Low-Frequency Oscillatory Stability Study on 500 kV Java-Indonesian Electric Grid

Herlambang Setiadi, *Student Member*, *IEEE*, N. Mithulananthan, *Senior Member*, *IEEE*, Awan Uji Krismanto, *Student Member*, *IEEE*, Rakibuzzaman Shah*, *Member*, *IEEE*.
School of Information Technology & Electrical Engineering, The University of Queensland, Brisbane, Australia
*School of Engineering and Technology, CQUniversity, Perth, Australia
E-mail: h.setiadi@uq.edu.au, mithulan@itee.uq.edu.au, a.krismanto@uq.edu.au, m.shah2@cqu.edu.au

Abstract— **The Java-Indonesia 500 kV network is the biggest interconnected system in Indonesia. This system extends from the western part of Java Island to eastern part with a distance of approximately 1000 km. This long tie-line may contribute to the instability of power system, in particular, low-frequency oscillation stability of the system at weak grid condition. However, small attention has been paid so far to investigate the low-frequency oscillation stability performance on Java 500 kV system. Hence, this paper investigates the low-frequency oscillation stability performance of Java 500 kV network. Eigenvalue analysis and damping ratio analyses are employed to examine the dynamic behavior of this system. Time domain simulation has been applied to verify the modal analysis of Java system. Furthermore, dual input power system stabilizer (DIPSS) has been applied in this paper to enhance the low-frequency oscillation stability margin of the system. The DIPSS parameters are tuned using Craziness particle swarm optimization (Craziness PSO). From the simulation results, it is found that there is a weak mode in the Java 500 kV system. The installation of DIPSS based on Craziness PSO in the Java 500 system enhanced the low-frequency oscillation stability margin of the system.**

***Keywords*-Craziness PSO, damping ratio, DIPSS, Java 500 kV, time domain simulation.**

I. Introduction

Most of the power plants in Java are the thermal type with few large hydropower plants. All these power plants are interconnected through the high voltage long transmission line. The weak tie-line in the system may result in the instability problem. One of the stability problems that can emerge in power system connected to long transmission line is low-frequency oscillation instability.

Low-frequency oscillation (LFO) instability has the frequency range from 0.1-2 Hz [1]. If this instability is not well damped, the oscillation may continue to grow until the system loss synchronization and lead to partial and fully blackout [2]. In Indonesia, partially black out was recorded in Jakarta and Banten for 3 hours due to small load fluctuation in 2005 [3]. However, researcher and transmission system operators (TSOs) have made a little or no effort to study the low-frequency oscillation in Java 500 kV system.

Low-Frequency oscillation instability can be minimized by damper windings in the rotor of the generator. However, over the time, the performance can be deteriorated. Therefore, the other methods to enhance the low-frequency oscillation stability performance should be considered. One such method is by adding power system stabilizer (PSS) in the excitation system [4]. Furthermore, due to the increasing load demand, conventional PSS alone is not enough to handle the oscillation in the large-scale power system. Hence, the deployment of dual input PSS (DIPSS) is essential. However, it is challenging to design DIPSS as it requires extensive computation for large power system such as the Java network. Design of DIPSS with desired performance requires a huge effort, especially if the DIPSS installed in large-scale power system such as Java 500 kV. Therefore, DIPSS design using metaheuristic algorithm can be considered.

Metaheuristic algorithm can be classified into three groups, namely metaheuristic based on social, physical and biological inspiration [5]. Imperialist competitive algorithm and tabu search algorithm can be categorized into social-based inspiration [5]. While particle swarm optimization, genetic algorithm, differential evolution algorithm, ant colony optimization and firefly algorithm are categorized into biological-based inspiration. Furthermore, simulated annealing algorithm can be categorized into physical-based inspiration [5-11]. Among them, particle swarm optimization becoming more popular due to robustness and simple mathematical representation of the process [12].

In this work, the low-frequency oscillation stability performance of Java network is investigated. Furthermore, DIPSS for low-frequency oscillation stability augmentation is proposed in this work. The rest of the paper is organized as follows; Section II describes the modeling of dual input PSS and low-frequency oscillation stability assessment framework. Section III briefly explain about Craziness PSO algorithm and the design algorithm of DIPSS based on Craziness PSO. Illustrative simulation results are presented in IV including the representative Java network. Section V highlights the contribution, conclusions and future direction of the research.

II. Fundamental Theory

A. Dual input power system stabilizer

The dual input of power system stabilizer (DIPSS) used a combination of rotor speed and electrical power generator as the input [13]. By considering those two signals, DIPSS can provide better damping signal to the excitation system. Fig. 1

shows the block diagram of DIPSS for low-frequency oscillation stability study [13].

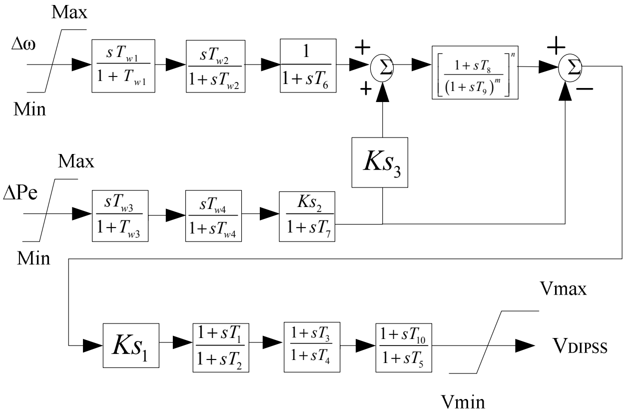

Fig. 1. Block diagram of DIPSS.

The signal input of DIPSS can be derived from the shaft motion that causes excessive modulation of the excitation system and torsional oscillation from electrical torque signal. Moreover, DIPSS can be used to damp the oscillation coming from different sources [13].

B. Low-frequency oscillation stability

Low-frequency oscillation emerged due to insufficient synchronization and damping torques [14]. Low-frequency oscillation can be classified as a local and global mode or inter-area mode [14]. Local mode is associated with oscillation generator in a particular power plant against the rest of the systems. This oscillation has a frequency around 0.7 to 2 Hz [14]. Inter-area mode is associated with the generator in one area oscillates against another machine from another area, with the frequency of this oscillation is 0.1 to 0.7 Hz [14]. There have been many incidents related to the low-frequency oscillation such as in Taiwan in 1984, 1989, 1990, 1991 and 1992 [15]. The incident in Taiwan can be considered as local oscillation phenomena (the frequency oscillation in this incident around 0.78-1.05 Hz). The incident due to the inter-area oscillation (global phenomena) is happening in China in 2003, the US in 2003, and Italy 2003 with the frequency oscillation ranging from 0.4 Hz to 0.55 Hz [15]. The latest incident happens in Continental Europe (CE) electricity system on 1st December 2016 at 11:18 to 11.23 with the frequency oscillation around 0.15 Hz [16]. This incident emerges due to an unexpected tripping of a line in the French system [16].

Low-frequency oscillation can be examined using eigenvalue analysis at an operating condition. To determine system eigenvalues, analysis of system state space model has to be conducted. State space representation of the system can be established using (1) [17]:

$$\begin{bmatrix} \Delta\dot{x} \\ 0 \end{bmatrix} = \begin{bmatrix} A & B \\ C & \begin{bmatrix} D_{11} & D_{12} \\ D_{21} & J_{LF} \end{bmatrix} \end{bmatrix} = \begin{bmatrix} \Delta x \\ \Delta y \end{bmatrix} + E\left[\Delta u\right] \quad (1)$$

In (1), Δx is a vector of state variables. Δy represents a vector of algebraic variables. Δu corresponded to the input vector. J_{LF} is the load-flow Jacobian. A and B are plant and control or input matrix respectively. While output and feedforward matrix are denoted by C and D, respectively. Furthermore, the reduced system state matrix of the entire system can be defined using (2) [17]:

$$A_{sys} = \left(A - B\left[\begin{pmatrix} D_{11} & D_{12} \\ D_{21} & J_{LF} \end{pmatrix}^{-1} \right] C \right) \quad (2)$$

The eigenvalue of the system matrix carries information about the stability of the system. Complex eigenvalue indicates frequency oscillation (f) and damping ratio (ξ) which can be described as given in (3), (4), and (5) [18, 19]:

$$\lambda_i = \sigma_i \pm j\omega_i \quad (3)$$

$$f_i = \frac{\omega_i}{2\pi} \quad (4)$$

$$\xi = \frac{-\sigma_i}{\sqrt{-\sigma_i^2 + -\omega_i^2}} \quad (5)$$

III. DESIGN DIPSS BASED ON CRAZINESS PSO

A. Particle swarm optimization

PSO is an optimization algorithm inspired by the behavior of animals in search of food. Kennedy and Eberhart introduced PSO in 1995. In PSO, particles can be assumed as a flock of birds where each of member of the group has a dependence on each other [20-22].

The bird population on the PSO optimization method is called swarm, and each individual bird as a particle. The location of the best food source is a representation of the optimal value. When a bird (e.g. bird A) finds a good source of food then other birds will follow the bird even though other birds have a great distance. If birds that follow bird A finds a better source of food than bird A, the other birds will following that bird. This process occurs continuously until it can be found where the best source of food [20-22].

When a flock of birds searches for food, each bird determines its position based on its own experience (P_{best}) and based on the experience of other birds (G_{best}). The most important parts of PSO algorithm is particle velocity and position. The mathematical representation of velocity and position particle of PSO can be described as given in (6). The completed mathematical representation of PSO algorithm can be found in [20].

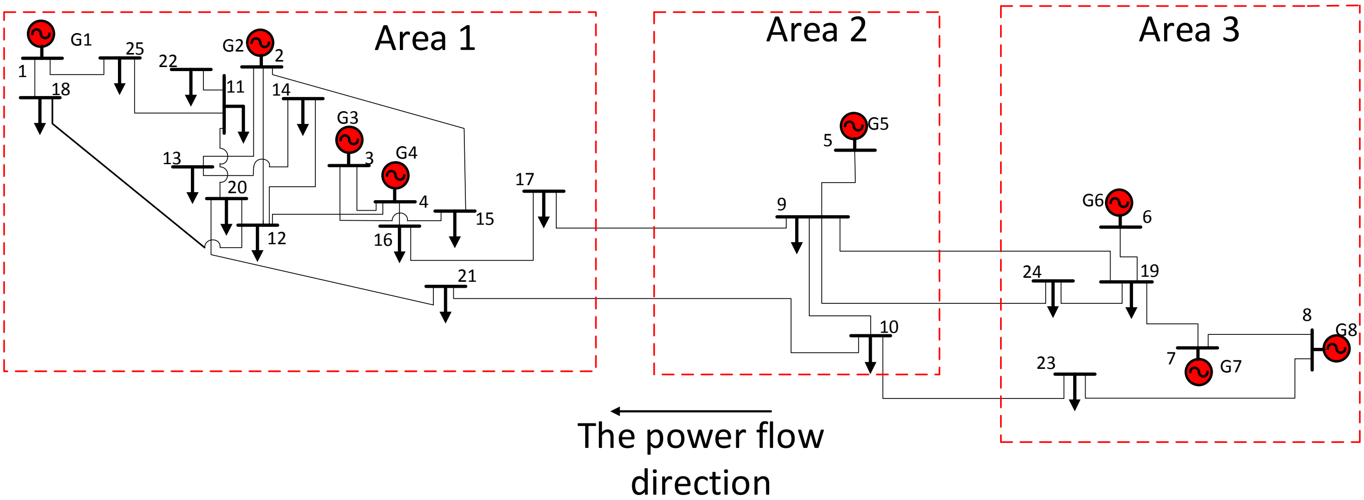

Fig. 2. Java 500 kV Indonesian network.

$$v_i^{k+1} = v_i + c_1 r_1 \left(P_{best} - x_i^k\right) + c_1 r_1 \left(G_{best} - x_i^k\right)$$
$$x_i^{k+1} = x_i + v_i^{k+1} \tag{6}$$

In (6), k_i is particle position, and v_i corresponds to the velocity of the particle. P_{best} and G_{best} are the best position of the particle and the best P_{best} in the population. C_1 and C_2 are learning factor, while r_1 and r_2 are a random value from 0 to 1 [20-22].

B. Craziness particle swarm optimization

Traditional PSO is effective for low-dimensions function optimization problem due to initial particle distributed evenly in the searching field. However, for the multi-dimensional optimization problem, this algorithm could be trapped in local optima. The traditional PSO can convergence fast. However, the will fall into local optima easily [23]. Hence, the traditional PSO will not find the best solution (global optimal). As modified into Craziness PSO, the problem regarding local optima can be minimized [24].

The difference between Craziness PSO and PSO is in the velocity function. In the Craziness PSO, the velocity of the particle moves randomly on the space to seek other probability of smallest value. The random movement of the particle is called crazy particle denoted by P_{craz}. The value of P_{craz} depends on the weighing functions as described in (7). While the mathematical representation of velocity can be expressed as in (8) [24]:

$$P_{craz} = w_{\min} - \exp\left(-\frac{w^k}{w_{\min}}\right) \tag{7}$$

$$v_i^k = \begin{cases} rand\left(0, v_{\max}\right) if & P_{craz} \le rand(0,1) \\ v_i^k & anothers \end{cases} \tag{8}$$

C. Design power system stabilizer

In this paper, the parameter of DIPSS is optimized using Craziness PSO based on the objective function as stated in (9):

$$E = \sum \int_0^{t1} t\left|\Delta\omega(t, X)\right| dt \tag{9}$$

In (9), $\Delta\omega(t,X)$ is the rotor speed deviation. X is composed of DIPSS parameters, while $t1$ is the period of the simulation. In this research, the objective function is to minimize the value of E. Moreover, the search constraints of the problems are the maximum and minimum parameter of DIPSS.

IV. RESULTS AND DISCUSSIONS

This section illustrates the low-frequency oscillation stability of the Java 500 kV network. Analysis has been conducted for the nominal operating condition as given in [28] and various power flow through the tie-line between area 1-3. Fig 2 shows the single line diagram of 500 kV Java network [25]. Furthermore, the performance of DIPSS is implemented and tested for the Java system. From the simulation results it is found that the craziness PSO needs 10 min to find the convergence value (optimal value) of DIPSS.

A. Modal analysis of Java network

This section shows the low-frequency oscillation stability results for Java network. Table I illustrates the modal (eigenvalue, damping value, frequency oscillation) analysis of electromechanical (EM) mode of the system. Table 1 also shows the contribution of the generator in the EM mode. In this section the system is consists of 25 bus and 8 machines. This system divided into three areas connected through the high voltage long transmission line. The distance between area 1 and area 2 is 500 km, while the distance between area 2 and area 3 is 500 km. Moreover, the distance between area 1 and area 3 is 1000 km. All of the parameters of the machine as well as the power flow is taken from the realistic condition in Java-Indonesia electric grid. The generator modeled as ninth order model including exciter and governor [26]. Hence, the total state variable on this system is 144 state variables. The completed data of this system can be found in [25]. It can be observed that the system has inter-area and seven local modes. It is also found that there are two modes with damping ratio

TABLE I. MODAL ANALYSIS OF THE TEST SYSTEM

Mode	Eigenvalue	Damping (%)	Frequency (Hz)	Participation of the Generator
Inter-area	-0.0680 + 4.7074i	1.44	0.7492	G3,G4,G5
Local 1	-0.8318 + 9.5226i	8.70	1.5155	G6
Local 2	-0.1389 + 7.0180i	1.98	1.1169	G5
Local 3	-0.4620 + 8.1046i	5.69	1.2911	G1
Local 4	-0.5189 + 8.6068i	6.02	1.3711	G2
Local 5	-1.1250 + 8.8033i	12.68	1.4011	G3G4
Local 6	-2.6601 + 7.4346i	33.69	1.2227	G7G8
Local 7	-0.6728 + 4.5518i	14.62	0.7261	G7G8

(%) under the threshold value (5%) [27]. Fig. 3 illustrates the eigenvalue of EM mode in a complex plane for base case. Furthermore, if those modes are not damped properly, it could potentially lead to the unstable condition.

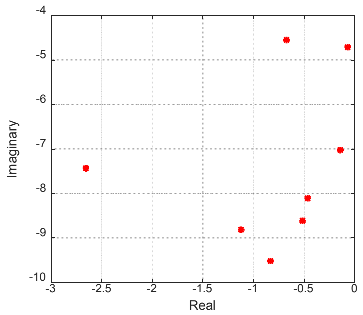

Fig. 3. Eigenvalue EM mode in complex plane.

To assess the low-frequency oscillation stability performance of the Java grid, different operating condition is performed. Table II illustrates the operating condition list to analyses the low-frequency oscillation stability performance of the Java grid, while table III shows the damping performance comparison of with base case operating condition and different operating condition. It is observed that the worst condition is when Java grid operated in base case operating condition indicated by smallest damping performance of inter-area (1.44%). Hence, adding additional controller such as DIPSS is essential to enhance the damping performance of the system.

TABLE II. OVERSHOOT AND SETTLING TIME OF ROTOR SPEED.

Operating condition	Changed system topologies from base case
OC1	G5 output is 991.35 MW and load demand in bus 9 and 10 are 217.125 and 410.625 MW
OC2	G4 output is 523.8 MW and load demand in bus 17 is 366.25 MW
OC3	G3 output is 711 MW and load demand in bus 17 and 21 are 329.625 and 149.625 MW
OC4	G6 output is 675 MW and load demand in bus 19 is 635 MW
OC5	G6 output is 675 MW and load demand in bus 19, 23 and 24 are 539, 529.125 and 777.75 MW

TABLE III. DAMPING RATIO COMPARISON OF DIFFERENT OPERATING CONDITION

Cases	Base	OC1	OC2	OC3	OC4	OC5
Inter-area	1.44	2.07	1.56	2.45	1.91	1.84
Local 1	8.70	8.95	8.70	8.68	9.86	9.84
Local 2	1.98	4.08	1.94	2.18	1.94	1.94
Local 3	5.69	5.00	5.21	5.08	5.09	5.11
Local 4	6.02	6.07	6.03	5.87	6.06	6.05
Local 5	12.68	13.25	12.92	13.60	13.23	13.14
Local 6	33.69	26.68	33.68	33.55	27.16	26.97
Local 7	14.62	18.58	14.57	14.87	17.99	18.32

B. Low-frequency oscillation stability enhancement using DIPSS based on Craziness PSO

This section focused on the augmentation of low-frequency oscillation stability in Java grid. The DIPSS are installed at G3, G4, G5 since these generators are contributing to the critical mode. Moreover, Craziness PSO is employed to tune parameters. Fig. 4 illustrates the convergence graph comparison of the traditional PSO and Craziness PSO. The red one corresponded to the convergence graph of PSO, while the black corresponds to the convergence graph of Craziness PSO.

It can be observed that Craziness PSO provide smaller fitness function (objective function) with compared to the traditional PSO. Hence, the smallest error of rotor speed was obtained by using Craziness PSO. Table IV shows the eigenvalue, while Table V illustrates the damping ratios for different scenarios. It can observe that most of the eigenvalue moved further towards the left-half plane. This is happened due to damping signal from DIPSS. Moreover, the damping performance of the overall system increased significantly when DIPSS based on Craziness PSO is used into the system. This is happened due to precise signals damping provided by DIPSS based on the Craziness PSO to the excitation system of the generator.

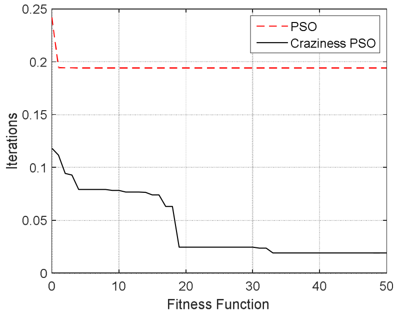

Fig. 4. Convergence graph comparison of different cases.

TABLE IV. EIGENVALUE COMPARISON OF DIFFERENT CASES

Cases	Base case	With DIPSS	DIPSS PSO	DIPSS Craziness PSO
Inter-area	-0.07+4.7i	-0.07+4.6i	-0.08+4.8i	-0.12+4.7i
Local 1	-0.83+9.5i	-0.83+9.5i	-0.84+9.5i	-0.83+9.5i
Local 2	-0.14+7.0i	-0.16+6.9i	-0.61+7.9i	-0.89+3.3i
Local 3	-0.46+8.1i	-0.47+7.8i	-0.46+6.9i	-1.76+7.5i
Local 4	-0.52+8.6i	-0.53+8.6i	-0.52+8.6i	0.52+8.6i
Local 5	-1.13+8.8i	-2.07+8.8i	-2.07+8.8i	-2.06+8.8i
Local 6	-2.66+7.4i	-2.66+7.4i	-2.66+7.4i	-2.66+7.4i
Local 7	-0.67+4.6i	-0.67+4.6i	-0.67+4.6i	-0.67+4.6i

TABLE V. DAMPING RATIO COMPARISON OF DIFFERENT CASES

Cases	Base case	With DIPSS	DIPSS PSO	DIPSS Craziness PSO
Inter-area	1.44	1.49	1.62	2.57
Local 1	8.70	8.70	8.75	8.8
Local 2	1.98	2.33	7.65	25.9
Local 3	5.69	6.07	6.64	23.02
Local 4	6.02	6.02	6.02	6.06
Local 5	12.68	22.98	22.99	22.93
Local 6	33.69	33.69	33.69	33.69
Local 7	14.62	14.62	14.62	14.62

To validate and verify the eigenvalue analysis, time domain simulations are carried out by giving 0.05 pu step input of load. The time domain simulation takes 2 min to finish the simulation. Fig. 5 illustrates the oscillatory condition of rotor speed G5, while Fig. 6 shows the rotor angle oscillatory condition of G5. A blue line presents the oscillatory system condition without DIPSS, while the green line corresponds to the system with DIPSS based on traditional PSO. The oscillatory condition of the system with PSO based DIPSS is indicated by the red line, while the oscillatory condition of the system with Craziness PSO based DIPSS is presented by black lines.

It is observed that the system without DIPSS experienced a higher oscillatory condition than a system with DIPSS tuned by PSO and Craziness PSO. The best oscillatory condition is experienced by the system when the Craziness PSO is employed to the DIPSS, indicated by smallest overshoot and fastest settling time in Tables VI and VII, respectively. In other words, the time domain simulation verified the linear analysis results.

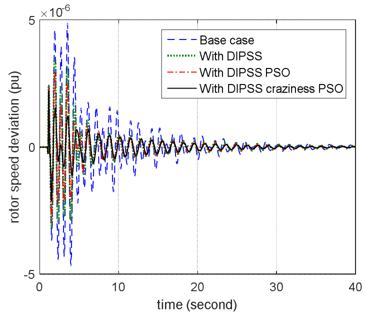

Fig. 5. Rotor speed oscillatory condition of G5.

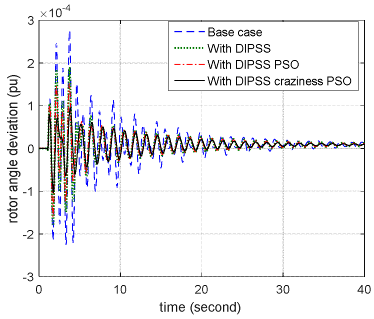

Fig. 6. Rotor angle oscillatory condition of G5.

TABLE VI. OVERSHOOT AND SETTLING TIME OF ROTOR SPEED.

Cases	Overshoot (pu)	Settling time (sec)
Base case	0.000002445	>50
With DIPSS	0.000002383	>30
DIPSS PSO	0.000002371	>30
DIPSS Craziness PSO	0.000002195	>20

TABLE VII. OVERSHOOT AND SETTLING TIME OF ROTOR ANGLE.

Cases	Overshoot (pu)	Settling time (sec)
Base case	0.0001153	>50
With DIPSS	0.0001052	>30
DIPSS PSO	0.00009978	>30
DIPSS Craziness PSO	0.00007818	>20

V. CONCLUSIONS

This paper investigates the low-frequency oscillation stability performance of 500 kV Java-Indonesia electric grid. This paper also proposed a method to enhance the low-frequency oscillation stability performance of the system by using the dual input of PSS tuned by Craziness PSO. From the investigated study cases, it is found that the system consists of seven local mode and one inter-area mode. It is also found that there are two weak modes (under 5% damping) associated to the inter-area mode and local mode of the system. It is observed that generator 5 (G5) is contributed in both of the weak modes (inter-area, local mode).

It is noticeable that the damping performance of the system is enhanced when DIPSS is applied to the system. Furthermore, the best performance is provided to the system with DIPSS based on Craziness PSO. However, it should be worth noting that even with the proposed of tuning method (DIPSS based on Craziness PSO), the damping performance of inter-area mode is still under the 5%. Hence, further research needs to be conducted by utilizing additional devices such as battery energy storage and FACTS devices to enhance the damping performance of the test system.

APPENDIX

The data for dual input of PSS used in this paper is based on the IEEE recommended practice for excitation system models for power system stability studies (IEEE Std 421. 5-2005) [28]. The upper and lower limit of the dual input PSS parameter used in craziness PSO is also based on that standard.

ACKNOWLEDGMENT

The first author would like to thank the Ministry of Finance of Indonesian Government for the Endowment Fund of Education Scholarship to pursue Doctoral degree at The University of Queensland, Australia.

REFERENCES

[1] A. U. Krismanto and N. Mithulananthan, "Identification of Modal Interaction and Small Signal Stability in Autonomous Microgrid Operation," *IET Generation Transmission & Distribution,* 2017.
[2] H. Setiadi, N. Mithulananthan, and M. J. Hossain, "Impact of Battery Energy Storage Systems on Electromechanical Oscillations in Power Systems," in *2017 IEEE Power and Energy General Meeting*, Chicago, USA, 2017.
[3] R. Duanaputri, "Optimasi Parameter PSS Berbasis Multi Mesin Menggunakan Modified Differential Evolution (MDE) Pada Sistem Jawa Bali 500 kv," Institut Teknologi Sepuluh Nopember, 2017.
[4] N. Mithulananthan, C. A. Canizares, J. Reeve, and G. J. Rogers, "Comparison of PSS, SVC, and STATCOM controllers for damping power system oscillations," *IEEE Transactions on Power Systems,* vol. 18, no. 2, pp. 786-792, 2003.
[5] H. Setiadi and K. O. Jones, "Power System Design using Firefly Algorithm for Dynamic Stability Enhancement," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 1, no. 3, pp. 446-455, 2016.
[6] D. Lastomo, H. Setiadi, and M. R. Djalal, "Optimization Pitch Angle Controller of Rocket System using Improved Differential Evolution Algorithm," *International Journal of Advances in Intelligent Informatics,* vol. 3, no. 1, 2017.
[7] D. Lastomo, H. Setiadi, and M. R. Djalal, "Optimization of SMES and TCSC using particle swarm optimization for oscillation mitigation in a multi machines power system," *Journal of Mechatronics, Electrical Power, and Vehicular Technology,* vol. 8, no. 1, pp. 11-21, 2017.
[8] D. Lastomo, Atmiasri, and H. Setiadi, "Stability enhancement of hybrid power systems using RFB based on Craziness PSO," in *2017 3rd International Conference on Science in Information Technology (ICSITech)*, 2017, pp. 188-194.
[9] D. Lastomo, Widodo, H. Setiadi, and M. R. Djalal, "Enabling PID and SSSC for load frequency control using Particle Swarm Optimization," in *2017 3rd International Conference on Science in Information Technology (ICSITech)*, 2017, pp. 182-187.
[10] M. Taufik, D. Lastomo, and H. Setiadi, "Small-disturbance angle stability enhancement using intelligent redox flow batteries," in *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI)*, 2017, pp. 1-6.
[11] M. Ulum, H. Setiadi, and D. Lastomo, "Design Controller Blade Pitch Angle Wind Turbine Using Hybrid Differential Evolution Algorithm-Particle Swarm Optimization," *Advanced Science Letters,* vol. 23, no. 12, pp. 12396-12399, 2017.
[12] K. Y. Lee and J.-B. Park, "Application of particle swarm optimization to economic dispatch problem: advantages and disadvantages," in *Power Systems Conference and Exposition, 2006. PSCE'06. 2006 IEEE PES*, 2006, pp. 188-192: IEEE.
[13] A. Sharma and M. Kothari, "Intelligent dual input power system stabilizer," *Electric Power Systems Research,* vol. 64, no. 3, pp. 257-267, 2003.
[14] H. Setiadi, A. U. Krismanto, N. Mithulananthan, and M. Hossain, "Modal interaction of power systems with high penetration of renewable energy and BES systems," *International Journal of Electrical Power & Energy Systems,* vol. 97, pp. 385-395, 2018.
[15] K. Prasertwong, N. Mithulananthan, and D. Thakur, "Understanding low-frequency oscillation in power systems," *International Journal of Electrical Engineering Education,* vol. 47, no. 3, pp. 248-262, 2010.
[16] entsoe, "Analysis of CE Inter-Area Oscillations of 1st December 2016," European Network of Transmission System Operators for Electricity, 2017.
[17] P. W. Sauer and M. Pai, "Power system dynamics and stability," *Urbana,* 1998.
[18] D. Lastomo *et al.*, "The effects of energy storages on small signal stability of a power system," in *2017 International Seminar on Intelligent Technology and Its Applications (ISITIA)*, 2017, pp. 52-57.
[19] H. Setiadi, A. U. Krismanto, and N. Mithulananthan, "Enabling BES in Large PV Plant for Stability Enhancement on Power Systems with High RES," in *2017 IEEE Innovative Smart Grid Technologies-Asia (ISGT-Asia)*, Auckland, New Zealand, 2017.
[20] R. C. Eberhart and J. Kennedy, "A new optimizer using particle swarm theory," in *Proceedings of the sixth international symposium on micro machine and human science*, 1995, vol. 1, pp. 39-43: New York, NY.
[21] M. Eslami, H. Shareef, A. Mohamed, and M. Khajehzadeh, "An efficient particle swarm optimization technique with chaotic sequence for optimal tuning and placement of PSS in power systems," *International Journal of Electrical Power & Energy Systems,* vol. 43, no. 1, pp. 1467-1478, 2012.
[22] X. Sui, Y. Tang, H. He, and J. Wen, "Energy-Storage-Based Low-Frequency Oscillation Damping Control Using Particle Swarm Optimization and Heuristic Dynamic Programming," *IEEE Transactions on Power Systems,* vol. 29, no. 5, pp. 2539-2548, 2014.
[23] A. Sahu, S. K. Panigrahi, and S. Pattnaik, "Fast convergence particle swarm optimization for functions optimization," *Procedia Technology,* vol. 4, pp. 319-324, 2012.
[24] K. T. Chaturvedi, M. Pandit, and L. Srivastava, "Particle swarm optimization with crazy particles for nonconvex economic dispatch," *Applied Soft Computing,* vol. 9, no. 3, pp. 962-969, 2009.
[25] A. Soeprijanto, M. Abdillah, D. F. U. Putra, Mardlijah, and Rusilawati, "Power System Stabilizer Based on Interval Type 2 Fuzzy Sliding Mode Controller for Oscillation Damping on 500kV Java-Bali Electrical Power System," *Journal of Electrical Systems,* no. Special issue AMPE2015, pp. 1-11, 2015.
[26] P. M. Anderson and A. A. Fouad, *Power system control and stability*. John Wiley & Sons, 2008.
[27] B. Pal and B. Chaudhuri, *Robust control in power systems*. Springer Science & Business Media, 2006.
[28] "IEEE Recommended Practice for Excitation System Models for Power System Stability Studies," *IEEE Std 421.5-2016 (Revision of IEEE Std 421.5-2005),* pp. 1-207, 2016.