Optimal PSS Design Using Particle Swarm Optimization Under Load Shedding Condition

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***Abstract*—Power System Stabilizer (PSS) is a supplementary control that provides additional control actions on the excitation side of the generator. In this study a Particle Swarm Optimization (PSO) based tuning method is proposed to optimize the PSS parameters. PSO optimization results obtained optimal tuning results and fast computing processes. With optimal PSS parameters, the optimal PSS performance is obtained. The combination of PSS and excitation is used to reduce the oscillation that occurs in the system. In this research a case study of load addition and load shedding is used. From the simulation results it is found that the performance of the system performance is improved by installing Power System Stabilizer which is optimized with PSO. System performance is shown by the response of the generator speed and rotor angle which results in a small overshoot and a faster settling time when there is an increase in load and also load shedding. Increased system performance is also viewed from the negative system eigenvalue, negative eigenvalue indicates the system is stable.**

Keywords : Particle Swarm Optimization, Power System Stabilizer, Overshoot, Damping, Eigenvalue.

I. INTRODUCTION

One important factor in producing quality electricity is the stability of the system. Stability is related to the ability of the system to be able to maintain synchronous conditions when interference occurs. There are two types of disturbances that affect the stability of the system, namely transient disturbances and dynamic disturbances. Transient disturbances are major disruptions that occur such as lightning strikes, or transmission line breaks [1]. While dynamic disturbances are small disturbances that often occur and can interfere with stability. One of the causes of dynamic disturbances is load changes [2].

When there is a change in the load, there is a change in power supply and power demand in the system. So there is a change in the operating point marked by oscillations that appear. Under stable system conditions, the oscillation that occurs can be muted in a short span of time. This shows that the system survived the new operating conditions. Whereas on an unstable system, oscillation is not successfully muted for a long period of time. This stability disturbance occurs in all parts of the system, starting from the distribution system, transmission system to the generator. Stability problems that cannot be overcome will cause synchronization loss and the possibility of system blackout is difficult to avoid [3].

To overcome the oscillation, needed auxiliary equipment that serves to reduce oscillation. One equipment that is currently widely used is the Power System Stabilizer (PSS) which is placed on the side of the generator. PSS provides an additional signal to the excitation of the generator to reduce the oscillation. Through PSS the disturbance that occurs can be muted, so it does not cause the generator to change from stable conditions. In its operation, optimizing parameter tuning from PSS is needed. The tuning can be done by trial error method, but in this method the accuracy of the parameters will be difficult to obtain.

The South, Southeast and West Sulawesi interconnection system (Sulselrabar) is a system that consists of several power stations, and serves a large load center. This system is prone to experiencing instability that causes oscillations in the system. For this reason, a study of system performance is needed, especially in conditions of load changes when the system is operating. Several previous studies have discussed the Sulselrabar system, such as generator optimization to reduce transmission losses [4], short circuit detection using neural networks [5], and economic dispatch optimization [6, 7].

Previously several studies have discussed the implementation of intelligent algorithms for tuning PSS in the Sulselrabar system, and showed good results, such as [8] discussing PSS optimization using firefly under normal conditions, in [9, 10] PSS optimization using cuckoo search under N-1 conditions, in [11] discusses the placement and optimization of PSS using the imperialist competitive algorithm in normal conditions.

PSO is a population-based optimization technique. PSO propagates a group of particle populations in a problem space. This particle is called swarm. PSO is widely used as an optimization method in electric power systems. The use of PSO in PSS optimization has also been previously done and shows good results, such as [12-14]. From the results of these studies become a reference for us to implement the PSO method for PSS tuning in the South Sulawesi system, with the case study used is load sheeding and then see the response of system performance before and after the installation of PSS optimized using PSO. Load Sheeding is an act of releasing loads that occur automatically or manually to secure the operation of generating units from the possibility of a black out.

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II. Power System Modeling

A. Generator Model

The synchronous linear generator equation is written in the following matrix model in (1) [8].

$$\begin{bmatrix} \Delta v_d \\ -\Delta v_F \\ 0 \\ \Delta v_q \\ 0 \\ \Delta T_m \\ 0 \end{bmatrix} = -\begin{bmatrix} r & 0 & 0 & \omega_0 L_q & \omega_0 kM_Q & \lambda_{q0} & 0 \\ 0 & rF & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & rD & 0 & 0 & 0 & 0 \\ -\omega_0 L_d & -\omega_0 kM_F & -\omega_0 kM_D & r & 0 & -\lambda_{d0} & 0 \\ 0 & 0 & 0 & 0 & rQ & 0 & 0 \\ \frac{\lambda_{q0}-L_d i_{q0}}{3} & \frac{-kM_F i_{q0}}{3} & \frac{-kM_D i_{q0}}{3} & \frac{-kM_Q i_{d0}}{3} & \frac{kM_Q i_{d0}}{3} & -D & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} \Delta i_d \\ \Delta i_F \\ \Delta i_D \\ \Delta i_q \\ \Delta i_Q \\ \Delta \omega \\ \Delta \delta \end{bmatrix}$$

$$-\begin{bmatrix} L_d & kM_F & kM_D & 0 & 0 & 0 & 0 \\ kM_F & L_F & M_R & 0 & 0 & 0 & 0 \\ kM_D & M_R & L_D & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L_q & kM_Q & 0 & 0 \\ 0 & 0 & 0 & kM_Q & L_Q & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -\tau_j & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \Delta \dot{i}_d \\ \Delta \dot{i}_F \\ \Delta \dot{i}_D \\ \Delta \dot{i}_q \\ \Delta \dot{i}_Q \\ \Delta \dot{\omega} \\ \Delta \dot{\delta} \end{bmatrix} \qquad (1)$$

Where:

- V_d V_q = Stator Voltage d and q axis
- V_F = Rotor Field Voltage
- V_D V_Q = Rotor Voltage d and q axis
- r = Stator Resistance
- L_d L_q = Rotor Inductance d and q axis
- λ_{q0} λ_{d0} = Initial flux d and *q axis*
- kM_F = Rotating Magnetic Field
- M_D M_Q = Mutual Inductance
- Δi_d Δi_q = Stator Current d and q axis
- Δi_F = Rotor Field Current
- Δi_D Δi_Q = Rotor Current d and q axis
- $\Delta\omega$ = Generator Speed Change
- $\Delta\delta$ = Generator Rotor Angle Changes

B. Excitation Modeling

Excitation systems are used to control generator output, such as voltage, current and power factors. In this study the type of fast exciter is used, because it has a fast response [15].

$$E_{fd} = K_A\left(V_t - V_{ref}\right)/\left(1 - T_A s\right) \qquad (2)$$

K_A is a reinforcement parameter and T_A is a time constant value. The excitation output is limited by, $V_{Rmin} < E_{fd} < V_{Rmax}$. Fig. 1 is modeling excitation.

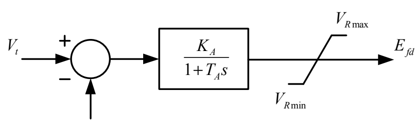

Fig. 1. Exciter Block Diagram

C. Governor Modeling

The governor functions to provide feedback for the new system balance in the event of a change in rotor generator rotation. Fig. 2 is governor modeling [2].

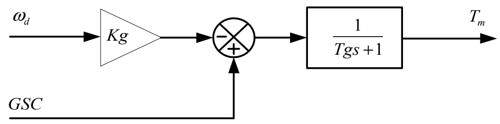

Fig. 2. Governor Modeling

Where:

- T_m = Mechanic torque
- ω_d = *Change in speed*
- GSC = *Governor Speed Changer* (GSC=0)
- K_g = Gain Constant=*1/R*
- T_g = Governor time constant
- R = Droop governor constant

D. Power System Stabilizer Modeling

The PSS model equation is written in (3) [11].

$$V_s = K_{pss}\frac{T_w s}{1+T_w s}\left[\frac{(1+sT_A)}{(1+sT_B)}\frac{(1+sT_C)}{(1+sT_D)}\right]\omega \qquad (3)$$

Where:

- Vs = Output PSS
- K_{PSS} = PSS Gain
- T_w = Washout Filter
- T_A, T_B, T_C, T_D = Lead-Lag Gain
- V_{Smax} V_{Smin} = Limiter

PSS is used to provide additional signals to the generator excitation to increase the damping system. Fig. 3 is PSS modeling [8].

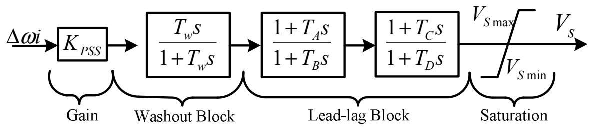

Fig. 3. PSS Block Diagram

The gain block is an amplifier that determines the amount of damping provided by the PSS. Washout filter serves to provide a steady state bias from the PSS output, which will modify the generator terminal voltage. The lead-lag block is used to compensate for the phase lag generated by the AVR and the generator field circuit. Limiter is used to limit PSS output.

III. Particle Swarm Optimization

PSO is a population-based optimization technique. PSO begins by spreading a group of particle populations in a problem space. These dispersed particles are called swarm [16]. This particle holds information about its existence and the potential value generated by that existence. Particles will provide information to each other, so from the information obtained it will be known which particles occupy the location with the most optimal results on a movement. From this information, other particles will then move to that location based on a motion function called velocity. During the flight process, each particle determines its own position based on its own experience (this value is called Pbest) and based on the experience of other particles (this value is called Gbest). The process of finding Pbest and Gbest can be illustrated in Fig. 4.

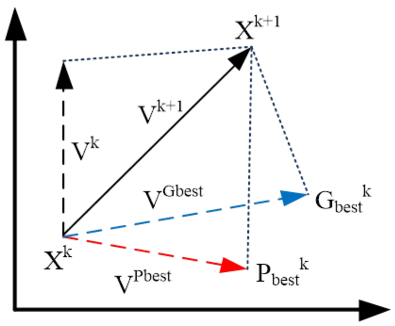

Fig. 4. The concept of searching for PSO [16]

The speed of each particle can be formulated from (4).

$$v_{k+1} = w.v_k + c_1 rand \times (P_{best} - x^k) + c_2 rand \times (G_{best} - x^k) \quad (4)$$

Using (4), Pbest and Gbest can be calculated based on particle velocity. Current position can be obtained from (5).

$$x^{k+1} = x^k + v_{k+1} \quad . \quad k = 1,2 \ldots n \quad (5)$$

Where:

X^k	=	Current search point
X^{k+1}	=	Modified search position
V^k	=	Current speed
V^{k+1}	=	Modified speed
Vpbest	=	Speed based on P_{Best}
Vgbest	=	Speed based on Gbest
n	=	Number of particles in a group
m	=	The number of members in the particle
$pbest_i$	=	Pbest from k
$gbest_i$	=	Gbest from group
w	=	Weight
c_i	=	Weight coefficient for the following terms - c1 and c2 are 2 positive constants - r1 and r2 are random numbers 0-1

w is the weight of inertia and iteration function of k as follows (6).

$$w(k) = w_{max} - \left(\frac{w_{max} - w_{min}}{max.iter}\right) \times k \quad (6)$$

To ensure uniform speed of all dimensions, the maximum speed is as follows (7).

$$v^{max} = \frac{(x^{max} - x^{min})}{N} \quad (7)$$

Where N is the maximum number of iterations.

Table I shows the PSO parameters used in this study.

TABLE I. PARTICLE SWARM OPTIMIZATION PARAMETERS

Number of Particles	30
Max Iteration	50
Number of Variables	3
C2 (Social Constant)	2
C1 (Cognitive Constant)	2
W (Moment Inersia)	0.9

IV. RESEARCH METHOD

In this study the system stability is analyzed by using eigenvalue analysis. The egenvalue analysis method requires a mathematical model of the system being analyzed. From the mathematical model obtained is converted into the form of a state matrix equation as in (8) and (9).

$$\Delta\dot{x} = A\Delta x + B\Delta u \quad (8)$$

$$\Delta y = C\Delta x + D\Delta u \quad (9)$$

Where:

Δx	=	State matrix ($n \times 1$)
Δy	=	Output variable matrix ($m \times 1$)
u	=	Input variable matrix ($r \times 1$)
A	=	System matrix ($n \times n$)
B	=	Input Matrix ($n \times r$)
C	=	Measurement matrix ($m \times n$)
D	=	Input matrix for output ($m \times r$)

Through the system matrix A, the stability of the system can be monitored:

$$\det(sI\text{-}A)=0 \quad (10)$$

Where I is the identity matrix and s is the eigenvalue of the matrix A. Matrix A is n x n, so the number of eigenvalues obtained is n, $\lambda = \lambda_1, \lambda_2, \lambda_3, \ldots, \lambda_n$.

$$\lambda_i = \sigma_i + j\omega_i \quad (11)$$

The oscillation frequency in Hz is:

$$f = \frac{\omega}{2\pi} \quad (12)$$

Where,

λ_i	=	*Eigenvalue* ke-*i*
σ_i	=	The real component of the i-i eigenvalue
ω_i	=	Imaginary component of the i-eigenvalue

Based on the matrix Eigenvalue A, the stability of the system can be known. The system is said to be stable if the real part of the eigenvalue is negative. This stability check is very important when installing control equipment on a system. In other words, before giving control to a system, the system to be controlled must be stable. If the system is stable, new controls are installed. The real part of the eigenvalue is the damping component, while the imaginary part is the oscillation component. The damping value can be determined using the damping ratio value (13). While the overall damping system can be known from the Comprehensive Damping Index (CDI) value formulated in (14).

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \quad (13)$$

$$CDI = \sum_{i=1}^{n} (1 - \zeta_i) \quad (14)$$

Where,

ζ_i	=	*Damping ratio*
n	=	number of eigenvalue

The Objective Function in this study is to maximize the minimum damping of ζ_{min}. Limitations of the optimized PSS parameters in this study are shown in Table II.

TABLE II. CONSTRAINT OF PSS PARAMETERS [9]

No	Parameter	Lower Limit	Upper Limit
1	K_{pss}	10	50
2	T_1	0	0.05
3	T_2	0	0.05
4	T_3	0	1
5	T_4	0	2
6	Tw	10	

Fig. 5 below shows the research flow chart.

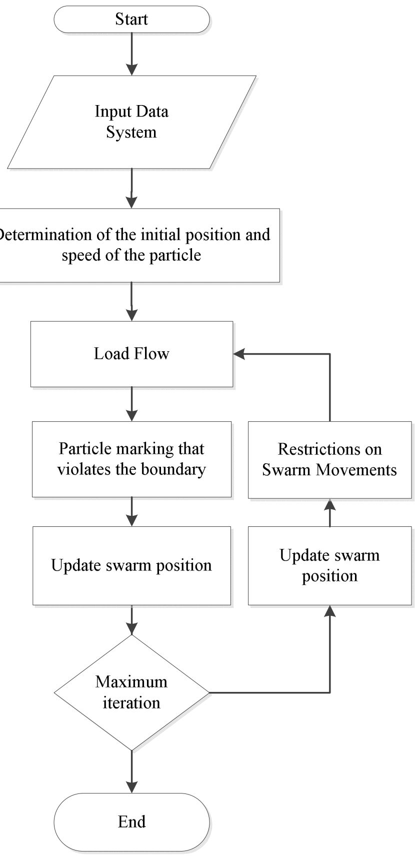

Fig. 5. Research Flowchart

V. SIMULATION AND ANALYSIS

Fig. 6 shows a PSO convergence graph. The picture above shows the PSO algorithm convergence process in optimizing PSS parameters. From the simulation results, the PSO algorithm converges the optimal value at the 37th iteration, with a fitness function 77.5622.

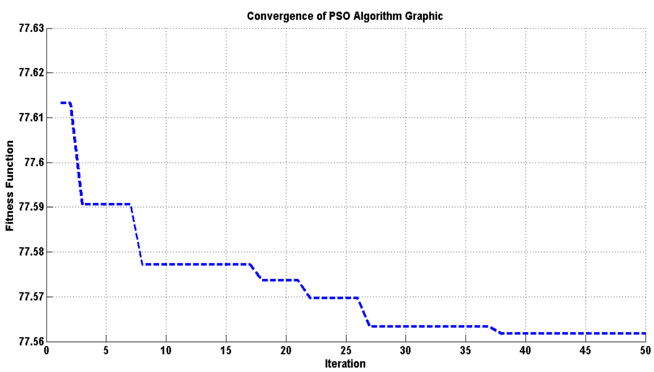

Fig. 6. PSO convergence graph

TABLE III. TUNING RESULTS OF PSS PARAMETER WITH TRIAL [10]

Power Plant	Kpss	T1	T2	T3	T4
Bakaru	48,2272	0,0478	0,8018	0,0493	0,8847
Pinrang	16,2895	0,0206	0,2886	0,3349	1,4885
Pare - Pare	13,5790	0,0472	0,3497	0,1713	2,7785
Suppa	16,5591	0,0443	0,7804	0,1024	1,6488
Barru	46,1332	0,0108	0,2612	0,1492	2,1633
Tello	35,3281	0,0425	0,3830	0,1935	1,4651
Tello lama	29,7565	0,0455	0,0864	0,3923	1,4842
Sgmnsa	38,1133	0,0045	0,0176	0,1988	1,7817
Bulukumba	29,7237	0,0246	0,7096	0,1953	1,5321
Sinjai	99,3400	0,0394	0,9427	0,1066	2,8044
Soppeng	97,0248	0,0047	0,9107	0,1836	0,1418
Sengkang	8,5956	0,0247	0,2484	0,4776	0,8827
Makale	78,1453	0,0228	0,1392	0,3335	1,9848
Palopo	17,9254	0,0341	0,3523	0,0405	0,5195

The number of PSS installations on the system is 14 PSS. PSS tuning results are shown in the following Table IV. As a comparison method, this study uses a trial error method.

PSS installation in 14 power plants, namely, Bakaru, Pinrang, Pare-Pare, Suppa, Barru, Tello, old Tello generators, Sungguminasa, Bulukumba, Sinjai, Soppeng, Sengkang, Makale, and Palopo.

TABLE IV. TUNING RESULTS OF PSS PARAMETER WITH PSO

Power Plant	Kpss	T1	T2	T3	T4
Bakaru	48.5602	0.0289	0.0419	0.5133	0.2456
Pinrang	43.0873	0.0246	0.0014	0.7356	0.4154
Pare - Pare	22.7839	0.0297	0.0269	0.8785	1.9742
Suppa	30.0260	0.0380	0.0392	0.2541	1.3418
Barru	45.7446	0.0175	0.0085	0.8929	1.1165
Tello	19.6694	0.0022	0.0024	0.0860	1.9510
Tello lama	40.8342	0.0228	0.0116	0.1709	0.6377
Sgmnsa	26.5757	0.0290	0.0136	0.7021	0.4035
Bulukumba	12.4808	0.0238	0.0111	0.7623	0.4923
Sinjai	20.6981	0.0435	0.0480	0.6897	1.4354
Soppeng	23.5041	0.0251	0.0168	0.0177	0.5564
Sengkang	42.7169	0.0118	0.0349	0.4758	0.9131
Makale	27.9075	0.0273	0.0470	0.5402	1.6980
Palopo	31.4958	0.0225	0.0136	0.7646	0.8144

After getting the optimal PSS parameter values, the next process is to test the stability of the system with a load shedding case study. Table V shows the overshoot response of the generator speed for each operating scheme.

The next system analysis is to look at the critical eigenvalue system for each control scheme. The results of the critical eigenvalue and oscillation mode are shown in Table VI.

The simulation results show that the system's eigenvalue is better. Eigenvalue values indicate the stability and instability of a system. The system is said to be stable if the system's eigenvalue is negative. Whereas the damping ratio shows how fast the decrease in overshoot or damping oscillations in the rotor. The value of the damping ratio actually comes from the eigenvalue component itself.

The next system analysis is to review the overshoot graph response of each control scheme. By using a case study of load shedding at 20 seconds, then the response of the generator to the speed and angle of the rotor generator is seen. Shown in figs. 7 and 8

TABLE V. OVERSHOOT OF SPEED GENERATOR

Power Plant	No PSS	Conv. PSS	PSS PSO
Bakaru	-0.022 to 0.005	-0.019 to 0.003	-0.012 to 0.0007
Pinrang	-0.023 to 0.006	-0.020 & 0.003	-0.014 to 0.0005
Pare – Pare	-0.024 to 0.005	-0.021 to 0.004	-0.017 to 0.0004
Suppa	-0.024 to 0.005	-0.021 to 0.004	-0.020 to 0.001
Barru	-0.084 to 0.036	-0.068 to 0.022	-0.033 to 0.0001
Tello	-0.211 to 0.054	-0.207 to 0.050	-0.203 to 0.046
Tello lama	-0.222 to 0.091	-0.151 to 0.0002	-0.110 to 0.0003
Sgmnsa	-0.057 to 0.007	-0.048 to 0.0001	-0.034 to 3.6e-05
Jeneponto	-0.025 to 0.006	-0.022 to 0.003	-0.020 to 0.001
Bulukumba	-0.024 to 0.01	-0.021 to 0.006	-0.017 to 0.003
Sinjai	-0.026 to 0.017	-0.023 to 0.014	-0.019 to 0.007
Soppeng	-0.024 to 0.011	-0.018 to 0.003	-0.017 to 0.002
Sengkang	-0.027 to 0.004	-0.024 to 0.003	-0.015 to 0.0005
Makale	-0.024 to 0.016	-0.020 to 0.011	-0.016 to 0.0055
Palopo	-0.024 to 0.018	-0.021 to 0.014	-0.016 to 0.006
Borongloe	-0.068 to 0.016	-0.060 to 0.008	-0.053 to 0.0019

TABLE VI. CRITICAL EIGENVALUE SYSTEM

No PSS (1.0e+02*)	Conv. PSS (1.0e+02*)	PSS PSO (1.0e+02*)
	-0.5026 + 6.5430i	
-0.5026 + 6.5431i	-0.5026 - 6.5430i	-0.5039 + 6.5572i
-0.5026 - 6.5431i	-0.4434 + 5.3185i	-0.5039 - 6.5572i
-0.4434 + 5.3188i	-0.4434 - 5.3185i	-0.4446 + 5.3235i
-0.4434 - 5.3188i	-0.4143 + 5.0623i	-0.4446 - 5.3235i
-0.4144 + 5.0625i	-0.4143 - 5.0623i	-0.4150 + 5.0635i
-0.4144 - 5.0625i	-0.3056 + 4.6945i	-0.4150 - 5.0635i
-0.3056 + 4.6944i	-0.3056 - 4.6945i	-0.3056 + 4.6944i
-0.3056 - 4.6944i	-0.3112 + 4.5333i	-0.3056 - 4.6944i
-0.3112 + 4.5333i	-0.3112 - 4.5333i	-0.3241 + 4.5272i
-0.3112 - 4.5333i	-0.1972 + 4.4653i	-0.3241 - 4.5272i
-0.1973 + 4.4655i	-0.1972 - 4.4653i	-0.1952 + 4.4630i
-0.1973 - 4.4655i	-0.0838 + 4.1613i	-0.1952 - 4.4630i
-0.1209 + 4.3280i	-0.0838 - 4.1613i	-0.1356 + 4.2817i
-0.1209 - 4.3280i	-0.1210 + 4.3278i	-0.1356 - 4.2817i
-0.0839 + 4.1614i	-0.1210 - 4.3278i	-0.1966 + 4.3135i
-0.0839 - 4.1614i	-0.1965 + 4.3135i	-0.1966 - 4.3135i
-0.1965 + 4.3135i	-0.1965 - 4.3135i	-0.0179 + 4.0888i
-0.1965 - 4.3135i	-0.2620 + 4.1920i	-0.0179 - 4.0888i
-0.2594 + 4.1886i	-0.2620 - 4.1920i	-0.2594 + 4.1886i
-0.2594 - 4.1886i	-0.0412 + 3.9001i	-0.2594 - 4.1886i
-0.0412 + 3.9001i	-0.0412 - 3.9001i	-0.0412 + 3.9001i
-0.0412 - 3.9001i	-0.0823 + 4.0441i	-0.0412 - 3.9001i
-0.0825 + 4.0439i	-0.0823 - 4.0441i	-0.0825 + 4.0439i
-0.0825 - 4.0439i	-0.0390 + 3.5539i	-0.0825 - 4.0439i
-0.0389 + 3.5546i	-0.0390 - 3.5539i	-0.0389 + 3.5546i
-0.0389 - 3.5546i	-0.0899 + 2.2973i	-0.0389 - 3.5546i
-0.1003 + 2.3007i	-0.0899 - 2.2973i	-0.1003 + 2.3007i
-0.1003 - 2.3007i	1.7321 + 0.0000i	-0.1003 - 2.3007i
1.7358 + 0.0000i	-0.1489 + 1.5172i	1.7357 + 0.0000i
-0.1490 + 1.5172i	-0.1489 - 1.5172i	-0.1489 + 1.5172i
-0.1490 - 1.5172i	-0.1169 + 1.3748i	-0.1489 - 1.5172i
-0.1171 + 1.3752i	-0.1169 - 1.3748i	-0.1171 + 1.3751i
-0.1171 - 1.3752i	-0.0041 + 0.0486i	-0.1171 - 1.3751i
-0.0033 + 0.0408i	-0.0041 - 0.0486i	-0.0033 + 0.0409i
-0.0033 - 0.0408i	-0.0032 + 0.0414i	-0.0033 - 0.0409i
-0.0044 + 0.0462i	-0.0032 - 0.0414i	-0.0044 + 0.0462i
-0.0044 - 0.0462i	-0.0043 + 0.0463i	-0.0044 - 0.0462i
	-0.0043 - 0.0463i	

.

Bakaru power plant is a generator that will be reviewed for performance in this study. Bakaru generator is a swing generator, which is a generator that functions as a system controller. Fig. 7 shows the speed response of the Bakaru generator. The performance of the system is reviewed based on two cases, namely the addition of load on the 5th second by 0.05 pu, and the second load shedding on the 20th second is 0.1 pu. From the graph, the speed response of the generator equipped with PSS-PSO results in a small overshoot, namely -0.01295 pu to 0.0007614 pu, using PSS-Trial overshoot of -0.0196 pu to 0.003705 pu, and without control produces overshoot of -0.02242 pu to 0.005254 pu. The simulation results also show that the response of the generator results in a fast settling time with PSS-PSO control, so the system returns to a steady state faster. Fig. 8 shows the response of the rotor angle generator in each control scheme. From this graph, the system with PSS-PSO results in a better rotor angle swing response compared to other control schemes.

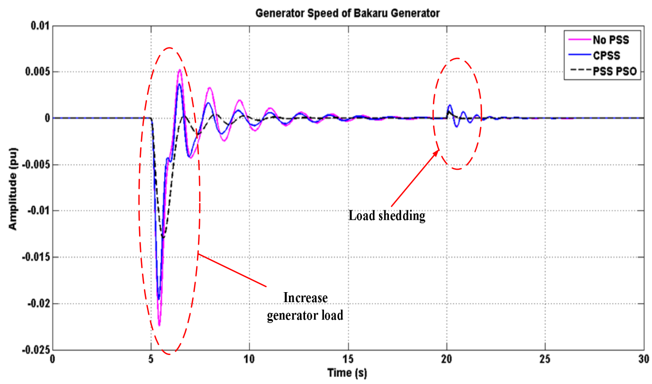

Fig. 7. Speed Deviation (Δω) Generator Bakaru

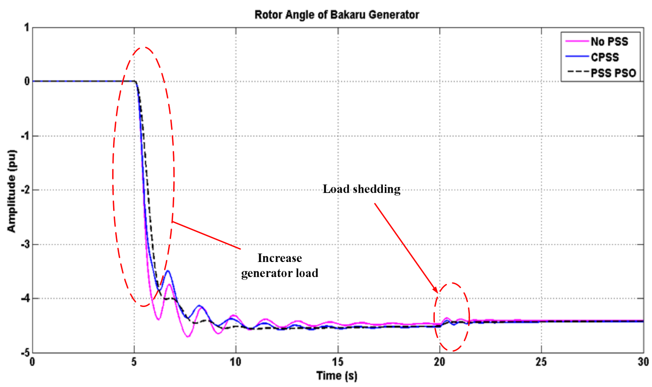

Fig. 8. Bakaru Generator Rotor Angle Variations

Table VII shows the inter-area and local area oscillation modes of each method. From the simulation results, it is found that the characteristics of the eigenvalues are improved with the PSS-based system method which is optimized using the Particle Swarm Optimization method.

TABLE VII. OSCILLATION MODE OF INTER-AREA AND LOKAL AREA

Mode Osilasi	No PSS	Conv. PSS	PSS PSO
Inter-Area	-0.3306 + 4.0844i -0.4445 + 4.6156i -0.5050 + 4.5408i -0.5121 + 4.5346i	-0.4073 + 4.8605i -0.3204 + 4.1437i -0.4289 + 4.6272i -1.1615 + 4.8368i	-33.3324 + 1.4322i -2.7707 + 3.2887i -0.3279 + 4.0856i -0.4449 + 4.6154i -0.5028 + 4.5450i -0.5125 + 4.5344i
Local	-1.0027 + 9.4221i -1.0063 + 8.4356i -1.0503 + 7.0820i -0.8538 + 6.9707i -1.4621 + 6.0617i -0.7878 + 5.3227i -1.2476 + 5.8462i -0.9420 + 5.4868i -1.1603 + 5.7431i -1.1475 + 5.6539i -0.9912 + 5.4670i -1.1526 + 5.6600i	-0.9735 + 9.4683i -0.9856 + 8.4736i -1.2685 + 7.3413i -0.8782 + 6.5147i -1.4486 + 6.1026i -1.2777 + 6.0015i -1.3828 + 5.9575i -1.2400 + 5.7470i -0.9416 + 5.6009i -0.8105 + 5.3667i -1.1423 + 5.6703i -1.0009 + 5.4804i	-18.9124 +12.1620i -1.0933 + 8.6715i -1.0481 + 7.1028i -0.8534 + 6.9708i -1.4526 + 6.0564i -0.7907 + 5.3176i -1.2476 + 5.8462i -0.9495 + 5.4797i -1.1712 + 5.7334i -1.1475 + 5.6533i -0.9912 + 5.4670i -1.1526 + 5.6600i

The first case study is the condition of the system before load shedding occurs. In this period the increase in load causes Pe> Pm, so from the graph at 5 seconds, the first response of the generator speed is downward, indicating an increase in load. As for the rotor angle response, due to Pe> Pm, the rotor experiences a slowdown so the rotor angle response becomes negative.

In the second case study, load shedding on a bakaru generator, the change in load that occurs causes Pe <Pm, so that from the graph at 20 seconds, the first response of the generator speed is upward, indicating load shedding. As for the rotor angle response, because Pe <Pm, the rotor will accelerate so that the rotor angle response becomes upward.

VI. CONCLUSION

In this study a PSO-based tuning method is proposed to optimize the PSS parameters. PSO optimization results obtained optimal tuning results and fast computing processes. With optimal PSS parameters, the optimal PSS performance is obtained. The combination of PSS and excitation is used to reduce the oscillation that occurs in the system. In this research a case study of load addition and load shedding is used.

From the simulation results it is found that the performance of the system performance is improved by installing Power System Stabilizer which is optimized with PSO. System performance is shown by the response of the generator speed and rotor angle which results in a small overshoot and a faster settling time when there is an increase in load and also load shedding. Increased system performance is also viewed from the negative system eigenvalue, negative eigenvalue indicates the system is stable.

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