Article citation info:
Boumous S, Boumous Z, Djeghader Y, Boumous M. New approach to power system stabilizer optimization techniques. Diagnostyka. 2024;25(4):2024409. https://doi.org/10.29354/diag/194669.

DIAGNOSTYKA, 2024, Vol. 25, No. 4

e-ISSN 2449-5220
DOI: 10.29354/diag/194669

NEW APPROACH TO POWER SYSTEM STABILIZER OPTIMIZATION TECHNIQUES

Samira BOUMOUS [1,*], Zouhir BOUMOUS [1], Yacine DJEGHADER [1], Moufida BOUMOUS [2]

[1] LEER Laboratory, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria
[2] University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria
[*]Corresponding author, e-mail: samira.boumous@univ-soukahras.dz

Abstract

Power System Stabilizers (PSS) are control devices used in synchronous generators to enhance the stability and damping of power systems by providing supplementary control signals to the generator excitation system. It's come in various types, each designed to address specific stability issues and accommodate different system configurations, Conventional Lead-Lag PSS, Phase-Compensation PSS, High-Speed PSS and Wide-Area PSS. Multi-area transitional stability hinges on the ability of a power system consisting of multiple interconnected areas or regions to maintain synchronous operation following a disturbance, such as a short circuit or a disturbance in the load. Ensuring transient stability in such systems is crucial for preventing cascading failures and blackouts. The proposed control illustrates the implementation of different strategies for PSS using the four machines two-area kundur test system.

Keywords: Power system stabilizer, Multi area system, kundur test system, control

1. INTRODUCTION

The history of Power System Stabilizers (PSS) dates back to the mid-20th century when researchers and engineers began developing control devices to improve the stability of the power supply systems, In the early years of power system engineering, stability analysis focused primarily on small-signal stability and frequency response [1]. Engineers developed simple control schemes, such as automatic voltage regulators (AVR), to regulate generator voltage and improve system stability [2-3]. The concept of supplementary damping control emerged, leading to the development of the first-generation PSS. These early PSS designs typically employed lead-lag compensators added to the excitation control loop of synchronous generators to provide additional damping torque and stabilize the system [4-5]. During the 1970s and 1980s, advancements in control theory and computer technology enabled the development of more sophisticated PSS designs. Researchers explored various control strategies, including phase compensation, optimal control, and adaptive control, to improve the effectiveness and robustness of PSS. The introduction of digital control systems facilitated the implementation of advanced PSS algorithms, allowing for real-time monitoring, optimization, and adaptive tuning [6]. Application in Large Interconnected Systems (1990s-2000s): As power systems grew larger and more interconnected, the importance of transient stability and inter-area oscillations became increasingly apparent. PSS evolved to address the unique challenges of multi-area power systems, with the development of wide-area PSS (WAPSS) and coordinated control schemes for inter-area damping. Model-based predictive control (MPC), neural networks and fuzzy logic, are the most well-known and suitable advanced control techniques. were applied to enhance PSS performance and adaptability in complex networked environments [7-10]. Integration with FACTS and HVDC Technologies (2000s-Present): In recent years, PSS has been integrated with modern technologies as the flexible alternative current Transmission Systems (FACTS) and High-Voltage Direct Current (HVDC) technologies to achieve greater dynamic stability and well-coordinated control enhancement. There are several types of FACTS devices, including thyristor-controlled series capacitors (TCSC) and varistor-controlled static compensators (SVC) are used in conjunction with PSS to improve system reliability by adjusting transient stability and voltage regulation. HVDC links enable power system operators to control the flow of power and provide supplementary damping across large geographical areas, enhancing overall system stability [11-13]. Power System Stabilizers

Received 2024-03-27; Accepted 2024-10-15; Available online 2024-10-26

have evolved from simple lead-lag compensators to sophisticated control devices employing advanced algorithms and technologies to enhance the stability and reliability of power systems[14-18].

2. METHODOLOGY

2.1. MB – PSS: multi band power system stabilizer

In MB-PSS, the stabilizer design relies on mathematical models in the complete electrical system, MB-PSS often begins with system identification, where mathematical models of the power system, including generator dynamics, excitation systems, and network parameters, are developed based on measurements and data analysis. The Multi-band Power System Stabiliser (MB-PSS) is a system based on multi-frequency variables at low, medium and high frequencies. The stabiliser principle of the MB-PSS multiband system is developed to introduce a moderate phase advance at all oscillation frequencies of interest [19].

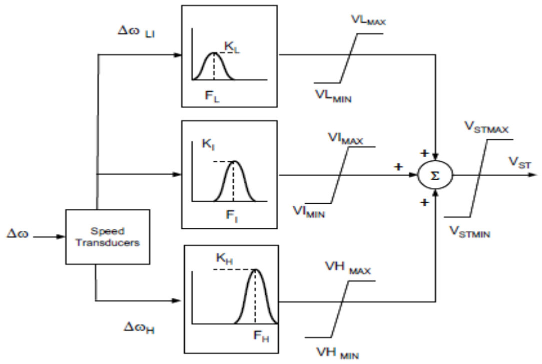

Fig 1. Basic structure of MB-PSS algorithm [20]

2.2. LF PSS: Fuzzy logic power system stabilizer

They are control devices used in electrical systems to improve the stability and damping of oscillations in electrical systems. They employ fuzzy logic, a mathematical framework that deals with uncertainty and imprecision, to mimic human-like decision-making processes. FLPSS offers several advantages over traditional PSS, such as the ability to manage non-linearities and uncertainties in the electricity power system more effectively. They can also adapt to changing operating conditions and provide smoother and more robust control [21-24].

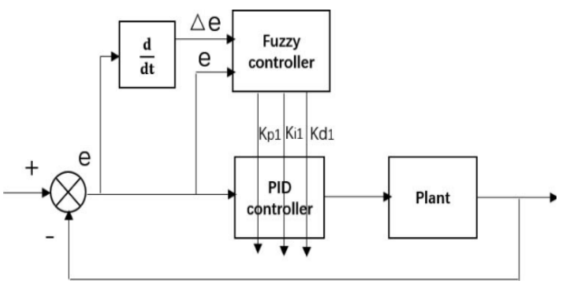

Fig. 2. Principle diagram of a fuzzy PID controller [21]

2.3. Delta PA: Generic power system stabilizer

A generic power system stabiliser (PSS) is a control system designed to improve the stability of these systems by damping out oscillations that may occur due to disturbances such as sudden changes in load or faults. PSS is typically installed in synchronous generators (usually large generators in power plants) to provide additional control beyond the automatic voltage regulator (AVR). Two major criteria can influence the generic design of PSSs, such as the specific requirements of the power system and the control philosophy adopted by the system operator. However, their primary objective remains consistent: to enhance the stability of the power system by damping out oscillations and ensuring reliable operation [25-27]. In this type of optimization technique, GPSS consists of four main components: a gain block, an output limiter, low-pass and high-pass filters, and a phase compensation system. [28-29].

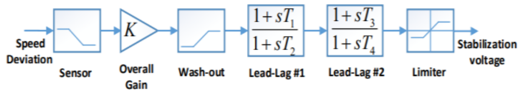

Fig 3. A generic power system stabilizer diagram [29]

2.4. GA PSS: algorithm Genetic power system stabilizer

An algorithmic approach to power system stabilization that draws inspiration from genetic algorithms. To find the best solution, two steps need to be taken. The first is to generate a population of potential solutions and then iteratively evolve them to a given problem. In the context of power systems, a Genetic Power System Stabilizer (GPSS) could be an algorithm designed to optimize the parameters of a power system stabilizer (PSS). PSSs are control devices used in power systems to dampen oscillations and maintain stability. By using genetic algorithms, the GPSS could iteratively adjust the parameters of the PSS to improve its performance in stabilizing the power system [30-33]. The genetic algorithm is one of the best-known optimization methods. It takes its name from the biological evolution of living beings in the real world. unfavorable environment [34].

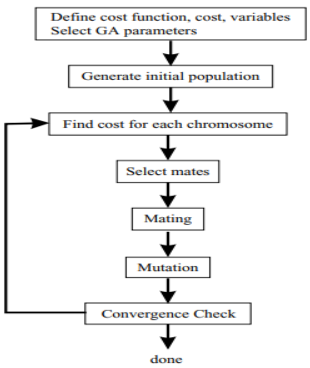

Fig 4. The continuous genetic algorithm Chart [33]

3. PROBLEM FORMULATION

In the present article, authors have chosen to solve the problem of stability of an electrical system after a three-phase fault on a transmission line. The chosen configuration is that of four machine two area kundur test system shown in figure 5 [28]. The previous methods were used to solve this problem. This is a standard benchmark system used in power systems for analyzing and testing various control strategies and algorithms. The system consists of four synchronous generators (machines) connected to two distinct areas via transmission lines. Each area represents a portion of the power grid, and the generators within each area work together to supply power demand. The system studied consists of two identical zones interconnected by a double 230KV line 220 km long with two identical round-rotor generators rated at 20KV/900MVA in each zone. The generator parameters are detailed in the reference [28].

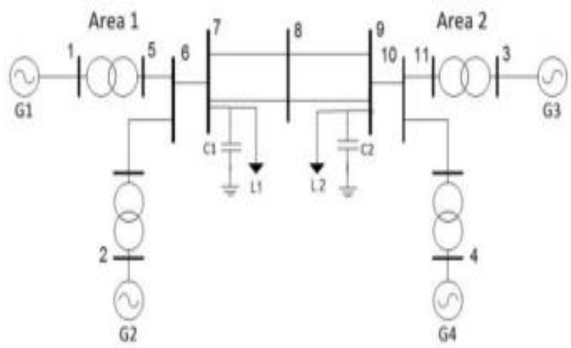

Fig 5. Single-line diagram of the system studied [28].

The characteristic quantities of the system studied are detailed in reference [28].

4. SYSTEM MODELLING

Optimization algorithms are used to obtain system damping controller parameters. The main objective of optimization is to find the best controller parameters to minimize system performance in terms of overshoot and settling time. This enables the system to operate correctly under all operating conditions and with a wide variety of loads. Simulation of the proposed system has been carried out for different PSS models. The simulation is performed in MATLAB/Simulink with a simulation time of 10s. The objective of our study is to apply the four optimization techniques outlined above to search the solution space for optimal or near-optimal PSS parameter sets that improve the stability of the power system. The proposed techniques are tested in the presence of a three-phase fault at the start of transmission line 1a and near bus B1 at t = 5 s for a duration of 0.2 s.

5. RESULTS AND DISCUSSION

A comparative study was conducted in this article, the results obtained by the optimization techniques used to improve the performance of electricity networks by demonstrating the effectiveness of these techniques, the proposed techniques were tested on the power system during a large disturbance. The positive sequence of voltage at buses B1 and B2 in PU, transfer active power between buses B1 and B2 in MW, rotor angle relative to machine 4-G1,2,3 in degrees, rotor speed and electrical power in PU are shown in those cases:
Case1: System response without PSS
Case2: System response with MB-PSS: for oscillations damping control in power systems two-inputs adaptive IEEE multi-bands power system stabilizer (PSS4B) was developed. The diagram and parameters of the model have been detailed by the authors of the reference [35].
Case3: System response with FLC-PSS: Five steps can be summarized in the design process of a fuzzy logic controller, after the selection and choice of the control variables, the membership function must be represented. In our approach, the fuzzy inference method chosen is of the Mamdani type, using the fuzzy centroid method as a defuzzification strategy. Due to the normalization performed on the physical variables, the membership functions of the two input variables were considered to be identical. The Mamdani fuzzy model with two inputs and one output. Seven membership functions generate the 49 rules. The inputs, rotor speed deviation (dw) and deviation of active power (DP) and the output field voltage (Vf). Two speed levels can be encountered, which determine the nature of the output signal:

- If the speed deviation is large but decreasing, the control must be moderate, i.e. when the machine is slowed down, even at high speed, the system is able to return to the desired stable state on its own.
- If the speed deviation is small but increasing, good optimization requires significant control. so if the machine accelerates, the control must be able to reverse the situation.

Case 4: System response with Delta PA
Case 5: System response with GA -PSS: The continuous genetic algorithm was used and chosen to solve the problem of optimizing the parameters of the PSS. Among these parameters, minimizing the variation in angular velocity was the objective of this optimization. Table 1 shows the parameters of genetic algorithm [36-37-38].

Table 1. Genetic algorithm parameters

Population type	Double vector
Population size	50
Generation number	400
Migration Fraction	0.2000
Elite Count	2.5
Crossover probability	0.8

Figure 6 represents the relative rotor angle of machine 4 with respect to machines 1,2,3 in degrees, the rotor speed response during fault without PSS are presented in figure 7; The generator's electrical power is shown in figure 8. The positive sequence of voltage at buses B1 and B2 for different cases are presented in figure 9. Figure 10 shows the transfer active power between buses B1 and B2 in MW , without power system stabilizer.

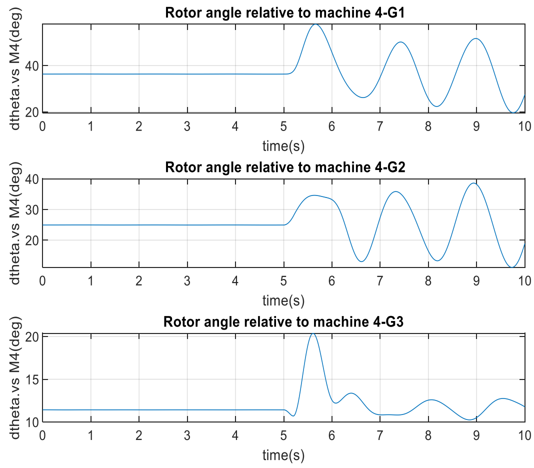

Fig 6. Rotor angle relative to machine 4-G1,2,3

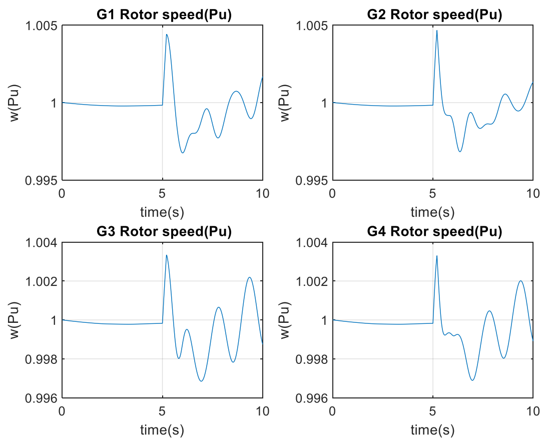

Fig 7. The rotor speed without PSS

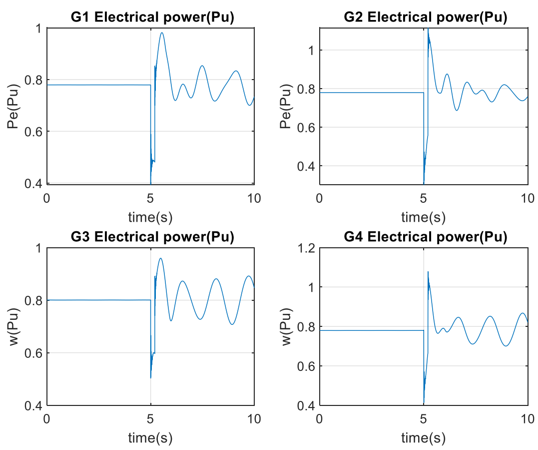

Fig 8. Generator electrical power without PSS

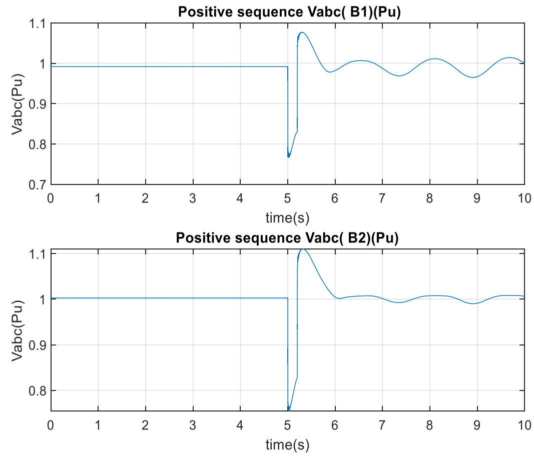

Fig 9. The positive sequence voltage Vabc without PSS

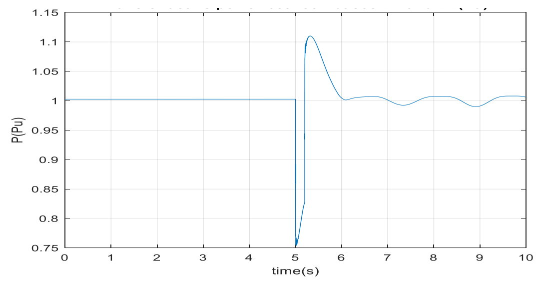

Fig 10. Transfer active power between bus B1 and bus B2

As shown in previous figures (7-10), the power system is subject to a large disturbance after a three phase fault, which lasted 0.2s, the responses of the various parameters shown in the figures, show that these parameters present peaks at the start of the fault, then try to stabilize and return to their healthy state, but without PSS the system is formally destabilized and very oscillatory.

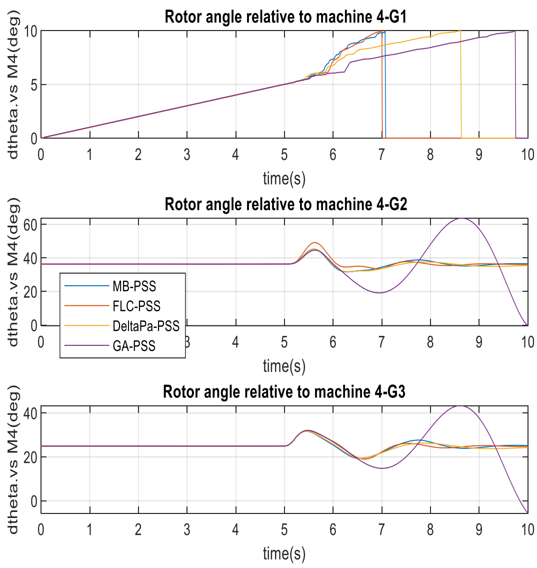

Fig 11. Rotor angle relative to machine 4-G1,2,3

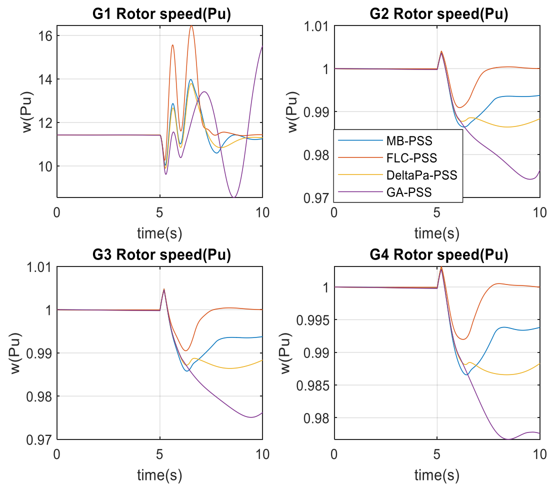

Fig 12. The rotor speed with different techniques

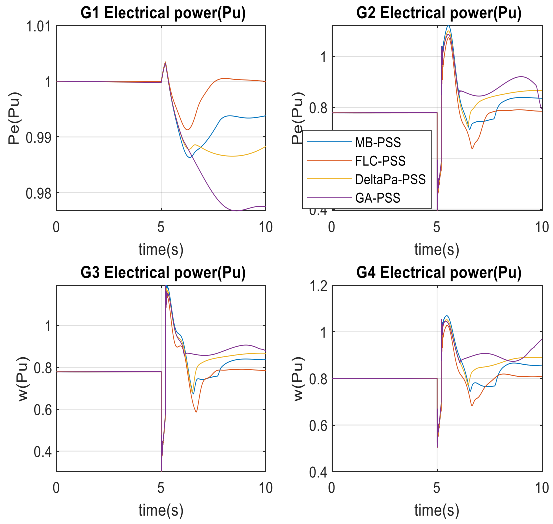

Fig 13. Generator electrical power with different techniques

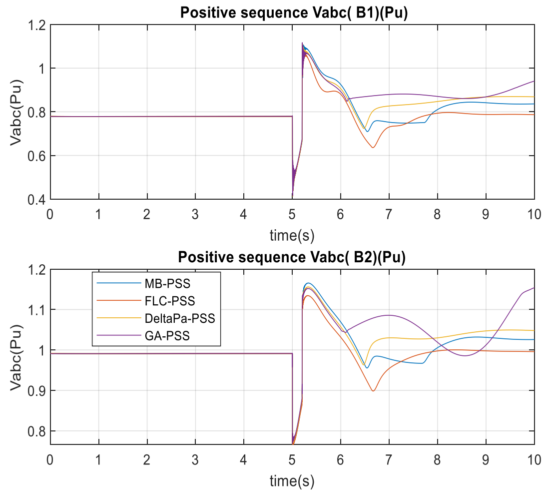

Fig 14. The positive sequence voltage Vabc with different techniques

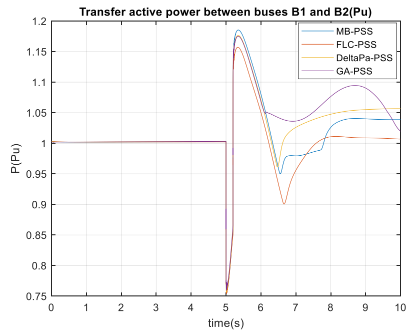

Fig 15. Transfer active power between bus B1 and bus B2

From the above results, we notice that the reliability of the techniques chosen and studied is well approved.

Case 6: Self-adaptative genetic algorithm power system stabilizer SAGA-PSS. Genetic algorithms are powerful search algorithms that rely on the parameters being set before the execution of a genetic algorithm (GA), and these parameters remaining fixed during execution. The problem of interest here is the self-adaptive adjustment of GA parameters. In this part of our research, our objective is the self-adaptive adjustment of GA parameters for PSS optimization. A new approach consists in adjusting the various GA parameters one by one until the best possible combination is obtained [39-40].

The first implementation focuses on self-adaptation of mutation rates. The results obtained are: Best PSS Parameters: a1= 3.4244, b1= 0.4769, c1= 0.1046, d1= 0.0006, Best Fitness: $2.3280e^{-05}$.

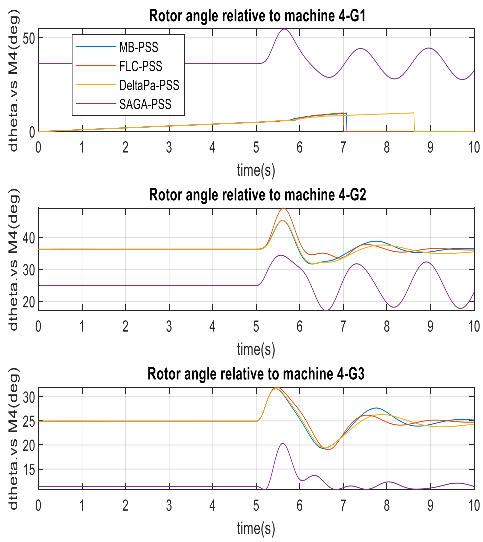

Fig 16. Rotor angle relative to machine 4 to G1, G2 and G3 with SAGA (adjustment of mutation rate)

The second test consists of self-adaptation of both mutation rates and crossover probabilities in a genetic algorithm (SAGAMC-PSS) at the same time [41-42]. Best PSS Parameters: a1= 4.6384, b1= -0.0238, c1=0.1187, d1= 0.0028, Best Fitness: $2.1922e^{-05}$.

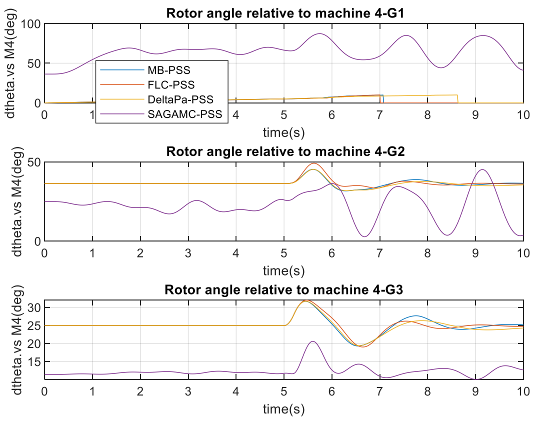

Fig 12. Rotor angle relative to machine 4 to G1, G2 and G3 with SAGAMC (adjustment of mutation rate and crossover probabilities)

6. CONCLUSION

This paper presents a contribution to improving the performance of power system stabilization techniques in the Kundur two-zone test system, in the presence of a three-phase fault in close to bus transmission line B1.

The aim of the work is to apply existing techniques for PSS and to try to choose the best parameters and coefficients to solve this problem. five cases of study have been detailed and simulated. firstly, the system parameters have been evaluated for the case without PSS. the synthesis of the results justifies the need to look for optimization techniques to try to stabilize the system again.

Genetic algorithms offer the best and most innovative solutions to this kind of problem.

Three different techniques have been used, simulated, the first is the continuous GA method, which gave satisfactory results, especially for electrical power Pe and network voltage Vabc, while the second technique studied is the self-adaptative genetic algorithm SAGA with adjustment of the parameter: mutation rate, rotor angle relative to machine 4 to G1, G2 and G3 is presented and evaluated. it's clear that the curve is still oscillating, but with a smaller amplitude than the other results obtained. the latest technique used is the self-adaptative genetic algorithm SAGA with adjustment crossover probabilities and mutation rate, with the same findings as the previous technique, but with a further improvement in system parameters.

As a follow-up to this work and in order to complete it, the authors will use other optimization techniques such as PSO and verify their performance in other systems with the integration of energy-based sources.

Source of funding: *This research received no external funding.*

Author contributions: *research concept and design, S.B., Z.B.; Collection and/or assembly of data, S.B., Y.D.; Data analysis and interpretation, S.B., Z.B.; Writing the article, S.B., Y.D., M.B.; Critical revision of the article, S.B, Z.B., Y.D., M.B.; Final approval of the article, M.B.*

Declaration of competing interest: *The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.*

REFERENCES

1. Chen Y, Xu W, Liu Y, Mao Z, Bao Z, Yao W, et al. Small-signal system frequency stability analysis of the power grid integrated with type-II doubly-fed variable speed pumped storage. IEEE Transactions on Energy Conversion 2023;38(1):611–23. https://doi.org/10.1109/TEC.2022.3207166.
2. Ayas MS, Sahin AK. A reinforcement learning approach to automatic voltage regulator system. Engineering Applications of Artificial Intelligence 2023; 121: 106050. https://doi.org/10.1016/j.engappai.2023.106050.
3. Rajan R, Fernandez FM. Small-signal stability analysis and frequency regulation strategy for photovoltaic sources in interconnected power system. Engineering 2021;103(6):3005–21. https://doi.org/10.1007/s00202-021-01293-7.
4. Buzcu Y, Topaloglu S, Ayten UE, Sagbas M. A novel lead and lag compensator circuit employing a single current feedback operational amplifier. Microelectronics Journal 2020; 105: 104913. https://doi.org/10.1016/j.mejo.2020.104913.
5. Shafiullah M, Pathan MIH, Shahriar MS, Ali A, Hossain MI, Alam MS. Real-time solution of PSS parameter tuning by GA-ANFIS in stabilizing the electrical power system. Arabian Journal for Science and Engineering 2023; 48(5): 6925–38. https://doi.org/10.1007/s13369-023-07666-3.
6. Zhu Y, Zhang Y, Xie X, Yang D, Gao S, Zhang W, et al. Configuration method of PSS lead-lag compensator parameters. E3S Web of Conferences 2021;233: 01059. https://doi.org/10.1051/e3sconf/202123301059.
7. Ansari J, Abbasi AR, Heydari MH, Avazzadeh Z. Simultaneous design of fuzzy PSS and fuzzy STATCOM controllers for power system stability enhancement. Alexandria Engineering Journal 2022; 61(4): 2841–50. https://doi.org/10.1016/j.aej.2021.08.007.
8. Ansari J, Abbasi AR, Heydari MH, Avazzadeh Z. Simultaneous design of fuzzy PSS and fuzzy STATCOM controllers for power system stability enhancement. Alexandria Engineering Journal 2022; 61(4): 2841–50. https://doi.org/10.1016/j.aej.2021.08.007.
9. Azizi N, Moradi H, Rouzbehi K, Mehrizi-Sani A. Direct current power system stabilizers for HVDC grids: Current status. IET Generation, Transmission & Distribution 2023; 17(23): 5117–23. https://doi.org/10.1049/gtd2.13045.
10. Bakolia V, Joshi SN. Design and analysis of fuzzy logic based power system stabilizer. International Journal Of Engineering Research & Technology (IJERT) 2020; 09(08).

11. Swain DR, Ray PK, Jena RK, Paital SR. Stability assessment using adaptive interval type-2 fuzzy sliding mode controlled power system stabilizer. Soft Computing 2023; 27(12): 7715–37. https://doi.org/10.1007/s00500-023-08037-8.
12. Azizi N, Moradi CheshmehBeigi H, Rouzbehi K. Optimal placement of direct current power system stabiliser (DC-PSS) in multi-terminal HVDC grids. IET Generation, Transmission & Distribution 2020; 14(12): 2315–22. https://doi.org/10.1049/iet-gtd.2019.1224.
13. Meegahapola L, Bu S, Gu M. Overview of HVDC technologies and power system stability. hybrid AC/DC power grids: Stability and control aspects. Power Systems2022; 17–56. https://doi.org/10.1007/978-3-031-06384-8_2.
14. Nocoń A, Paszek S. A comprehensive review of power system stabilizers. Energies 2023; 16(4): 1945.
15. Hatziargyriou N, Milanovic J, Rahmann C, Ajjarapu V, Canizares C, Erlich I, et al. Definition and classification of power system stability – Revisited & Extended. IEEE Transactions on Power Systems 2021; 36(4): 3271–81. https://doi.org/10.1109/TPWRS.2020.3041774.
16. Shair J, Li H, Hu J, Xie X. Power system stability issues, classifications and research prospects in the context of high-penetration of renewables and power electronics. Renewable and Sustainable Energy Reviews 2021; 145: 111111. https://doi.org/10.1016/j.rser.2021.111111.
17. Waheed S. A strong action power system stabilizer employment to improve large scale power systems' stability. Journal of Electrical Systems 2021.
18. Alotaibi IM, Ibrir S, Abido MA, Khalid M. Nonlinear power system stabilizer design for small signal stability enhancement. Arabian Journal for Science and Engineering 2022; 47(11): 13893–905. https://doi.org/10.1007/s13369-022-06566-2.
19. Vijaya Lakshmi ASV, Siva Kumar M, Ramalinga Raju M. Interval approach based decentralized robust PID-PSS design for an extended multi-machine power system. Arabian Journal for Science and Engineering 2024; 49(5): 6293–304. https://doi.org/10.1007/s13369-023-08197-7.
20. Peres W, Coelho FCR, Costa JNN. A pole placement approach for multi-band power system stabilizer tuning. International Transactions on Electrical Energy Systems 2020; 30(10).https://doi.org/10.1002/2050-7038.12548.
21. Jigang H, Jie W, Hui F. An anti-windup self-tuning fuzzy PID controller for speed control of brushless DC motor. Automatika 2017; 58(3): 321–35. https://doi.org/10.1080/00051144.2018.1423724.
22. Douidi B, Mokrani L, Machmoum M. A new cascade fuzzy power system stabilizer for multi-machine system stability enhancement. Journal of Control, Automation and Electrical Systems 2019; 30(5): 765–79. https://doi.org/10.1007/s40313-019-00486-7.
23. Touil S, Bekakra Y, Ben Attous D. Influence of fuzzy power system stabilizer using different membership functions for single and multi-machine. Journal of Control, Automation and Electrical Systems 2021; 32(5): 1269–78. https://doi.org/10.1007/s40313-021-00739-4.
24. Sahithya P, Kumar N. Enhancement of transient stability of a smib system using fuzzy logic-based power system stabilizer. Recent Advances in Power Systems 2022; 812; 311–9. https://doi.org/10.1007/978-981-16-6970-5_24.
25. Arora A, Bhadu M, Kumar A. Simultaneous power oscillation damping and frequency control in AC microgrid considering renewable uncertainties: a coordinated control of multiple robust controllers with imperfect communication. Iranian Journal of Science and Technology, Transactions of Electrical Engineering 2024; 48(1): 165–85. https://doi.org/10.1007/s40998-023-00649-y.
26. Prakash A, Singh P, Kumar K, Parida SK. Design of TCSC based optimal wide area power system stabilizer for low-frequency oscillation. 2021 IEEE 4th International Conference on Computing, Power and Communication Technologies (GUCON) 2021;1–6. https://doi.org/10.1109/GUCON50781.2021.9573982.
27. Kumar A, Bhadu M. A Comprehensive study of wide-area damping controller requirements through real-time evaluation with operational uncertainties in modern power systems. IETE Journal of Research 2022: 1–22. https://doi.org/10.1080/03772063.2022.2043784.
28. Kundur P. Power system stability and control. EPRI Power System Engineering Series McGraw-Hill 1994.
29. Vajpayee V, Top E, Becerra VM. Analysis of transient interactions between a pwr nuclear power plant and a faulted electricity grid. Energies 2021; 14(6): 1573. https://doi.org/10.3390/en14061573.
30. Zadehbagheri M, Sutikno T, Kiani MJ, Yousefi M. Designing a power system stabilizer using a hybrid algorithm by genetics and bacteria for the multi-machine power system. Bulletin of Electrical Engineering and Informatics 2023; 12(3): 1318–31. https://doi.org/10.11591/eei.v12i3.4704.
31. MurgaŜ J, Sekaj I, Foltin M, Miklovičová E. Optimization of power system stabilizer by genetic algorithm. IFAC Proceedings Volumes 2005; 38(1): 274–8. https://doi.org/10.3182/20050703-6-CZ-1902.01774.
32. Sebaa K, Boudour M. Optimal locations and tuning of robust power system stabilizer using genetic algorithms. Electric Power Systems Research 2009; 79(2): 406–16. https://doi.org/10.1016/j.epsr.2008.08.005.
33. Keskes S, Bouchiba N, Sallem S, Chrifi-Alaoui L, Kammoun MBA. Optimal tuning of power system stabilizer using genetic algorithm to improve power system stability. 2017 International Conference on Green Energy Conversion Systems (GECS) 2017; 1–5. https://doi.org/10.1109/GECS.2017.8066200.
34. Abdel-Magid YL, Dawoud MM. Tuning of power system stabilizers using genetic algorithms. Electric Power Systems Research 1996; 39(2): 137–43. https://doi.org/10.1016/S0378-7796(96)01105-4.
35. Obaid ZA, Muhssin MT, Cipcigan LM. A model reference-based adaptive PSS4B stabilizer for the multi-machines power system. Electrical Engineering

2020; 102(1): 349–58. https://doi.org/10.1007/s00202-019-00879-6.
36. Jebali M, Kahouli O, Hadj Abdallah H. Optimizing PSS parameters for a multi-machine power system using genetic algorithm and neural network techniques. The International Journal of Advanced Manufacturing Technology 2017; 90(9–12): 2669–88. https://doi.org/10.1007/s00170-016-9547-7.
37. Kaymaz E, Güvenç U, Döşoğlu MK. Optimal PSS design using FDB-based social network search algorithm in multi-machine power systems. Neural Computing and Applications 2023; 35(17): 12627–53. https://doi.org/10.1007/s00521-023-08356-9.
38. Alkhatib H, Duveau J. Dynamic genetic algorithms for robust design of multimachine power system stabilizers. International Journal of Electrical Power & Energy Systems 2013; 45(1): 242–51. https://doi.org/10.1016/j.ijepes.2012.08.080.
39. El-Mihoub TA, Hopgood AA, Nolle L. Self-adaptive learning for hybrid genetic algorithms. Evolutionary Intelligence 2021; 14(4): 1565–79. https://doi.org/10.1007/s12065-020-00425-5.
40. Sun N, Lu Y. Retracted article: A self-adaptive genetic algorithm with improved mutation mode based on measurement of population diversity. Neural Computing and Applications 2019; 31(5): 1435–43. https://doi.org/10.1007/s00521-018-3438-9.
41. Xue Y, Zhu H, Liang J, Słowik A. Adaptive crossover operator based multi-objective binary genetic algorithm for feature selection in classification. Knowledge-Based Systems 2021; 227: 107218. https://doi.org/10.1016/j.knosys.2021.107218.
42. Dombo DA, Folly KA. Self-adaptive differential evolution based power system stabilizers. 2017 IEEE Symposium Series on Computational Intelligence (SSCI) 2017; 1–6. https://doi.org/10.1109/SSCI.2017.8285412.

Dr. Samira BOUMOUS
Presently she is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Power system, heigh voltage, FACTS.
E-mail: samira.boumous@univ-soukahras.dz

Dr. Zouhir BOUMOUS
Presently he is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria; Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Power system, Control, diagnosos.
E-mail: zohir.boumous@univ-soukahras.dz

Dr. Yacine DJEGHADER
Presently he is Associate Professor in Department of Electrical Engineering, University of Mohamed-Cherif Messaadia of Souk Ahras, Algeria; Electrotechns and Renwable energy Laboratory (LEER). His fields of interest are Power Quality, Power System, FACTS, Power Electronic.
E-mail: yacine.djeghader@univ-soukahras.dz

Dr. Moufida BOUMOUS
She is an English teacher at Souk Ahras University, specializing in technical engineering English and interdisciplinary studies.
E-mail: m.boumous@univ-soukahras.dz