Enabling PID and SSSC for Load Frequency Control using Particle Swarm Optimization

Dwi Lastomo
Widodo
Electrical Engineering Department
University of PGRI Adi Buana
Surabaya, Indonesia
E-mail: dtomo23@gmail.com,
widodo.adibuana@gmail.com

Herlambang Setiadi
Muhammad Ruswandi Djalal
School of Information Technology & Electrical Engineering
The University of Queensland
Brisbane, Australia
Department of Mechanical Engineering State Polytechnic of Ujung Pandang
Makassar, Indonesia
E-mail: h.setiadi@uq.edu.au, wandi@poliupg.ac.id

***Abstract*—Rapid human population has led to increasing number of load demand. This load demand increased could potentially lead to instability of power system such as frequency stability. It is well known that governor has a significant role in controlling frequency on the generator. Generally, the governor usually used simple integral controller as the controller. However, with increasing number of load and rapid load changing, integral control only is not enough to handle the problems. Hence, deployment additional devices such as flexible alternating current transmission systems (FACTS) devices and changing the governor controller to PID controller is crucial. This paper proposed an enhancement of load frequency control using PID controller and Static Synchronous Series Compensator (SSSC). A Particle Swarm Optimization (PSO) is used as an optimization method to find the best parameter. Two area power system are used as a test system to analyze the performance of system with proposed method (PID and SSSC based on PSO). To examine the performance of the system with or without proposed method. From the simulation, it is found by using PID and SSSC based on PSO the frequency performance of the system is enhanced.**

Keywords—LFC; FACTS Devices; SSSC; PSO

I. INTRODUCTION

Frequency is a variable that represents active power on the power system. Frequency is a measure of the power system performance [1]. On large-scale, interconnected power system comprises a large number of synchronizing power plant to supply power system demand. Hence, the frequency in the power plant should be kept in constant and equal value. Moreover, it is required to divide each power plant to supply the demand. The problem emerges when there is a fluctuation of the demand resulting in the oscillatory condition in the frequency. If the network frequency change more than 10% the system might loss synchronization [1]. Hence, load frequency control (LFC) is crucial.

Generally, LFC can be done by taking feedback signals of frequency to the system and controlled using integral control. However due to the fluctuation of the demand complete PID controller become popular. Moreover, PID controller is the cheapest and easiest to design and installed [2]. In last few decade the increasing number of human population and development of the technology, is effected on increased power system demand. It should be considered to add additional controller such as a FACTS devices.

The most advantages of FACTS devices could be located anywhere in the systems [3]. There are widely type of FACTS devices, namely Unified Power Flow Control, Static Var Compensator, Thyristor Control Series Compensator, Static Synchronous Compensator, Solid Phase Shifter, Interline Power Flow Control and Static Synchronous Series Compensator (SSSC) are used to maintain, load flow, voltage, damping as well as frequency of the system [3-8]. Among them, SSSC becoming popular due to the ability to control real power flow [6]. In this paper SSSC use for damp the overshoot and accelerate frequency by adding SSSC in the middle of interconnected two area power system. Furthermore, the proper design method is essential to get better performance of the system.

World problem-solving method is based on a strict rule with detailed steps that follow each component of the system. These problems are designing a basic system to perform certain tasks. Conventional approaches can be used to solve the problem. However, the conventional approach might not provide efficient solutions when the problems are complex engineering problems. The ability of nature is far superior to conventional technology to solve problem. Nature provides many examples with simple basic component compressing of competition and cooperation, which later turned into a complex overall coordination. The concept of adapting nature behavior into the algorithm is called metaheuristic algorithm. There is some metaheuristic algorithm such as imperialist competitive algorithm inspired by social nature; differential evolution algorithm, ant colony optimization, genetic algorithm, bat algorithm, firefly algorithm and particle swarm optimization (PSO) inspired by biological nature [9-11]. PSO is becoming more popular because of its simple concepts, easy implementation, and robustness compared with other metaheuristic techniques [12].

The novelty of this research is a method for controlling frequency of the system by using PID controller as governor controller and adding SSSC to the tie line. Furthermore, this research also contributes how to design and to tune PID controller and SSSC using PSO optimally. The following paper organized as follows: Section II presents the load frequency control, modeling of PID controller and SSSC for load frequency control. A brief explanation of PSO and tuning PID controller and SSSC are presented in section III. Section IV illustrates the result and discussion of the paper. Section V highlight the conclusions.

II. Grand Theory

A. Load Frequency Control

In electric power systems, active power is closely related to the frequency. Active power changes lead to changes in frequency. Load in power system is unpredictable; it can vary at any time. Active power load variation can emerge frequency oscillation on generator [1]. In a large-scale interconnected power system, the problems of frequency fluctuation become more complex. Hence it is necessary to stabilize between load and demand by using Load Frequency Control [13-17]. Fig. 1 depict the schematic diagram of LFC.

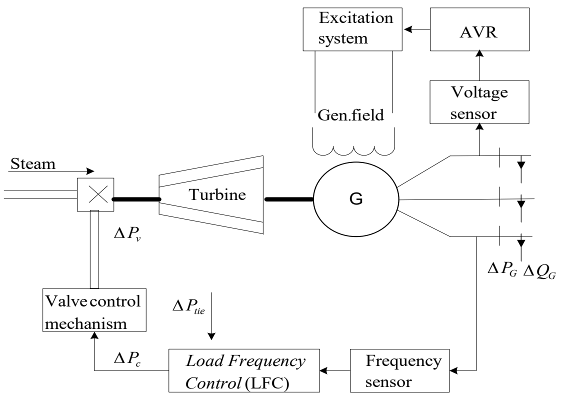

Fig. 1. Schematic Diagram of LFC [13].

B. PID Controller

The function of the controller is to reduce error signal, namely the deferent between signal settings and signal actually. The faster the reaction system following the actual signal and the smaller the errors that occur, the better the performance of control systems are applied. PID controller until now a lot of industrial used it. This is because its use is easy, and can improve the performance of the system quickly. Output PID controller is the combination of output proportional control, the output of integral control, output differential control. Fig. 2 shows the block diagram of PID controller [11, 18].

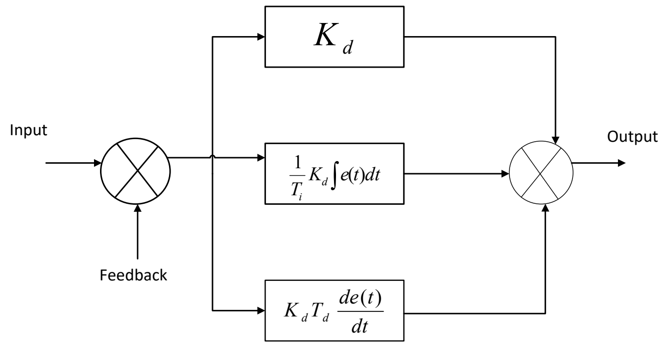

Fig. 2. PID Controller Block Diagram.

C. Static Synchronous Compensator

SSSC was first established in 1989 by Gyigyi in [19]. SSSC can inject controllable voltage in series with the transmission line. By injecting voltage in transmission line SSSC can provides the virtual compensation of transmission line impedance [6]. The SSSC is located in series with the tie line between a two-area interconnected power system can be seen in Fig 3. Fig. 4 illustrates the dynamic model of SSSC for load frequency control

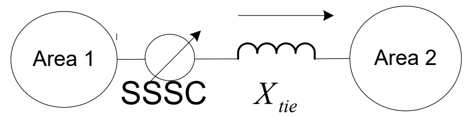

Fig. 3. Schematic Diagram of SSSC Placement.

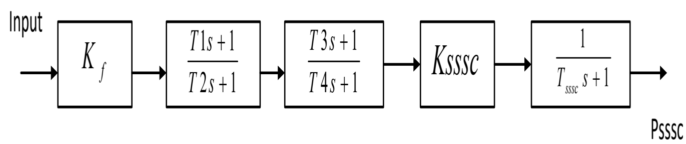

Fig. 4. SSSC Block Diagram.

III. Parameter Tuning of PID Controller and SSSC using Particle Swarm Optimization

A. Particle Swarm Optimization

Particle Swarm Optimization was introduced by Kennedy and Eberhart in 1995 [20]. PSO is an optimization method that is flexible, reliable population-based stochastic. PSO pattern inspired by the activities of a group of birds while looking for food. When the birds eat, the birds will move into a flock of birds in large numbers. Moreover, birds will mutually inform each other about the presence of food. Furthermore, this pattern becomes an inspiration to develop PSO methods [20].

PSO is an optimization technique based on population. PSO start by spreading swarm of the population at a space problem. The dispersed particle is the referred as a swarm.

The particle will provide information to another, so the most optimal value would be known. The information will continue to spread because these particles will continue to move to obtain a position with the most optimal value. A particle that moves will learn from the experience of the previous particle for time to time. Each particle will always control the position based on the particle around experience [20-25].

PSO begins with the initial position of a particle on space problems in the x and y coordinates, with each particle will move to shift position based on a function of velocity. Each particle would be given the best result based on the position in the spaces. The best result on every particle is expressed as $pb[]$ and the position expressed as $pbx[]$ and $py[]$ [20]. [] sign indicated an array whose length is determined by many birds or particles are used in the optimization process, in this paper the total array for PSO is six arrays. Each particle the move to evaluating the new position with the movement of which is determined by the velocity of x or y. When the position of pbx located on the right side of current particle's position with respect to x, the new x velocity is the result of a reduction in velocity x in the previous iteration with random number *weight*. It can be expressed in (1)[20].

$$sx[] = sx - (rand()p_{inc}) \quad (1)$$

Whereas, if the particle's position at this time on the x component located on the left of pbx the new velocity is the sum of the velocity at the previous iterations with random number *weight*. As written in (2). The same formula applies to the position of y, only in this case the movement is upward or downward[20].

$$sx[] = sx + (rand()p_{inc}) \quad (2)$$

The second part of the algorithm is that each particle would remember well the best evaluation result (global best position) during the iteration or particles traveling in progress and also considering the value position. To get the value is by setting the array index of the best group of position x and $pby[gb]$ is the best group of y position. Based on the results pbx and pby then each velocity x and y position is set by (3)-(6) [20].

$$If\ x[] > pbx[gb]\ moreover\ sx[] = sx - (rand()p_{inc}) \quad (3)$$

$$If\ x[] < pbx[gb]\ moreover\ sx[] = sx + (rand()p_{inc}) \quad (4)$$

$$If\ y[] > pby[gb]\ moreover\ sy[] = sy - (rand()p_{inc}) \quad (5)$$

$$If\ y[] < pby[gb]\ moreover\ sy[] = sy + (rand()p_{inc}) \quad (6)$$

Variable pb, gb, and changes in the two variables is an important part of the PSO algorithm. Conceptually pb an autobiographical memory of a particle, because every particle will always remember his own experiences and changes in velocity associated with pb can be described as a nostalgic simple, where gb can be expressed as a knowledge or standards published to each particle and the desire to achieve that [20].

Although so far the algorithm works well, but there is a prat of the algorithm that is aesthetically unpleasant and difficult to understand. Namely the change in the particle velocity based on a rough test inequalities. Where if $x > bx$ the $presentx$ become smaller, if $x < bx$ then it would become larger. Several revisions latter made to make the algorithm easier to understand and improve its performance. So the velocity is made simpler by following the difference per dimension to the best locations. As written in (7).

$$sx[][] = sx[][] + (rand()p_{inc}(pbx[][] - x[][])) \quad (7)$$

After conducting experiments and realized that there was no way that appropriate to guess the value and so that the two variables are removed from the equation velocity functions in the algorithms. The mathematical enhancement of (7) is described as given in (8).

$$sx[][] = sx[][] + 2\big(rand()(pbx[][] - x[][])\big) + 2\big(rand()(pbx[][gbest] - x[][])\big) \quad (8)$$

The subsequent development of PSO methods is added weight component particles in velocity function. PSO model is the developed to solve the problems of optimal values that have more than two positions or more components of the two-dimensional. Based on the PSO concept, it can be written in a mathematical equation as follow: vector position and velocity of particles i-th of a space dimensional problem d can be represented as $X_i = (x_{i1}, x_{i2}, \ldots, x_{id})$ and $S_i = (s_{i1}, s_{i2}, \ldots, s_{id})$[26]. By applying the objective function of an evaluation of each particle will evaluate the influence on the position of each particle to the optimum target value. The objective function used varies for each issue. From the result of this evaluation will obtain the best local position and global best position represented respectively $pb_g = (p_{i1}, p_2, \ldots, p_{id})$ and $pb_g = gb_g = (p_{g1}, p_{g2}, \ldots, p_{gd})$, with g are particles that are in a position to function optimum results. Each particle would attempt to modify the position using $velocity$ function between the pb and gb distance. Repair function of speed and the function of the position change of each particle is written in (9) and (10).

$$s_i^{k+1} = w^k s_i + c1r1\big(pb_i - x_i^k\big) + c2r2\big(gb - x_i^k\big) \quad (9)$$

$$x_i^{k+1} = x_i + s_i^{k+1} \quad (10)$$

With, k, s_i, x_i, $c1, c2$, $r1$, $r2, pb, gb$ are iteration, particle velocity, particle position, accelerate constant 1 and 2, random constant 1 and 2, local best position, global best position.

In these equations are written w^kvariable corresponded to weights function. The purpose of the placement of the weighing function is to regulate the global and local exploration undertaken by the particles for each iteration. The number of moves is determined by the number of iterations. Weighing repair function (weight) written in (11) [27, 28].

$$w^k = (w_{max} - w_{min})\left(\frac{iter_{max} - iter^k}{iter_{max}}\right) + w_{min} \quad (11)$$

With, w, w_{max}, w_{min}, $iter_{max}, iter$ are weight, maximum weight, minimum weight, maximum iteration, and iteration.

B. Objective Function Design

Objective function E is defined as (12)

$$E = \sum \int_0^t t|\Delta ACE(t, X)|dt \quad (12)$$

In (12) $\Delta ACE(t, X)$ is the area control error of the system with PID controller and SSSC. t is the time simulation and X is the optimization parameters $(K_p, K_i, K_d, K_{fi}, K_{sssc}, T_{sssc})$. The objective of this optimization algorithm is to find the minimum objective function. The minimum objective function would make the system has better performance in terms of less oscillatory condition. Fig 5 shows the flowchart of PSO for tuning PID controller and SSSC devices.

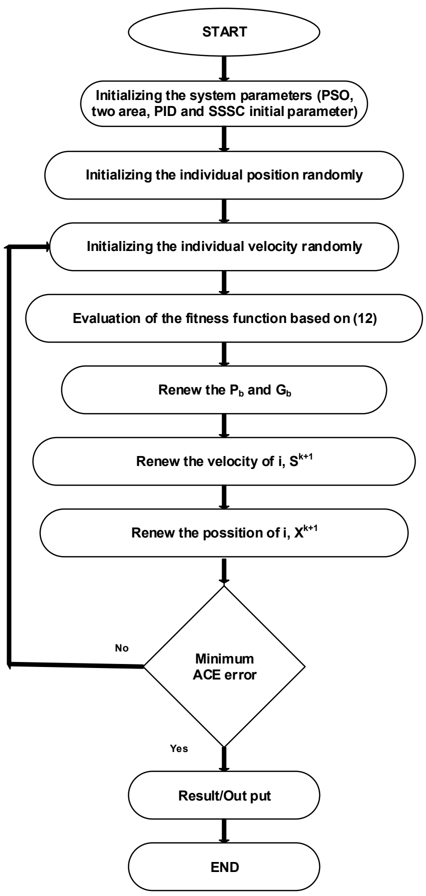

Fig. 5. PSO flowchart.

IV. Experimental and Result

A one line diagram of LFC two area power system with PID controller and SSSC is depicted in Fig. 6. The total number of order in this study are presented by 12 order model, 6 order coming from LFC two are a power system, 4 order from the PID controller and 3 order from SSSC. LFC two area power system with PID and SSSC was simulated in SIMULINK environment, and PSO was conducted in MATLAB M-File. Table I shows the optimized parameter of PID controller and SSSC. Fig. 7 depicts the convergence graph of the proposed method. The time domain simulation has been performed over a period of 60 seconds to investigate the oscillatory condition of the system.

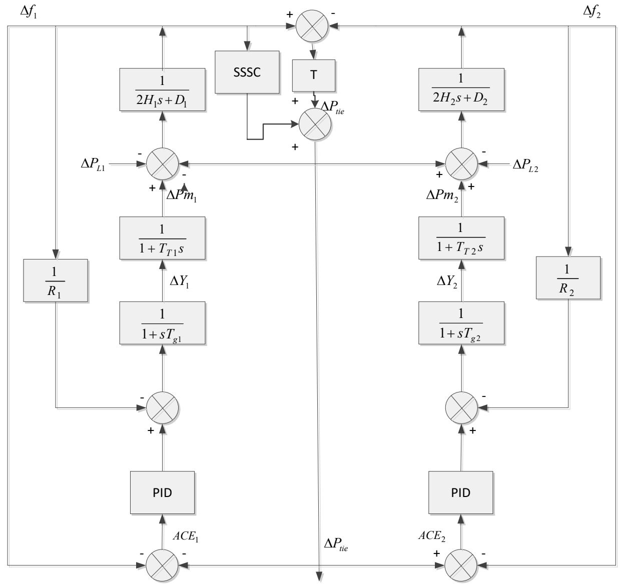

Fig. 6. Load Frequency Control of Two Area System with PID and SSSC.

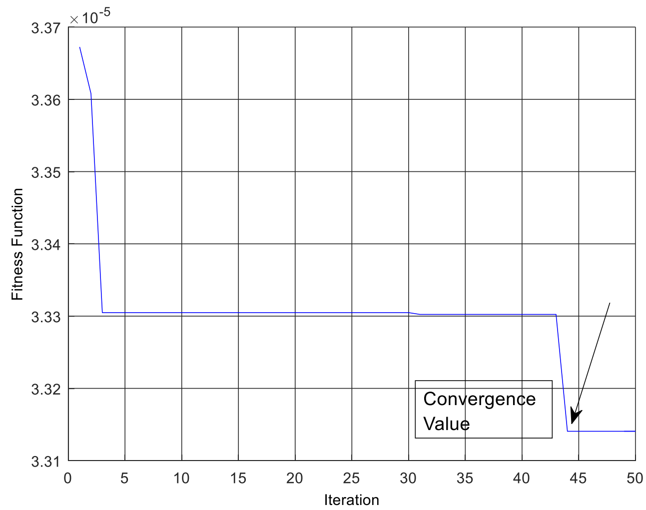

Fig. 7. PSO Convergence Graph.

TABLE I. OPTIMIZED PARAMETER

Parameter	Optimized value
Kp	1.2341
Ki	4.0480
Kd	3.0796
Kf	0.2279
Ksssc	0.2014
Tsssc	0.1029

A. Frequency Oscillation Area 1

Response frequency in area 1 can be seen in Fig 8. LFC coordinated only with PID controller has overshoot -0.0002656 pu and settling time above 10 seconds. LFC coordinated with PID controller, and SSSC has overshoot -0.000267 pu and the settling time above 10 seconds. LFC coordinated with PID and SSSC optimized with PSO has overshoot -0.0002139 pu and settling time above 10 seconds. The comparison of overshoot and settling time frequency response area 1 can be seen in Table II.

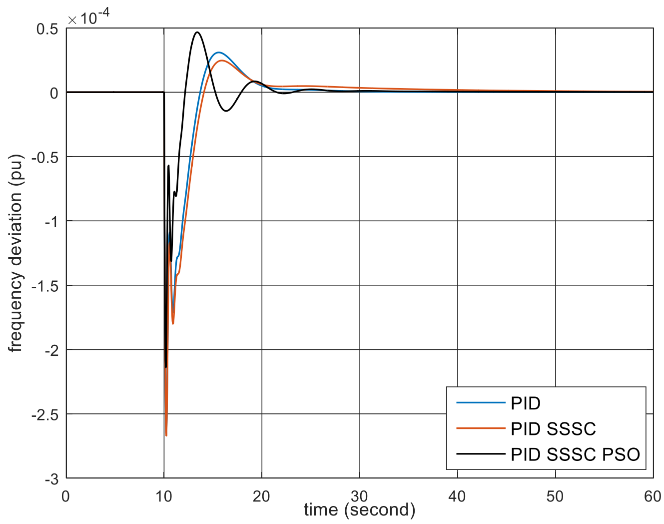

Fig. 8. Frequency Response in Area 1.

TABLE II. COMPARISON OF OSCILLATORY CONDITION IN AREA 1

Control Method	Cases		
	PID	***PID SSSC***	***PID SSSC PSO***
Overshoot (pu)	-0.0002656	-0.000267	-0.0002139
Settling time (s)	<10	<10	<10

B. Frequency Oscillation Area 2

Response frequency in area 2 can be seen in Fig. 9. LFC coordinated only with PID controller has overshoot -0.000003339 pu and settling time above 20 seconds. LFC coordinated with PID controller, and SSSC has overshoot -0.000001365 pu and the settling time above 20 seconds. LFC coordinated with PID and SSSC optimized with PSO has overshoot -0.000006237 pu and settling time above 20 seconds. The simulation shows that LFC coordinated with PID and SSSC optimized by PSO provide the best response compared to the other scenarios. The comparison of overshoot and settling time frequency response area 2 can be seen in Table III.

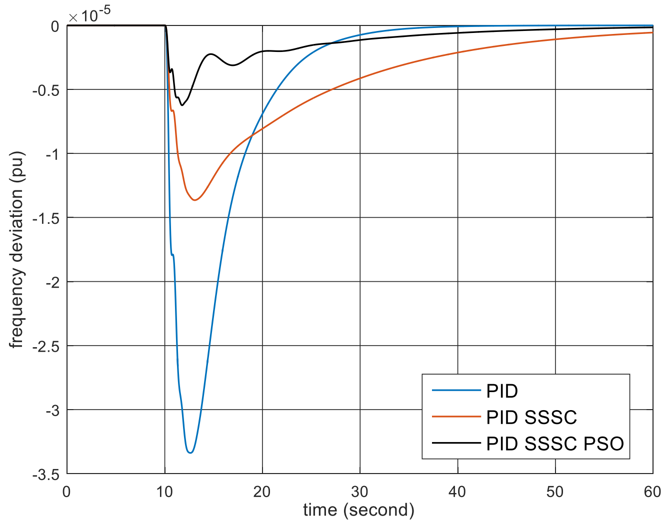

Fig. 9. Frequency Response in Area 2.

TABLE III. COMPARISON OF OSCILLATORY CONDITION IN AREA 2

Control Method	Cases		
	PID	***PID SSSC***	***PID SSSC PSO***
Overshoot (pu)	-0.000003339	-0.000001365	-0.000006237
Settling time (s)	<20	<20	<20

C. Inter-area Power Oscillation

Response Ptie can be seen in Fig. 10. LFC coordinated only with PID controller has overshoot -0.0005605 pu and settling time above 20 seconds. LFC coordinated with PID controller and SSSC has overshoot -0.0002335 pu and the settling time above 20 seconds. LFC coordinated with PID and SSSC optimized with PSO has overshoot -0.0001018 pu and settling time above 20 seconds. The comparison of overshoot and settling time Ptei can be seen in Table IV.

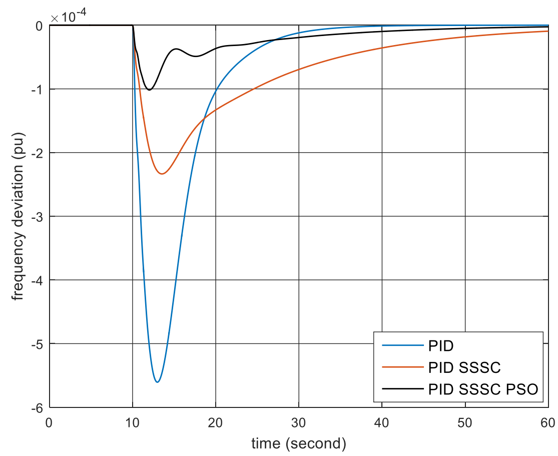

Fig. 10. Inter-area Power Response.

TABLE IV. COMPARISON OF OSCILLATORY CONDITION IN INTER-AREA POWER

Control Method	Cases		
	PID	***PID SSSC***	***PID SSSC PSO***
Overshoot (pu)	-0.0005605	-0.0002335	-0.0001018
Settling time (s)	20<	20<	20<

V. CONCLUSIONS

This paper shows the application of PID controller and SSSC to improve the frequency stability of the system. From the case studies, it is found that PID and SSSC have a significant impact on improving frequency stability of the system. It was also found that PSO can provide the optimum value of PID and SSSC parameter. Further research is required to utilize PID controller and SSSC in bigger systems such as 3 area load frequency control. Also combining PSO with another metaheuristic algorithm such as genetic algorithm or differential evolution algorithm

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REFERENCES

[1] P. Kundur, N. J. Balu, and M. G. Lauby, *Power system stability and control* vol. 7: McGraw-hill New York, 1994.

[2] N.V. Kumar and M.M.T. Ansari, "A new design of dual mode Type-II fuzzy logic load frequency controller for interconnected power systems with parallel AC–DC tie-lines and capacitor energy storage unit," *International Journal of Electrical Power & Energy Systems,* vol. 82, pp. 579-598, 2016.

[3] N. Mithulananthan, C.A. Cañizares, and J. Reeve, "Hopf bifurcation control in power system using power system stabilizers and static var compensators," in *Proc. of NAPS'99*, 1999, pp. 155-163.

[4] M. Abido, "Simulated annealing based approach to PSS and FACTS based stabilizer tuning," *International Journal of Electrical Power & Energy Systems,* vol. 22, pp. 247-258, 2000.

[5] 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, pp. 786-792, 2003.

[6] P. Bhatt, S. Ghoshal, and R. Roy, "Optimized automatic generation control by SSSC and TCPS in coordination with SMES for two-area hydro-hydro power system," in *Advances in Computing, Control, & Telecommunication Technologies, 2009. ACT'09. International Conference on*, 2009, pp. 474-480.

[7] S. Panda, "Differential evolutionary algorithm for TCSC-based controller design," *Simulation Modelling Practice and Theory,* vol. 17, pp. 1618-1634, 2009.

[8] A. Rahman, L.C. Saikia, and N. Sinha, "Maiden application of hybrid pattern search-biogeography based optimisation technique in automatic generation control of a multi-area system incorporating interline power flow controller," *IET Generation, Transmission & Distribution,* vol. 10, pp. 1654-1662, 2016.

[9] 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, pp. 446-455, 2016.

[10] 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, 2017.

[11] D. Lastomo, H. Setiadi, and M.R. Djalal, "Design Controller of Pendulum System using Imperialist Competitive Algorithm," *Jurnal Intek Politeknik Negeri Ujung Pandang,* vol. 4, pp. 53-59, 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.

[13] H. Saadat, *Power system analysis*: WCB/McGraw-Hill, 1999.

[14] R.W.W. Atmaja, S. Herlambang, and I. Robandi, "Optimal Design of PID Controller in Interconnected Load Frequency Control using Hybrid Differential Evolution–Particle Swarm Optimization Algorithm," in *Seminar on Intelligent Technology and Its Applications 2014*, 2014.

[15] M. Abdillah, H. Setiadi, A.B. Reihara, K. Mahmoud, I.W. Farid, and A. Soeprijanto, "Optimal selection of LQR parameter using AIS for LFC in a multi-area power system," *Journal of Mechatronics, Electrical Power, and Vehicular Technology,* vol. 7, pp. 93-104, 2016.

[16] H. Setiadi, and I. Robandi, "Optimal coordination proportional integral differential (PID) using ant colony optimization (ACO) algorithm," in *The 13th Seminar on Intelligent Technology And Its Applications (SITIA 2012)*, Surabaya Indonesia, 2013.

[17] S. Kalyani, S. Nagalakshmi, and R. Marisha, "Load frequency control using battery energy storage system in interconnected power system," in *Computing Communication & Networking Technologies (ICCCNT), 2012 Third International Conference on*, 2012, pp. 1-6.

[18] H. Setiadi, W.K. Kautsar, A. Swandaru, and I. Robandi, "Optimal Tunning PID Controler for Inter Area Using Imperialist Competitive Algorthm (ICA)," in *International Seminar on Applied Technology, Science, and Arts 2011*, Surabaya, 2011.

[19] S. Sinha, R. Patel, and R. Prasad, "Applications of FACTS devices with fuzzy controller for oscillation damping in AGC," in *Recent Advancements in Electrical, Electronics and Control Engineering (ICONRAEeCE), 2011 International Conference on*, 2011, pp. 314-318.

[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, pp. 39-43.

[21] S. Panda and N. Padhy, "Robust power system stabilizer design using particle swarm optimization technique," *Fuel,* vol. 337, p. 14723, 2008.

[22] H.M. Soliman, E.H. Bayoumi, and M.F. Hassan, "PSO-based power system stabilizer for minimal overshoot and control constraints," *JOURNAL OF ELECTRICAL ENGINEERING-BRATISLAVA-,* vol. 59, p. 153, 2008.

[23] A. El-Zonkoly, A. Khalil, and N. Ahmied, "Optimal tunning of lead-lag and fuzzy logic power system stabilizers using particle swarm optimization," *Expert Systems with Applications,* vol. 36, pp. 2097-2106, 2009.

[24] H. Shayeghi, H. Shayanfar, S. Jalilzadeh, and A. Safari, "A PSO based unified power flow controller for damping of power system oscillations," *Energy conversion and management,* vol. 50, pp. 2583-2592, 2009.

[25] H. Shayeghi, H. Shayanfar, S. Jalilzadeh, and A. Safari, "Design of output feedback UPFC controller for damping of electromechanical oscillations using PSO," *Energy Conversion and Management,* vol. 50, pp. 2554-2561, 2009.

[26] A.T. Al-Awami, Y. Abdel-Magid, and M. Abido, "A particle-swarm-based approach of power system stability enhancement with unified power flow controller," *International Journal of Electrical Power & Energy Systems,* vol. 29, pp. 251-259, 2007.

[27] K.T. Chaturvedi, M. Pandit, and L. Srivastava, "Particle swarm optimization with crazy particles for nonconvex economic dispatch," *Applied Soft Computing,* vol. 9, pp. 962-969, 2009.

[28] 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, pp. 11-21, 2017.