khalid, M. Mustafa, and R. Idris, "Optimal parameters tuning of power system stabilizer via bees algorithm", *Applied Mechanics and Materials*, vol. 781, pp. 397–401, 2015.

[8] E. Roshandel and M. Moattari, "Genetic-TLBO algorithm for power system stabilizer", *Current Signal Transduction Therapy*, vol. 15, no. 3, pp. 270 – 283, 2020.

[9] D. E. Ghouraf, N. Abdellatif, and S. Abdelkader, "Power system stabilizer design using genetic algorithms and particle swarm optimization", *Control Systems and Optimization Letters,* vol. 1, no. 1, pp. 52–57, 2023.

[10] SEPS, a. s., *Technical conditions for access and connection, grid code for the operation of the transmission system, document B*, tech. rep., Slovenská elektrizačná prenosová sústava (SEPS), a. s., 2024.

[11] Power System Dynamic Performance Committee, *Dynamic Models of Turbine-Governors in Power System Studies*, Tech. Rep. PES-TR1, IEEE Power & Energy Society, Piscataway, NJ, USA, 2013.

[12] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies," in *IEEE Std 421.5-2016 (Revision of IEEE Std 421.5-2005)*, vol., no., pp.1-207, 26 Aug. 2016, doi: 10.1109/IEEESTD.2016.7553421.

[13] W. G. Heffron and R. A. Phillips, "Effect of a modern amplidyne voltage regulator on underexcited operation of large turbine generators", *Transactions of the American Institute of Electrical Engineers. Part III: Power Apparatus and Systems*, vol. 71, no. 3, pp. 692–697, 1952.

[14] K. Padiyar, *Power System Dynamics: Stability and Control*. Anshan, 2004.

[15] J. Murgaš, I. Sekaj, M. Foltin, and E. Miklovičová, "Optimization of power system stabilizer by genetic algorithm", *in Proceedings of the 16th IFAC World Congress, (Prague, Czech Republic)*, 2005.

[16] J. Murgaš and M. Ernek, "Optimization of PSS parameters," *in 10th International Conference, Control of Power Systems, (Tatranské Matliare, Slovakia)*, 2012.

Appendix

Table 4. Generator parameters used for the simulation example

Description	Symbol	Value
Nominal power	S_n (MVA)	250
Direct synchronous reactance	x_d (pu)	1.85
Quadrature synchronous reactance	x_q (pu)	1.7
Direct transient reactance	x_d' (pu)	0.32
Quadrature transient reactance	x_q' (pu)	0.42
Direct subtransient reactance	x_d'' (pu)	0.17
Quadrature subtransient reactance	x_q'' (pu)	0.17
Direct transient open-circuit time constant	T_{d0}' (s)	6
Direct subtransient open-circuit time constant	T_{d0}'' (s)	0.03
Quadrature transient open-circuit time constant	T_{q0}' (s)	2
Quadrature subtransient open-circuit time constant	T_{q0}'' (s)	0.04
Inertia time constant	H (s)	6

Table 5. Excitation system AC7 parameters used for the simulation example, parameters not specified have zero value

Description	Symbol	Value
Voltage regulator proportional gain	K_{PR} (pu)	20
Voltage regulator integral gain	K_{IR} (pu s^{-1})	5
Maximum regulator output	V_{Rmax} (pu)	3.2
Minimum regulator output	V_{Rmin} (pu)	–3.2
Field current regulator proportional gain	K_{PA} (pu)	1/3.2
Potential circuit gain coefficient	K_P (pu)	5
Demagnetizing factor, function of exciter alternator reactances	K_D (pu)	0.1
Exciter field proportional constant	K_E (pu)	1.1
Exciter field time constant	T_E (s)	0.016
Maximum exciter field current	V_{FEmax} (pu)	4
Minimum exciter voltage output	V_{Emin} (pu)	0
Rectifier loading factor proportional to commutating reactance	K_C (pu)	0.113
Rectifier loading factor proportional to commutating reactance	K_{C1} (pu)	0.4

Table 6. PSS2a parameters for $w_u = 0.5$ and $run = 8$ from simulation example

Description	Symbol	Value
PSS gain	K_{S1} (pu)	69.4
PSS gain	K_{S2} (pu)	0.173
PSS gain	K_{S3} (pu)	1.1
PSS transducer time constant	T_6 (s)	0
PSS transducer time constant b	T_7 (s)	2.08
PSS washout time constant	T_{w1} (s)	2.08
PSS washout time constant	T_{w2} (s)	2.08
PSS washout time constant	T_{w3} (s)	2.08
PSS washout time constant	T_{w4} (s)	0
PSS transducer time constant	T_8 (s)	0.22
PSS washout time constant	T_9 (s)	0.044
PSS ramp-tracking filter order	M (-)	5
PSS ramp-tracking filter order	N (-)	1
PSS numerator (lead) compensating time constant (first block)	T_1 (s)	0.88
PSS denominator (lag) compensating time constant (first block)	T_2 (s)	0.16
PSS numerator (lead) compensating time constant (second block)	T_3 (s)	0.52
PSS denominator (lag) compensating time constant (second block)	T_4 (s)	0.88

Received 19 March 2025