CYCLOTRON : Jurnal Teknik Elektro
(P-ISSN 2614-5146) dan (E-ISSN 2614-5499) | Vol. 9 | No. 01 | Halaman 20-26
Januari 2026

Optimization of Power System Stabilizer Parameters Using Genetic Algorithm Considering WECC Criteria

Kevin Marojahan Banjar-Nahor[1], Rofi Maytsa Syahida[1], Nanang Hariyanto[1]
[1]School of Electrical Engineering and Informatics Institut Teknologi Bandung
Jl. Ganesa no 10 Bandung, 40132
e-mail: kevin@staff.stei.itb.ac.id

***Abstract*— Makalah ini membahas optimasi parameter *Power System Stabilizer* (PSS) menggunakan Genetic Algorithm (GA) yang diimplementasikan pada MATLAB dan DIgSILENT PowerFactory, dengan tujuan meningkatkan stabilitas sistem terhadap osilasi frekuensi rendah akibat pertukaran energi kinetik antar generator. Fokus utama diberikan pada model PSS2B, yang merupakan stabilizer yang banyak digunakan, dengan penyetelan parameter ditujukan untuk memenuhi standar performa yang ditetapkan oleh Western *Electricity Coordinating Council* (WECC) dan Aturan Jaringan Listrik Indonesia. Optimasi difokuskan pada parameter-parameter penting, termasuk gain stabilizer, konstanta waktu washout, dan konstanta waktu pada blok Lead-Lag Compensator. Melalui analisis eigenvalue dan evaluasi respon frekuensi, proses optimasi menunjukkan bahwa pendekatan Genetic Algorithm menghasilkan parameter yang memenuhi persyaratan regulasi yang ketat. Efektivitas parameter hasil optimasi dievaluasi menggunakan berbagai indikator performa, seperti bode plot, lokasi nilai eigen, dan simulasi domain waktu. Hasil penelitian ini menegaskan kemampuan teknik *Genetic Algorithm* dalam meningkatkan kinerja PSS, mempercepat proses PSS tuning, serta memastikan kepatuhan terhadap standar yang berlaku.**

Kata kunci: ***Power System Stabilizer, Optimasi Parameter, Genetic Algorithm, Stabilitas Sistem***

Abstract— This study investigates the optimization of Power System Stabilizer (PSS) parameters using Genetic Algorithms (GA) within MATLAB and DIgSILENT Power Factory, aimed at enhancing system stability against low-frequency oscillations caused by kinetic energy exchanges in generators. The focus is on the PSS2B model, a widely used PSS model, with the objective of tuning parameters to meet performance criteria established by the Western Electricity Coordinating Council (WECC) and the Indonesian Grid Code. The GA approach optimizes key parameters including gain, washout time constant, and the time constants of the Lead-Lag Compensator block. By leveraging eigenvalue data and frequency response analysis, the optimization process demonstrates that GA yields PSS parameters which comply with such rigorous standards. The results are validated through various performance metrics, including bode plots, eigenvalue analysis, and time-domain simulations, underscoring the advantages of the GA method in enhancing PSS performance, reducing the PSS tuning duration, and ensuring the adherence to the established criteria.

Keywords: ***Power system stabilizer, parameter tuning, genetic algorithm, optimization.***

I. INTRODUCTION

Electric power systems predominantly utilize alternating current (AC) with a consistent frequency across the network, achieved through the use of AC synchronous machines [1]. However, as power systems are increasingly tasked with handling higher power transfer levels driven by economic demands. To manage stability of these elevated power transfers, the control systems for generators have become critical. Speed governors are employed to maintain system frequency, while excitation controls, including exciters and Power System Stabilizers (PSS), are used to regulate system voltage. Researchers in [2] explore enhancing system stability through real-time instability prediction and rapid steam turbine valve activation, whereas [3] focuses on improving rotor angle stability using a cascaded PID control strategy optimized with a marine predator algorithm.

Effective tuning of PSS—typically applied to generators with significant system participation—is crucial for mitigating small-signal oscillations caused by disturbances [4], [5]. Numerous studies have investigated various methods for tuning PSS [6], [7], [8]. Determining PSS parameters is a critical task, as it ensures that the PSS can adequately dampen oscillations across different scenarios, modes, and evolving system conditions. The challenge lies in obtaining optimal parameters that function effectively under diverse conditions and wide frequency oscillation range, necessitating complex and in-depth analysis.

Designing a PSS controller requires careful consideration of tuning order and placement to achieve optimal damping performance. Although a set of PSS parameters can effectively dampen oscillations at specific frequencies, this may lead to reduced effectiveness at other frequencies. Thus, adjusting the placement and configuration of the PSS can result in varying oscillatory behaviors. Grid codes, such as Indonesian Grid Code, requires the PSS to provide additional damping at a range of oscillation frequency spectrum, i.e. 0.1 Hz to 3 Hz.

Various PSS types have been developed to address these challenges. For instance, [9] presents a decentralized approach to design robust PSS for each generator, employing Quantitative Feedback Theory (QFT) to enhance robustness and performance. Additionally, [12] proposes a method for identifying modal parameters of low-frequency oscillations using empirical mode decomposition (EMD) and techniques such as Subspace State-Space Identification (SSI) and Prony methods. [13] introduces the Improved Particle Swarm Optimization (IPSO) algorithm for optimizing and coordinating the parameters of Energy Storage Systems (ESS) and PSS. However, most papers only focus on damping specific oscillation frequencies occurring in the power system. It should be noted that with additional power plants and future capacity expansions, new oscillation modes may appear and should also be damped.

In this context, optimizing PSS parameters using artificial intelligence, particularly Genetic Algorithms (GA), offers a promising approach to achieving precise parameter values and improving PSS performance [10]. The application of GA for optimization is well-documented [10], [11], [12], [13], [14], [15], [16], with some studies, such as [17], utilizing multi-objective GA to enhance stability by optimizing damping ratio and damping factor. This study is working on solving a current challenge of PSS tuning with GA, including satisfying the Western Electricity Coordinating Council (WECC) criteria for phase compensation, specifically maintaining phase shifts within ±30 degrees for electromechanical modes. This paper proposes an innovative third objective function to account for torque phase shifts relative to rotor angular speed, ensuring compliance with WECC standards [18]. This research aims to optimize PSS parameters using GA with three objectives: damping factor, damping ratio, and frequency response, to adhere to grid code and WECC standards.

Among various PSS models, dual-input PSS-P stabilizers, such as PSS2A, PSS2B, and PSS2C, are widely used in industry [19]. This study focuses on the PSS2B model, which is notably prevalent in Indonesia.

II. Theoretical Backgrounds

A. PSS Tuning and Requirements

In the realm of small-signal stability analysis, system stability is evaluated through modal analysis utilizing eigenvalue and eigenvector techniques [20]. Accurate modeling of Single-Machine Infinite-Bus (SMIB) systems is essential, as it aligns with transfer levels, generation dispatch, network structure, and load characteristics. This modeling is crucial because the damping characteristics of these systems are highly dependent on it [21].

For a system to be considered stable, all eigenvalues must have negative real parts, and the corresponding damping ratios must be monitored within the frequency range of interest to ensure sufficient stability margins. Small disturbances, such as those arising from incremental changes in load or generation, are analyzed using a linearized model of the system.

According to the WECC criterion, the phase compensation resulting from the combination of the phase lead provided by the PSS and the phase lag of the excitation control system should remain within ±30 degrees over the frequency range of 0.2 to 2 Hz [18], [20]. Manual tuning of PSS parameters often employs the Large Criteria Method, where the system's inertia H is increased significantly to maintain rotor angle and speed in accordance with the swing equation [22].

While the root locus method offers valuable insights into compensation strategies, the prevailing industry practice for designing Power System Stabilizers (PSS) predominantly relies on frequency domain techniques. Comprehensive procedures and criteria for this design approach are detailed in [18], [23], [24].

The dual-input Power System Stabilizer (PSS2B) has gained prominence due to its distinct features and benefits. Research by [25] investigates the structure and frequency response of PSS2B, employing phase-frequency characteristic analysis and root locus methods to explore how interactions between sub-synchronous and low-frequency signals impact PSS2B parameter settings.

B. Genetic Algorithm

Genetic Algorithms (GA) are a class of optimization techniques inspired by the principles of natural selection and genetics. They operate using a population of potential solutions, known as individuals, which are initially generated randomly. These individuals are represented as strings or chromosomes, often utilizing a binary encoding (e.g., {0, 1}), which maps their values directly to the decision variables of the problem [26].

The process begins with generating a population of individuals, followed by evaluating their performance using an objective function that defines the problem to be solved. This performance measure, known as fitness, guides the selection process for reproduction. Individuals with higher fitness scores are more likely to pass their genetic material to the next generation. This approach allows GA to explore various regions of the solution space concurrently, gradually focusing on areas with superior performance. Selected individuals are then modified through genetic operators:

1. Selection: Chooses the fittest individuals from the current population to form the next generation.
2. Crossover: Allows pairs or groups of individuals to exchange genetic information, creating new offspring.
3. Mutation: Alters the genetic representation of individuals based on probabilistic rules, introducing new genetic structures.

GA are particularly advantageous because they are more likely to find global optima compared to traditional optimization methods, which often converge to local optima [27]. This advantage arises from their population-based approach and probabilistic transition rules. Additionally, GA can better handle discontinuities and noisy function evaluations than conventional methods, such as deterministic hill-climbing algorithms, which are limited to finding local optima.

In applications of genetic algorithms, especially for optimizing systems like power system stabilizers, defining appropriate upper and lower bounds for the decision variables is crucial [27]. These bounds ensure that the solutions remain feasible and within practical limits, balancing the exploration of new solutions with the exploitation of existing ones. Properly setting these bounds is essential for maintaining stability and performance within the operational constraints of the power system.

III. DATA AND METHODOLOGY

A. System Study

A generator is typically interconnected to the power system interconnection via a step up transformer. The interconnected system itself is typically stiff, hence can be represented as an ideal voltage source (infinite bus) in series with an equivalent impedance. This simplistic representation is practically adequate for power system stabilizer study, and largely recommended by PSS tuning guidelines and codes, such as by PLN Transmission System Operator in [5], [6], [7], [8], Western Electricity Coordinating Council, [18], and the India's Western Regional Power Committee [28]. This also helps with the difficulty of obtaining the power system's complete model. The power system used as the base case in this study is a single machine infinite bus (SMIB) model. The external reactance and the infinite bus represent the multi-machine interconnection systems. The infinite bus voltage is typically 1 per unit, while the external reactance is calculated based on the reactive power response of the generator following an AVR voltage step. It is calculated (in per unit) with the following equation.

$$Z_{ext} \approx \frac{V_1 - V_2}{\frac{Q_1}{V_1} - \frac{Q_2}{V_2}} \tag{1}$$

Where:

Z_{ext} = external reactance [pu]
V_1= initial terminal voltage [pu]
V_2= terminal voltage after voltage step response [pu]
Q_1= intial generator reactive power [pu]
Q_2= generator reactive power after voltage step response [pu]

The power system simulated in Digsilent PowerFactory, is shown in Figure 1.

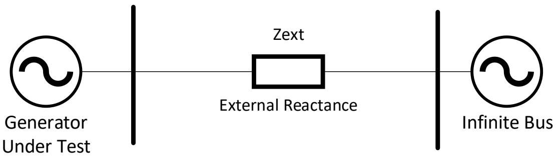
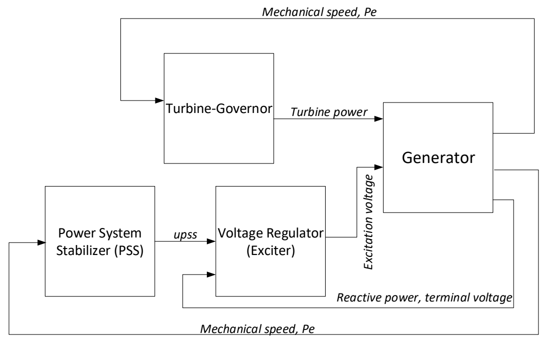
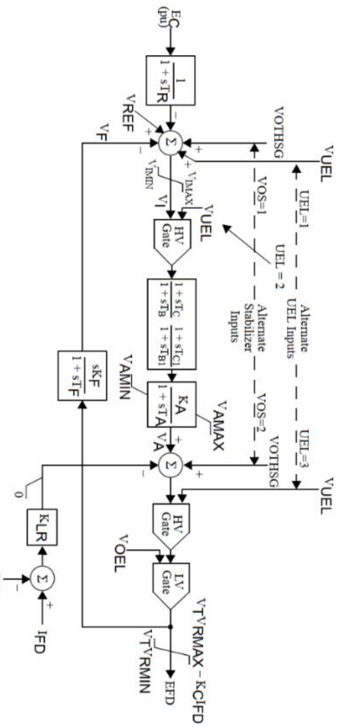


Figure 1. Single Machine Infinite Bus Model for PSS Tuning

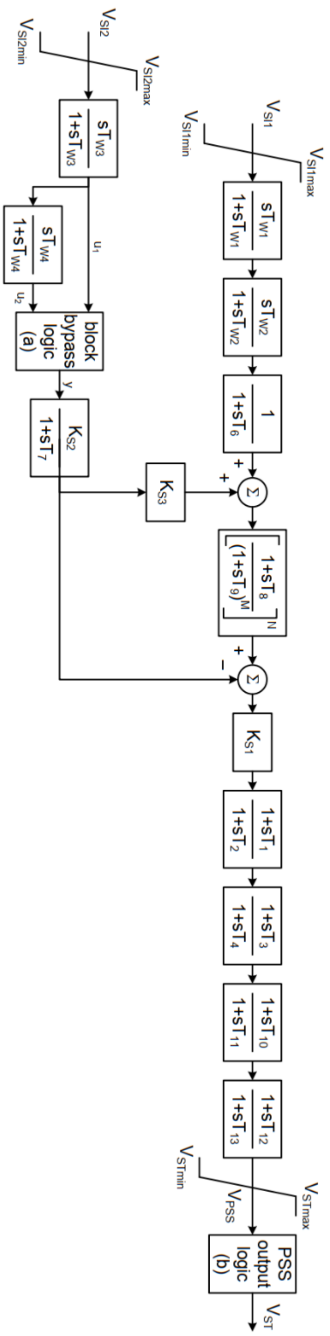
The system includes a hydropower generator, rated at 175 MW, with its terminal voltage rated voltage of 16.5 kV. It incorporates an equivalent external reactance of 0.249 ohms, transmission lines, and an infinite bus. In the system utilizing a PSS2B, the block diagram of the PSS2B contains of three main components: the phase compensator block, the signal washout block, and the gain block. The phase compensator block compensates for the phase lag between the exciter input and the electrical torque of the generator. The signal washout block serves as a high-pass filter with a time constant *Tw*, preventing steady-state signals from causing terminal voltage fluctuations. During the PSS Tuning process, the generator is operated at 80% loading, i.e. 140 MW. The control composite model, exciter model, and PSS model of the generator under test are shown in Figure 2.



(a)



(b)



(c)

Figure 2. (a) Generator Control Models (b) ESST1A exciter model (c) PSS2B Block Diagram

B. Genetic Algorithm Tuning Method

The control system of Power System Stabilizers (PSS) can be effectively optimized by implementing a Genetic Algorithm (GA) for parameter selection. GA's capability to handle multi-objective functions makes it suitable for this task. This approach utilizes eigenvalue and frequency response criteria to achieve standards for damping and phase shift. The objectives are structured as follows:

1. Objective 1 and 2 : Minimize eigenvalue deviations from desired stability criteria [17].
2. Objective 3: Minimize frequency response deviations to ensure adequate damping [22].

By integrating these objectives into the GA framework, optimal PSS parameters can be determined efficiently, enhancing system stability and meeting operational standards. square of error (ISE) indices have proved to be the most meaningful and convenient measures of dynamic performance [29] . In this optimization process, we utilized a method to derive the best PPS parameters by minimizing objective functions based on eigenvalues and frequency response. In this study, integral of square of error (ISE). chosen for performace indices. These functions, defined in equation (1), collectively represent J, which is target to minimize.

$$J = min\left(\alpha \sum_{j=1,\, \sigma_i \geq \sigma_o}^{n} [\sigma_i - \sigma_o]^2 + \beta \sum_{j=1, \zeta_i \leq \zeta_o}^{n} [\zeta_i - \zeta_o]^2 + \gamma \sum_{j=1}^{n} [C_j - C_o]^2 \right) \quad (2)$$

The symbols σ_o (e.g., -5) and ζ_o (e.g., 0.5) represent threshold values for the real part of eigenvalues and the damping ratio, respectively. Here, σ denotes the real part of the i-th eigenvalue, while ζ signifies the damping ratio associated with that eigenvalue. The parameters α and β are predefined weighting factors, with α set to 1, β set to 10, and γ set to 0.2. Additionally, C_j denotes the phase compensation at the J-th frequency, where C_o (e.g., -10 degrees) serves as the reference phase.

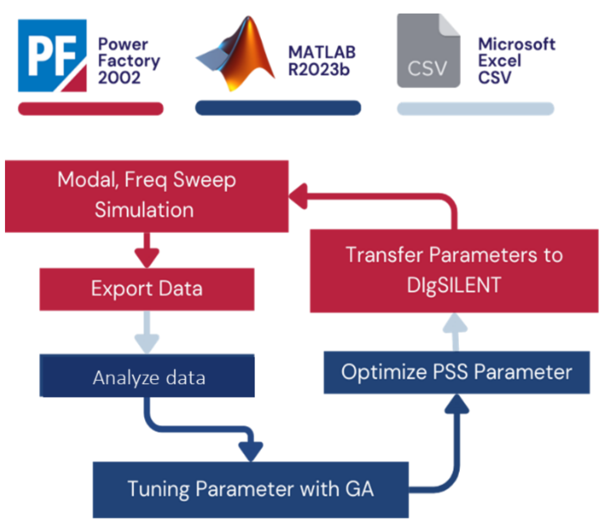


Figure 3. PowerFactory anda Matlab Data Exchange Scheme

C. PowerFactory MATLAB Data Exchange

The tuning process for the PSS2B is divided into two stages. First, modal simulation is performed using DIgSILENT PowerFactory, where eigenvalue data is generated. This data is then imported into MATLAB for optimization using a Genetic Algorithm (GA) [5]. In DIgSILENT PowerFactory, the DIgSILENT Programming Language (DPL) is used to write scripts for automated modal and frequency response simulations. These results are exported as CSV files and imported into MATLAB. Next, the Optimization Toolbox in MATLAB is utilized to analyze the modal simulation data and determine the PSS parameters using the Genetic Algorithm. The data exchange process between matlab and power factory is shown in Figure 3.

Data transfer involves 4 main files: Psspar.csv, Data.csv, Flag.csv, and Stop.csv, operating as follows [30] :

1. DIgSILENT reads Psspar.csv containing PSS2B parameter values and writes simulation modal results to Data.csv.
2. MATLAB reads Data.csv, utilizes eigenvalue data for GA optimization, and updates parameter values in Psspar.csv.
3. Flag.csv serves as a switch to control DIgSILENT and MATLAB execution with values of 1 or 0. 1 triggers DIgSILENT while halting MATLAB; conversely, 0 allows MATLAB to operate while stopping DIgSILENT.
4. This iteration will end once the stopping criteria are met. The file Stop.csv indicates to DIgSILENT that the GA process has been completed.

IV. RESULT AND DISCUSSION

In the automation process, optimization is aimed at achieving a minimized objective function J to push weak damping eigenvalues towards the left side of the complex S-plane curve and the compensation value obtained must not exceed ±30 degrees to meet the established WECC criteria. Matlab genetic algorithm toolbox is used with the following parameters: population size of 10, max generations of 10, SelectionFcn of 5, EliteCount of 1, CrossoverFcn of crossover heuristic, and MutationFcn of mutation adaptive feasible. Population size of 10 and max generation of 10 were selected after a sensitivity analysis. Intially, a population size of 20 and a max generation of 20 were tested, as it is considered sufficiently large for genetic algorithm implementation. However, due to the multiobjective functions, we found out that typically the population size of 10 and max generation of 6-7 are sufficient to achieve the convergence. This has proved to speed up the total simulation time.

For each iteration, eigenvalues are continuously updated until the best generation value is achieved to satisfy the predefined objective function.

Table 1. Constraints and Tuned Parameters

PARAMETER (IEEE PSS2B)	LOWER LIMIT	UPPER LIMIT	TUNED RESULT
KS1	1	100	13.352
KS2	T7/2H		0
KS3	1	10	1
TS1	0.217	0.277	0.446
TS2	0.040	0.050	0.017
TS3	0.217	0.277	0.56
TS4	0.040	0.0506	0.014
T7	Tw2		2.594
TW1	1	10	3.912
TW2	1	10	2.594
TW3	1	10	7.898
TW4	bypassed		0

Before initiating the simulation, the proposed tuning methodology is executed by running the DPL script alongside the Genetic Algorithm (GA). Upon completion of the optimization process, the algorithm provides the optimal values for the PSS2B parameters, as presented in Table 1.

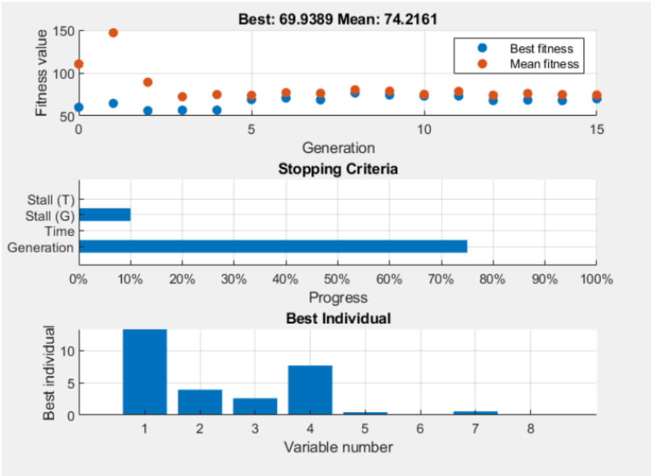


Figure 4. Status of GA in MATLAB

It can be seen in Figure 4 shows that the GA successfully found an optimal parameter composition solution by the 15th generation.

A. Frequency Response (Bode) Plot Analysis

Figure 5 illustrates the frequency response when using an eigenvalue-based objective function with WECC criteria through genetic algorithm. It is evident that the compensated phase (shown by the black dash-dotted line) falls within the ±30-degree range across the 0.1 to 3 Hz frequency spectrum (indicated by the red dotted lines), meaning it meets the WECC standard for the electromechanical mode frequency range. This compliance is achieved due to the use of multi-objective optimization in equation (x), which incorporates the compensated phase objective.

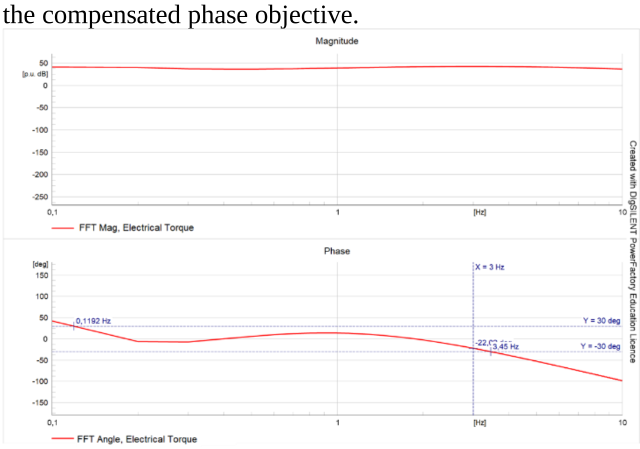


Figure 5. Bode Plot Result with GA Considering WECC Requirement

B. Oscillation Mode (Modal) Analysis

The dominant oscillation mode is a crucial factor in power system stability, as it reflects the power system's least stable behavior. When disturbances occur, such as sudden load changes or faults, this mode is the most likely to affect overall system performance. In Table 2, it is evident that the system without a PSS installed shows poor damping. Once a PSS is added, both tuning methods deliver comparable results. This indicates that the GA method, when adjusted with the WECC criterion, not only ensures compliance but also maintains the level of damping performance.

Tabel 2 provides the modal analysis results for each modes for the base case and the proposed method with GA.

Table 2. Modal Analysis Results

	NAME	REAL PART	IMAGINARY PART	DAMPED FREQUENCY	DAMPING	DAMPING RATIO
	Mode	1/s	rad/s	Hz	1/s	%
BASE	1	-0,45	0,82	0,13	0,45	48,10
	2	-0,45	-0,82	0,13	0,45	48,10
	3	-1,18	15,84	2,52	1,18	7,40
	4	-1,18	-15,84	2,52	1,18	7,40
GA	1	-0,38	0,79	0,13	0,38	43,12
	2	-0,38	-0,79	0,13	0,38	43,12
	3	-4,37	5,12	0,81	4,37	64,95
	4	-4,37	-5,12	0,81	4,37	64,95
	5	-7,67	44,02	7,01	7,67	17,17
	6	-7,67	-44,02	7,01	7,67	17,17

It can be seen that provides tuning PSS with GA provide a very high damping for the electromechanical mode, over 17%, indicating excellent damping capability at the dominant frequency range of 0.1 – 3 Hz.

C. Time Domain Simulation Analysis

To evaluate the performance of the PSS with the designed parameter settings and adjusted overall gain, two step response tests were conducted on the AVR voltage reference of the unit under test, with the PSS alternately in and out of service. The step size was set to 1.03 pu.

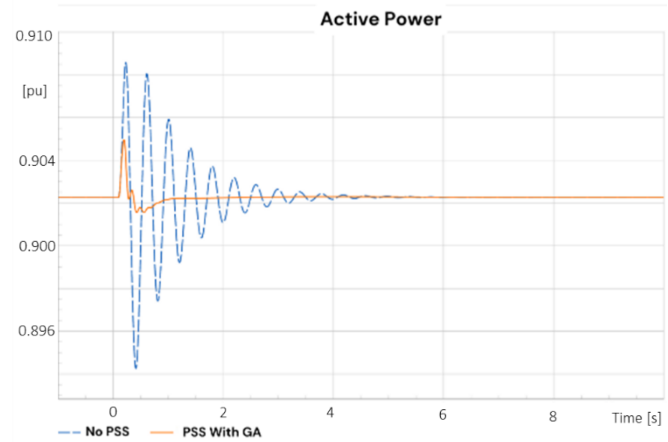


Figure 6. AVR Step Test 3% Respones

Figure 6 illustrates that the active power oscillation damping following a step response is significantly improved. This validates the conclusions drawn in the previous subsection about the damping performance of the three alternative PSS tuning designs presented seen in Table 2.

D. Comparison with the Existing PSS Tuning Method

In Indonesia, as reported in [5-8], PSS Tuning is already conducted in compliance with Indonesia's grid code, which is more demanding than WECC guidelines. However, the PSS parameter tuning is conducted manually which will depend on the tuner's experience and expertise. The tuner will typically follow IEEE's PSS parameter recommendation [31], and then modify it accordingly to comply with the Indonesia grid code's requirements. This process takes typically 3-4 hours, and in some cases 1-2 days. Such challenges no more exist when the tuning is conducted with computer program, equipped with GA optimization method. The total PSS parameter tuning process may take 10-20 minutes only, saving considerable amount of time, and can be conducted by a non-expert, as long as the PSS tuning parameter range and objective function are already set. The quality of the results do not possess significant difference, as both manual tuning and automatic (via GA) tuning comply with the grid code.

V. Conclusion

The PSS2B tuning process was conducted using a MATLAB and DIgSILENT interface with a genetic algorithm, significantly improving the damping of oscillation modes. Simulation results show that GA-based optimization provides optimized PSS parameters which meets the WECC standards and effectively enhances system stability over a required range of oscillation frequency spectrum.

Reference

[1] P. Kundur, *Power system stability controls*. New York, 2017.

[2] S. Robak, J. Machowski, and M. Skwarski, "Enhancement of power system stability by real-time prediction of instability and early activation of steam turbine fast valving," *Energy Rep.*, vol. 8, pp. 7704–7711, 2022, doi: 10.1016/j.egyr.2022.05.285.

[3] A. Yakout, W. Sabry, and H. M. Hasanien, "Enhancing rotor angle stability of power systems using marine predator algorithm based cascaded PID control," *Ain Shams Eng. J.*, vol. 12, no. 2, pp. 1849–1857, 2021, doi: 10.1016/j.asej.2020.10.018.

[4] G. Rogers, "Demystifying Power System Oscillations," *Ieee Comput. Appl. Power*, pp. 30–35.

[5] L. ITB, "Kajian studi & konsultansi tuning pss pembangkit sistem sulawesi bagian selatan 2023," PLN, 2023.

[6] "PSS Tuning Sistem Jawa-Bali 2022 Rembang," 2022.

[7] "PSS Tuning Sistem Jawa-Bali 2022 PEC Paiton," 2022.

[8] "PSS Tuning P3B Sulawesi 2023 PLTU Punagaya," 2023.

[9] M. R. Esmaili, A. Khodabakhshian, P. G. Panah, and S. Azizkhani, "A New Robust Multi-Machine Power System Stabilizer Design Using Quantitative Feedback Theory," *Procedia Technol.*, vol. 11, no. Iceei, pp. 75–85, 2013, doi: 10.1016/j.protcy.2013.12.164.

[10] M. Facta and Hermawan, "The application of algorithm genetic for tuning power system stabilizer in suralaya power plant generation - West Java," *First Int. Power Energy Conf. PECon 2006 Proc.*, pp. 73–75, 2006, doi: 10.1109/PECON.2006.346622.

[11] K. Sebaa and M. Boudour, "Optimal locations and tuning of robust power system stabilizer using genetic algorithms," *Electr. Power Syst. Res.*, vol. 79, no. 2, pp. 406–416, 2009, doi: 10.1016/j.epsr.2008.08.005.

[12] P. Khampariya, S. Panda, H. Alharbi, A. Y. Abdelaziz, and S. S. M. Ghoneim, "Coordinated Design of Type-2 Fuzzy Lead–Lag-Structured SSSCs and PSSs for Power System Stability

Improvement," *Sustain. Switz.*, vol. 14, no. 11, 2022, doi: 10.3390/su14116656.

[13] D. Penchalaiah, G. N. Kumar, M. M. Gade, and S. E. Talole, "Optimal Compensator Design using Genetic Algorithm," 2018. doi: 10.1016/j.ifacol.2018.05.087.

[14] M. Nurdin, N. Hariyanto, R. Fela, L. Fredrik, and P. Musa, "Power System Stabilizer (PSS) and Static VAR Compensator (SVC) Placement Coordination and Tuning with Genetic Algortihm for Dampen Power System Oscillations."

[15] M. Jebali, O. Kahouli, and H. Hadj Abdallah, "Optimizing PSS parameters for a multi-machine power system using genetic algorithm and neural network techniques," *Int. J. Adv. Manuf. Technol.*, vol. 90, no. 9–12, pp. 2669–2688, 2017, doi: 10.1007/s00170-016-9547-7.

[16] A. Kharrazi, "The Use of Artificial Intelligent in Power System Stability," 2015.

[17] Y. L. Abdel-Magid and M. A. Abido, "Optimal multiobjective design of robust power system stabilizers using genetic algorithms," *IEEE Trans. Power Syst.*, vol. 18, no. 3, pp. 1125–1132, 2003, doi: 10.1109/TPWRS.2003.814848.

[18] W. E. C. Council, "WECC Power System Stabilizer Tuning Guidelines."

[19] M. Izdebski, R. Małkowski, and P. Miller, "New Performance Indices for Power System Stabilizers," *Energies*, vol. 15, no. 24, pp. 1–23, 2022, doi: 10.3390/en15249582.

[20] G. J. Rogers, "Control for Stability in Interconnected Power Systems," *IEEE Control Syst. Mag.*, vol. 9, no. 1, pp. 19–22, 1989, doi: 10.1109/37.16745.

[21] J. M. Ramirez, A. R. Messina, and J. M. C. Caiedo, "An Investigation on The Use of power System Stabilizers for Damping Inter-Area Oscillations in Longitudinal Power System," *Power*, vol. 13, no. 2, pp. 552–559, 1998.

[22] S. R. Winchen Wangdi, Wijarn Wangdee, "Power System Stabilizer Tuning by Incorporating WECC Criteriation into Particle Swarm Optimization," pp. 5–8, 2019.

[23] P. P. E. C. Mva, "PROSEDUR PSS TUNING," pp. 1–7, 2023.

[24] M. A. Pai and A. R. Bergen, "Power System Stabilizers — Analytical Techniques and Practical Criteria for Design," *IFAC Proc. Vol.*, vol. 19, no. 16, pp. 175–182, 1986, doi: 10.1016/s1474-6670(17)59377-5.

[25] M. Fan, K. Wang, and J. Zhang, "Parameters Setting of Power System Stabilizer PSS2B," vol. 112, no. Icreet 2016, pp. 63–70, 2017, doi: 10.2991/icreet-16.2017.12.

[26] MathWorks, "Genetic Algorithm." [Online]. Available: https://www.mathworks.com/discovery/genetic-algorithm.html

[27] F. Herrera, M. Lozano, and J. L. Verdegay, "Tackling Real-Coded Genetic Algorithms: Operators and Tools for Behavioural Analysis," *Artif. Intell. Rev.*, vol. 12, no. 4, pp. 265–319, 1998, doi: 10.1023/A:1006504901164.

[28] "PROCEDURE FOR PSS TUNING IN INDIAN POWER SYSTEM - Detailed Guide for PSS Tuning in Indian Power Sector." Western Regional Power Committee, Jun. 30, 2023.

[29] W. C. Schultz and V. C. Rideout, "Control system performance measures: Past, present, and future," *IRE Trans. Autom. Control,* vol. AC-6, no. 1, pp. 22–35, 2013, doi: 10.1109/tac.1961.6429306.

[30] A. Stativa, *Matlab - DIgSILENT automatic data exchange v.3 - explained*.

[31] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies," *IEEE Std 4215-2016 Revis. IEEE Std 4215-2005*, pp. 1–207, Aug. 2016, doi: 10.1109/IEEESTD.2016.7553421.