Optimal Placement and Tuning Power System Stabilizer Using Participation Factor and Imperialist Competitive Algorithm in 150 kV South of Sulawesi System

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***Abstract*— In this study will be explained determination of the location of the power system stabilizer (PSS) and the tuning parameters of the PSS in South Sulawesi electrical system using the Imperialist Competitive Algorithm (ICA) for tuning and Participation Factor for determining the placement of PSS. From the simulation results obtained placement and proper tuning PSS parameters can improve the stability of South Sulawesi generator electrical system, which can reduce the overshoot and settling time speed up the frequency response to speed up the system reaches steady state conditions. The critical eigenvalue of the system using a conventional PSS and PSS ICA, which showed an increase with increasing eigenvalue damping ratio. Damping values greater than 0.1 indicate that the eigenvalue condition is secure and allows stable higher. The proposed of method can be improved stability south of Sulawesi system. The method used here will also be used without PSS and comparison with conventional methods.**

Keywords*— *Power System Stabilizer; Imperialist Competitive Algorithm; Participation Factor; Damping Ratio; Settling Time; Eigenvalue; Overshoot;

I. INTRODUCTION

In interconnected power systems, a low frequency oscillation is one of the most important in power system. The low frequency oscillations (LFO) are related to the small signal stability of a power system [1-3]. Load changes occur suddenly and can not periodic responded well by the generator so that it can affect the stability of dynamic system, therefore proposed use additional equipment with using PSS [4].

Artificial intelligence methods have been widely used for optimization of power system stabilizer (PSS), both for tuning and placement PSS. Several previous studies discuss tuning parameters and placement of PSS. Both the conventional method and the use of artificial intelligence. Artificial intelligent method is excellent for complex or large system, which requires a degree of precision high calculation accuracy. Previous calculation process used conventional methods for the placement and tuning PSS, including : [5] using Pole-Placement and Participation Factor Identify, [6] using Eigenvalue Analysis & Frequency Response, [7] using Reduced-Order Modal Control Analysis Mating Optimization, [8] using Participation Factor and Residue, [9] using Frequency Response, [10] using Normal Form Theory, [11] using Optimum PSS Location Index (OPLI), [12] using Second Order Eigenvalue Sensitivity Analysis, [13] using Principal Component Analysis, while the use of artificial intelligence including widely used for tuning PSS, such as [14] using Genetic Algorithms for tuning and placement, [15] using a hybrid Particle Swarm Optimization Algorithm (PSO) for tuning, and Takagi-Sugeno (TS) fuzzy for placement, and for tuning PSS many methods have been used include : [16] using Honey-Bee algorithm, [17] using modified PSO for tuning, [18] using Imperialist Competitive Algorithm for tuning, [19] using Bat algorithm for tuning, [20] using firefly algorithm for tuning and last [21] using Cuckoo Search Algorithm.

In the present study will be analyzed using the electrical system in South Sulawesi, which consists of 37 buses, where for placement using participation factor and tuning using Imperialist Competitive Algorithm (ICA).

II. POWER SYSTEM MODELLING

A. Generator Modelling

Modeling linear synchronous generator is needed to analyze the effects of changes in the frequency response and power to the rotor angle. By using Transformation Park the synchronous generator can be modeled into a mathematical equation and the linearized in Equation 1 below [4].

B. Exciter Modelling

Excitation equipment is a part of the system that serves to regulate the generator output variables, such as voltage, current, and power factor [4].

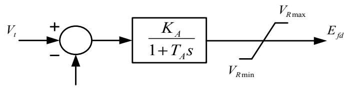

Fig. 1. Block Diagram Exciter

Where, K_A is gain and T_A is time constant value.

$$\begin{bmatrix} Dv_d \\ -Dv_F \\ 0 \\ Dv_q \\ 0 \\ DT_m \\ 0 \end{bmatrix} \begin{bmatrix} r & 0 & 0 & w_0 L_q & w_0 kM_Q & l_q 0 & 0 \\ 0 & r_F & 0 & 0 & 0 & 0 & 0 \\ 0 & 0 & r_D & 0 & 0 & 0 & 0 \\ -w_0 L_d & -w_0 kM_F & -w_0 kM_D & r & 0 & -l_d 0 & 0 \\ 0 & 0 & 0 & 0 & r_Q & 0 & 0 \\ \frac{l_q 0 - L_d i_q 0}{3} & \frac{-kM_F i_q 0}{3} & \frac{-kM_D i_q 0}{3} & \frac{-kM_Q i_d 0}{3} & \frac{kM_Q i_d 0}{3} & -D & 0 \\ 0 & 0 & 0 & 0 & 0 & -1 & 0 \end{bmatrix} \begin{bmatrix} Di_d \\ Di_F \\ Di_D \\ Di_q \\ Di_Q \\ Dw \\ Dd \end{bmatrix} - \begin{bmatrix} L_d & kM_F & kM_D & 0 & 0 & 0 & 0 \\ kM_F & L_F & M_R & 0 & 0 & 0 & 0 \\ kM_D & M_R & L_D & 0 & 0 & 0 & 0 \\ 0 & 0 & 0 & L_q & kM_Q & 0 & 0 \\ 0 & 0 & 0 & kM_Q & L_Q & 0 & 0 \\ 0 & 0 & 0 & 0 & 0 & -t_j & 0 \\ 0 & 0 & 0 & 0 & 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} Di_d \\ Di_F \\ Di_D \\ Di_q \\ Di_Q \\ D\dot{w} \\ D\dot{d} \end{bmatrix} \quad (1)$$

C. Governor Modelling

Governor is a controller that serves to regulate the mechanical torque Tm value input of the generator [4].

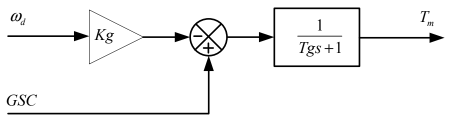

Fig. 2. Governor Modelling

Where, *Kg* is gain constant (*1/R) and Tg* is governor time.

D. Power System Stabilizer Modelling

PSS is used to generate additional damping components to produce electrical torque corresponding to the rotor speed deviation [4].

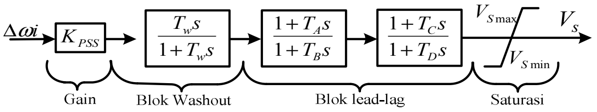

Fig. 3. Block Diagram PSS

E. Objective Function

The value of damping ratio (ξ) defined in Equation 2. The damping system as a whole can be seen from the value of the Comprehensive Damping Index (CDI).

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

$$CDI = \sum_{i=1}^{n} (1 - \xi_i) \quad (3)$$

III. METHODOLOGY

A. Participation Factor method for placement

The eigenvalues of the system matrix can be used to determine the stability of the linear system. In order to study small signal stability, it is necessary to know which state variables significantly participate in the selected modes [23]. PFs are the measure of state variable participation, and PF analysis aids in the identification of how each state variable affects a given mode. The PF can be defined as,

$$PF_{ki} = W_{ki} V_{ki} \quad (4)$$

where W_{ki} and V_{ki} are the k_{th} entries in the left and right eigenvectors respectively and associated with the ith eigenvalues. The activity of state variable x_k in the i_{th} mode is measured by V_{ki} and the contribution weight of this activity to the mode is determined by w_{ki} The sensitivity of the eigenvalue λ_i with respect to a parameter,

$$\frac{\partial \lambda_i}{\partial a_{kk}} = w_i^T \frac{\partial A_{(akk)}}{\partial a_{kk}} v_i \quad (5)$$

B. Imperialist Comppetitive Algorithm for Tuning PSS

PSS Variable, Kpss, T1, T2, T3 and T4 will be tuned using ICA based on objective function (CDI). The process in each variable phase PSS tuning is initialized as a kingdom with restrictions predetermined parameters. This method has Several steps as follow :

- Select some random points and initialize the empires.
- Move the colonies toward their relevant imperialist
- If there is a colony in an empire which has lower cost than that of imperialist, exchange the positions of that colony and the imperialist.
- Compute the total cost of all empires (Related to the power of both imperialist and its colonies).
- Pick the weakest colony (colonies) from the weakest empire and give it (them) to the empire
- Eliminate the powerless empires.
- If there is just one empire, stop, if not go to back (2).

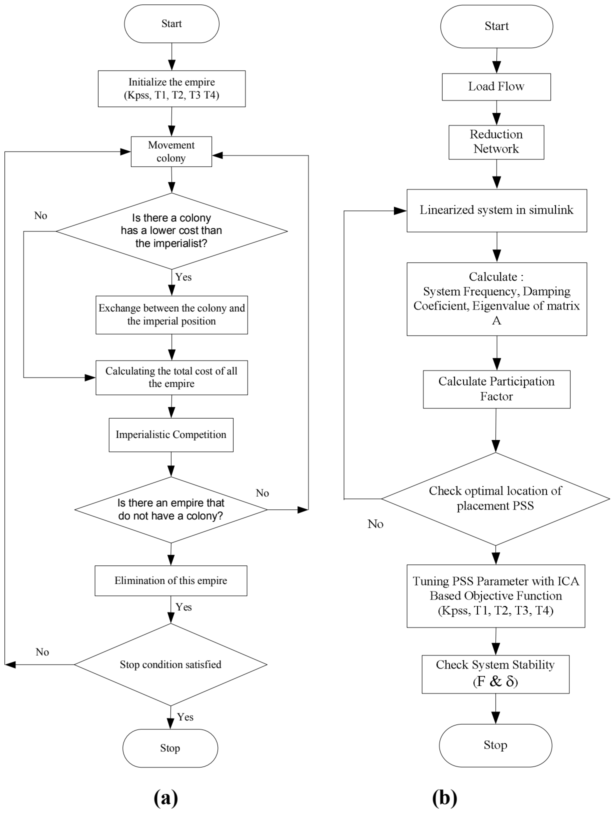

Fig. 4. Flowchart of Research (a) ICA Flowchart, (b) PSS Flowchart

IV. SIMULATION RESULT AND ANALYSIS

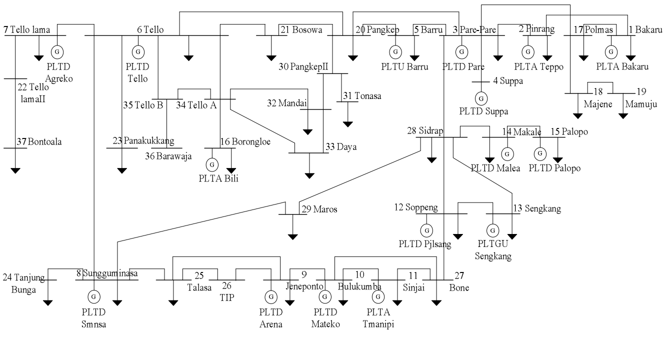

Fig. 5. Single Line Diagram South of Sulawesi

Table 1 showed power flow analysis that used to reduce the admittance matrix to obtain the corresponding number of generator matrix of 16 x 16, with using Newton Raphson.

TABLE I. RESULT OF LOAD FLOW

Bus	V (pu)	Angle (^{o})	Bus	V (pu)	Angle (^{o})
1	1.000	0.000	20	0.974	-16.421
2	1.000	-3.882	21	0.976	-18.390
3	1.000	-5.142	22	0.987	-21.291
4	1.000	-4.059	23	0.949	-23.029
5	1.000	-9.859	24	0.993	-20.979
6	0.990	-20.741	25	0.994	-19.494
7	1.000	-21.307	26	0.994	-18.453
8	1.000	-20.244	27	1.010	-9.240
9	1.000	-16.338	28	0.992	-4.634
10	1.000	-13.092	29	0.992	-17.748
11	1.000	-11.720	30	0.954	-16.048
12	1.000	-2.563	31	0.927	-17.079
13	1.000	2.866	32	0.970	-21.329
14	1.000	-11.415	33	0.974	-21.321
15	1.000	-13.424	34	0.983	-20.787
16	1.000	-21.348	35	0.986	-20.764
17	0.992	-3.079	36	0.986	-20.764
18	0.974	-5.224	37	0.975	-22.591
19	0.965	-6.394			

A. Placement Power System Stabilizer Using PF Method

PSS placement method participation factor (PF) generator. PF is calculated and connected with all modes of mechanical, written participation factor for each contained 144 eigenvalues and participation factors associated with the system state variables respectively.

TABLE II. PARTICIPATION FACTORS OF MECHANICAL MODE

Gen	Mode	Max. PF	Gen	Mode	Max. PF
1	1	0.975409	9	73	0.000309
	2	1.244401		74	0.088405
	3	0.000818		75	0.002578
	4	0.244995		76	0.000390
	5	0.007144		77	0.171999
	6	0.000746		78	3.292311
	7	0.329332		79	3.533766
	8	1.495633		80	0.135371
	9	1.615674		81	0.040635
2	10	0.067301	10	82	0.003414
	11	0.181785		83	0.000438
	12	0.015275		84	0.193274
	13	0.000811		85	3.527264
	14	0.357988		86	4.792765
	15	4.809695		87	0.090220
	16	5.532570		88	0.632181
	17	0.002197		89	0.259852
	18	0.064375		90	0.000978
3	19	0.001877	11	91	0.431664
	20	0.000526		92	0.955406
	21	0.232333		93	1.069600
	22	4.696154		94	0.064022
	23	5.051430		95	0.245245
	24	0.199184		96	0.020607
	25	0.397714		97	0.001083
	26	0.033418		98	0.478030
	27	0.000211		99	0.460126
4	28	0.093100	12	100	0.460991
	29	10.483060		101	0.000485
	30	11.510022		102	0.231800
	31	0.023833		103	0.019477
	32	2.866325		104	0.001067
	33	0.104189		105	0.470722
	34	0.009240		106	0.052397
	35	4.077906		107	0.055693
	36	4.533350		108	0.001848
5	37	4.810626	13	109	0.000254
	38	0.006435		110	0.000021
	39	0.835612		111	0.000001
	40	0.030374		112	0.000298
	41	0.002514		113	0.000000
	42	1.109641		114	0.045599
	43	0.329883		115	0.000793
	44	0.353493		116	0.037806
	45	0.000548		117	0.102372
6	46	0.039827	14	118	0.000000
	47	0.001448		119	0.005963
	48	0.000139		120	0.010925
	49	0.061206		121	0.020783
	50	0.003792		122	0.060962
	51	0.005111		123	0.000001
	52	0.000739		124	0.025836
	53	0.007296		125	0.036526
	54	0.000613		126	0.016753
7	55	0.000035	15	127	0.053465
	56	0.015544		128	0.000002
	57	0.263016		129	0.024281
	58	0.280528		130	0.142276
	59	0.009818		131	0.190893
	60	0.044106		132	0.060079
	61	0.003706		133	0.000000
	62	0.000225		134	0.063599
	63	0.099411		135	0.096226
8	64	0.182181	16	136	0.104842
	65	0.201935		137	0.134182
	66	0.011075		138	0.000000
	67	0.105202		139	0.071805
	68	0.008840		140	0.117756
	69	0.000444		141	0.098003
	70	0.196115		142	0.148595
	71	0.431918		143	0.000002
	72	0.533730		144	0.038319

From table 1 the results of the calculation of the mechanical mode participation factor of each generator indicates that the instability mode section, the eigenvalues of 9th mode associated with G1, the eigenvalues of 16th mode associated with G2, the eigenvalues of 23th mode associated with G3, the eigenvalues of 30th mode associated with G4, 37th mode associated with G5, 58th mode associated with G7, 72th mode associated with G8, 79th mode associated with G9, 86th mode associated with G10, 93th mode associated with G11, 105th mode associated with G12, 117th mode associated with G13, 131th mode associated with G15, 142th mode associated with G16. The Eigenvalues are associated with a state variable and has a major influence on the factors of participation. Thus the optimum position of the PSS are G1, G2, G3, G4, G5, G7, G8, G9, G10, G11, G12, G13, G15, and G16.

B. Tuning Power System Stabilizer Using ICA

PSS Parameters, consisting of T1, T2, T3 and T4. While Tw parameter 1-16 = 10. The process of tuning used using ICA method. The following parameters were used ICA.

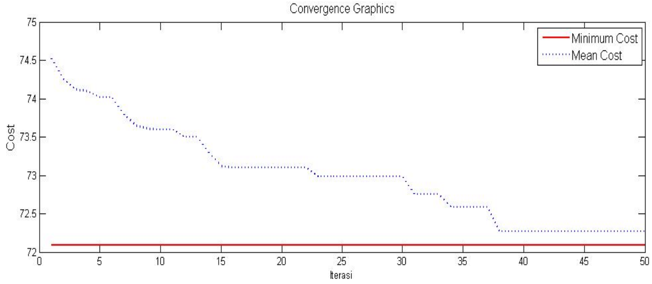

Fig. 6. Convergence Graphic of ICA

TABLE III. ICA PARAMETERS

Number of country	100
Number of imperialist	10
Number of decade	50
Revolution rate	0.3
Coefficient of assimilation (β)	2
Zeta (ξ)	0.02
Coefficient of assimilation angle (γ)	0.5

TABLE IV. PSS PARAMETERS LIMIT

No	Parameter	Lower Limit	Upper Limit
1	K_{pss}	10	50
2	T_1	0,02	1
3	T_2	0,01	0,05
4	T_3	1	4
5	T_4	3	6

TABLE V. TUNING RESULTS OF PSS PARAMETER

Power Plant	Kpss	T1	T2	T3	T4
Bakaru Hydro	46.0885	0.5583	0.0413	2.7426	3.6513
Pinrang Hydro	45.9066	0.0200	0.0100	3.2192	3.4526
Pare Diesel	1.0000	0.0200	0.0154	3.0517	4.7853
Suppa Diesel	37.2131	0.7130	0.0269	1.0000	3.4375
Barru Steam	31.1308	0.4286	0.0266	4.0000	3.0000
Tello Lama	1.0000	1.0000	0.0197	2.5773	3.0000
Tello lama Diesel	50.0000	0.9365	0.0236	3.3018	6.0000
Sgmnsa Diesel	45.1494	0.2190	0.0469	2.7681	4.3793
Jeneponto Steam	1.0000	0.6989	0.0197	2.0825	3.0000
Bulukumba Diesel	10.1208	0.0200	0.0100	4.0000	3.0235
Sinjai Hydro	50.0000	0.4916	0.0345	4.0000	3.8499
Soppeng Diesel	41.8184	1.0000	0.0201	2.3274	3.0000
Sgkang Steam-Gas	49.0428	0.0291	0.0148	2.1197	5.1915
Makale Hydro	50.0000	1.0000	0.0495	1.0000	6.0000
Palopo Hydro	27.0971	0.2402	0.0442	2.6105	3.0000
Borongloe Hydro	1.0000	0.5054	0.0100	4.0000	5.9552

TABLE VI. OVERSHOOT OF FREQUENCY SYSTEM

Power Plant	No PSS (pu)	CPSS (pu)	ICA PSS (pu)
Bakaru Hydro	0,001960	0,0002791	0,00029470
Pinrang Hydro	0,005070	0,0031620	0,00038290
Pare Diesel	0,001303	0,0007247	0,00051540
Suppa Diesel	0,004778	0,0024540	0,00261100
Barru Steam	0,018530	0,0070990	0,00009871
Cogindo Tello Diesel	0,145900	0,1442000	0,14070000
Tello lama Diesel	0,040920	0,0147400	0,00057320
Sgmnsa Diesel	0,004041	0,0014360	0,00017220
Jeneponto Steam	0,004016	0,0024800	0,00129300
Bulukumba Diesel	0,006523	0,0044520	0,00156200
Sinjai Hydro	0,003565	0,0019360	0,00061260
Soppeng Diesel	0,006569	0,0043750	0,00044700
Sengkang Steam-Gas	0,003472	0,0020680	0,00020640
Makale Hydro	0,008515	0,0063040	0,00156000
Palopo Hydro	0,009491	0,0070970	0,00251800
Borongloe Hydro	0,008114	0,0032280	0,00143300

TABLE VII. CRITICAL EIGENVALUE SYSTEM

Convensional PSS	ICA PSS
-0.5135 ± 6.5409i	-0.5110 ± 6.5370i
-0.3850 ± 5.0533i	-0.3799 ± 5.0400i
-0.4149 ± 4.7360i	-0.5012 + 5.0088i
-0.3059 ± 4.6962i	-0.3060 + 4.6970i
-0.3198 ± 4.5278i	-0.3204 + 4.5288i
-0.1906 ± 4.4418i	-0.1851 + 4.4206i
-0.1258 ± 4.3179i	-0.1291 + 4.2943i
-0.0413 ± 3.9001i	-0.0413 + 3.9001i
-0.0225 ± 3.6534i	-0.0278 + 3.6607i
-0.1311 ± 1.4773i	-0.1347 + 1.4794i
-0.1088 ± 1.3683i	-0.1055 + 1.3629i

TABLE VIII. DAMPING RATIO AT THE CRITICAL EIGENVALUE

Convensional PSS	ICA PSS
7.83e-02	1.79e-01
7.60e-02	7.52e-02
8.73e-02	9.96e-02
6.50e-02	6.50e-02
7.05e-02	7.06e-02
2.91e-02	3.01e-02
4.18e-02	4.17e-02
1.06e-02	1.06e-02
6.16e-03	7.59e-03
8.84e-02	9.07e-02
7.93e-02	7.72e-02

From table 6 can be seen that the optimal use of PSS-ICA can reduce overshoot and speed up to go to the stable state than other method. While Table 7-8 shows the critical eigenvalue of the system using a conventional PSS and PSS ICA, which showed an increase with increasing eigenvalue damping ratio. Damping values greater than 0.1 indicate that the eigenvalue condition is secure and allows stable higher.

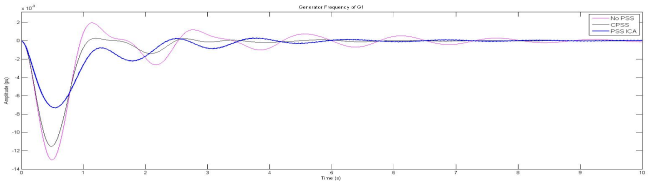

Fig. 7. Frequency of Bakaru Generator

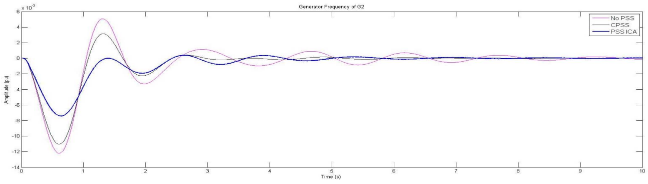

Fig. 8. Frequency of Pinrang Generator

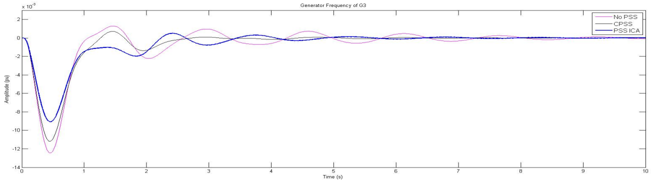

Fig. 9. Frequency of Pare Generator

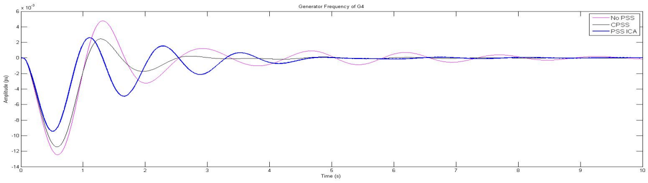

Fig. 10. Frequency of Suppa Generator

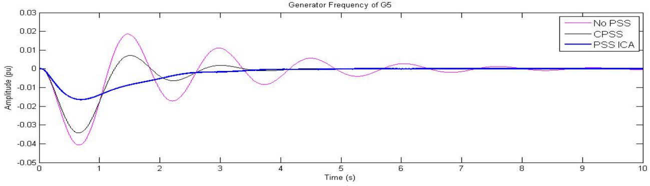

Fig. 11. Frequency of Barru Generator

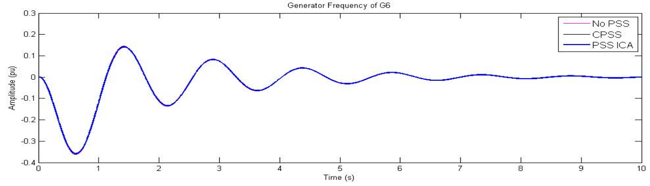

Fig. 12. Frequency of Tello Generator

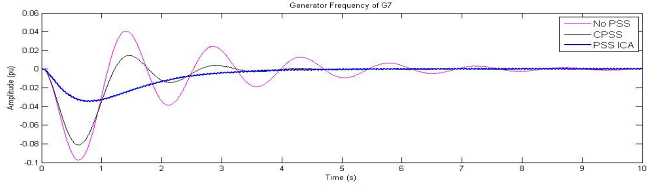

Fig. 13. Frequency of Tello Lama Generator

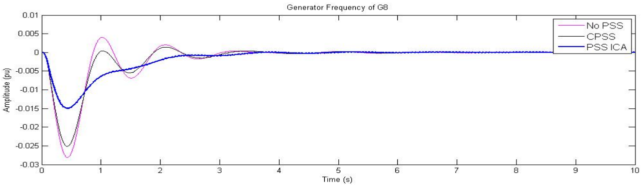

Fig. 14. Frequency of Sungguminasa Generator

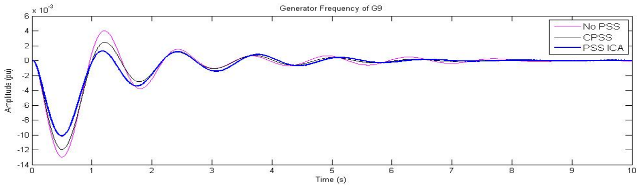

Fig. 15. Frequency of Jeneponto Generator

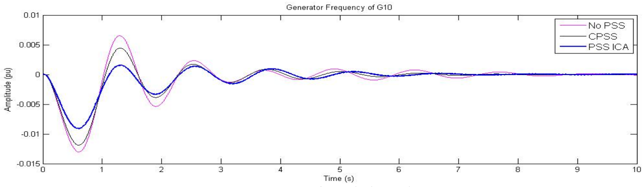

Fig. 16. Frequency of Bulukumba Generator

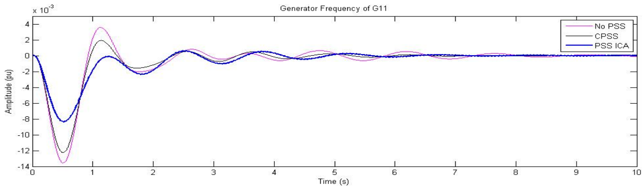

Fig. 17. Frequency of Sinjai Generator

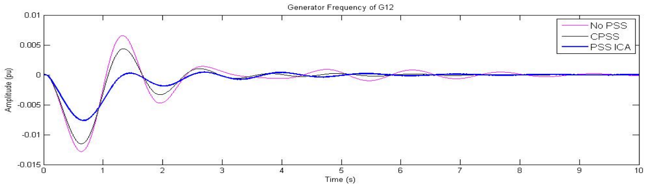

Fig. 18. Frequency of Soppeng Generator

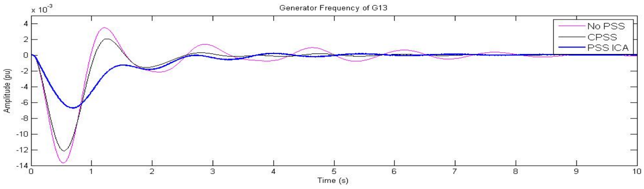

Fig. 19. Frequency of Sengkang Generator

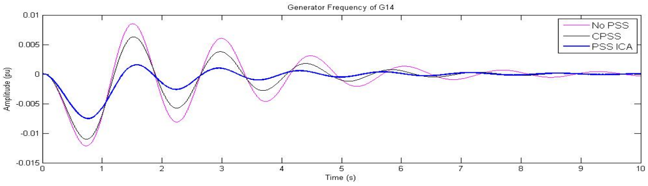

Fig. 20. Frequency of Makale Generator

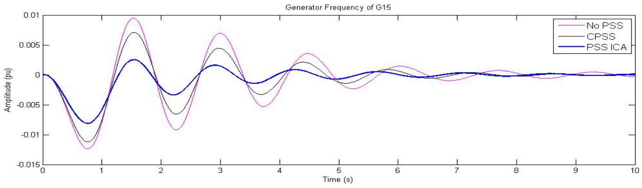

Fig. 21. Frequency of Palopo Generator

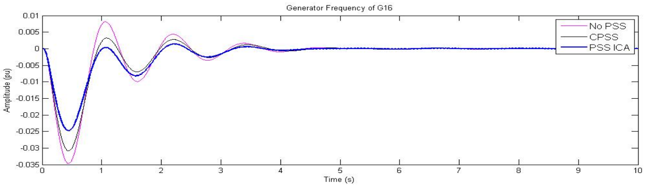

Fig. 22. Frequency of Borongloe Generator

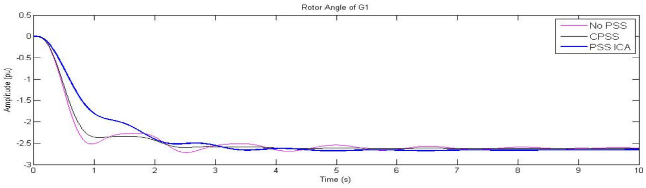

Fig. 23. Rotor angle of Bakaru Generator

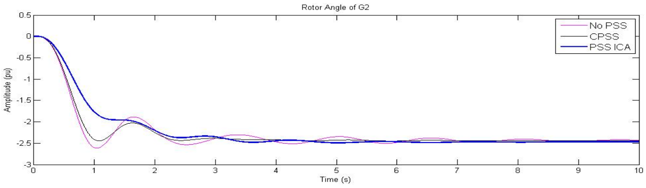

Fig. 24. Rotor angle of Pinrang Generator

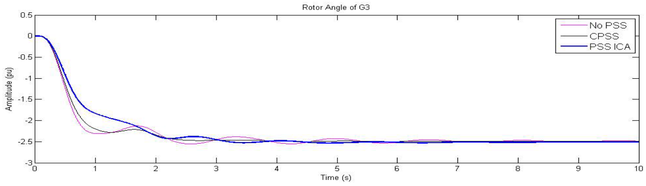

Fig. 25. Rotor angle of Pare Generator

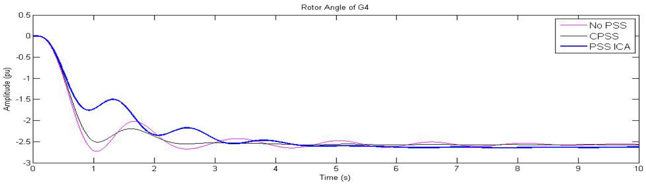

Fig. 26. Rotor angle of Suppa Generator

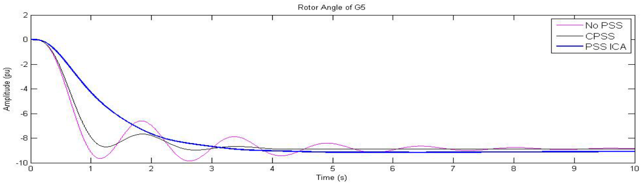

Fig. 27. Rotor angle of Barru Generator

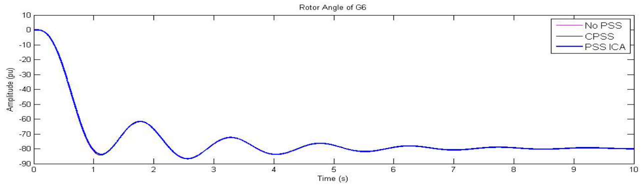

Fig. 28. Rotor angle of Tello Generator

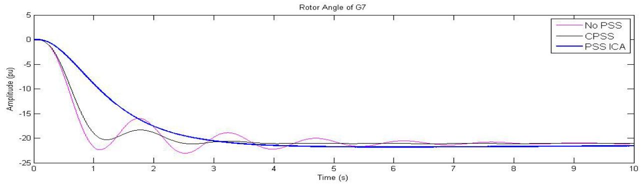

Fig. 29. Rotor angle of Tello Lama Generator

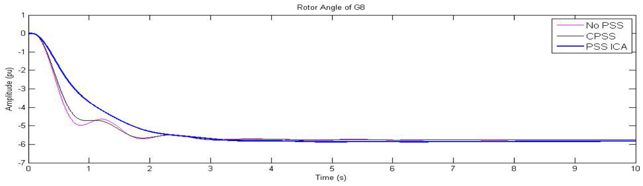

Fig. 30. Rotor angle of Sungguminasa Generator

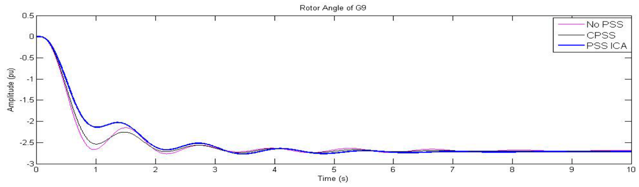

Fig. 31. Rotor angle of Jeneponto Generator

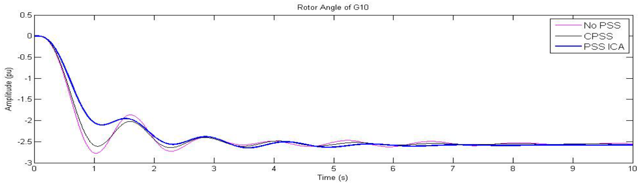

Fig. 32. Rotor angle of Bulukumba Generator

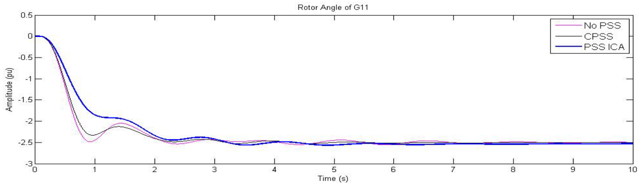

Fig. 33. Rotor angle of Sinjai Generator

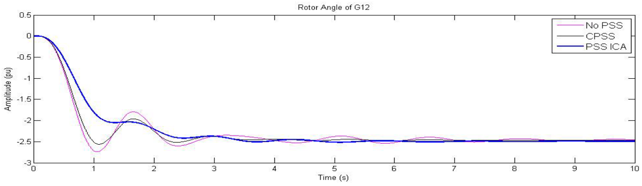

Fig. 34. Rotor angle of Soppeng Generator

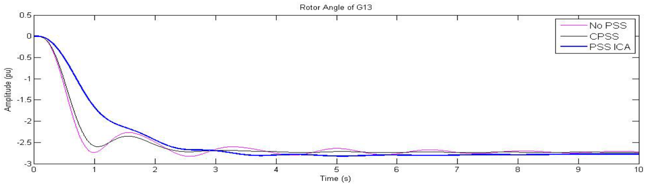

Fig. 35. Rotor angle of Sengkang Generator

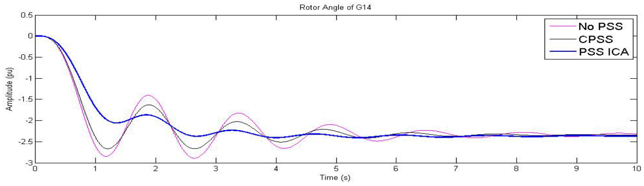

Fig. 36. Rotor angle of Makale Generator

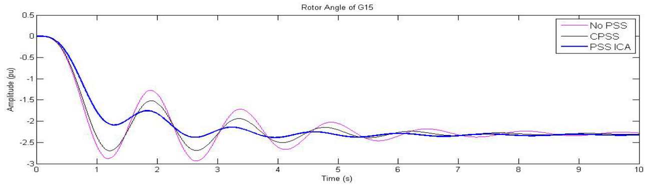

Fig. 37. Rotor angle of Palopo Generator

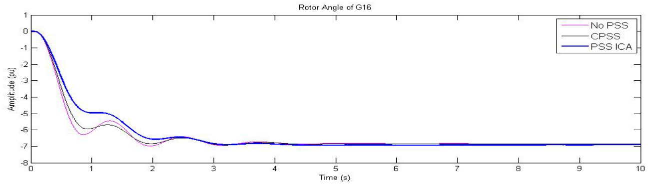

Fig. 38. Rotor angle of Borongloe Generator

The proposed method, ICA and PF, have resulted in a good optimization to tune parameters and placement PSS of South of Sulawesi system. The above chart is composed of two responses can be seen, the frequency response graph and change the angle of the rotor of each generator. From figure 6, show the convergence graph of algorithm, where the optimization is to find the optimal solution converges on the 38th iteration. Figure 7-22 shows the frequency response of each generator, in which the graph can be viewed using the PSS-ICA can reduce the overshoot oscillations, thus speeding up the settling time to get to steady state conditions. For example, for Pinrang generator without PSS, overshoot oscillation of 0.005070, with conventional PSS 0.0031620, and PSS ICA 0.00038290.

As for the other generators, can be seen changes in the frequency response after the addition of PSS on the optimal location of the PSS, in which the oscillations are generated smaller than without PSS and with conventional PSS. While charts 23-38 show the response of the rotor angle changes, which can be generated oscillations decreased, compared with those without conventional PSS and PSS.

V. CONCLUSION

From the result of simulation, ICA method for tuning PSS parameters that Kpss, T1, T2, T3, T4 and Participation Factor method for PSS placement that installed in G1, G2, G3, G4, G5, G7, G8, G9, G10, G11, G12, G13, G15 and G16, can increase performance system by reducing the overshoot value of the frequency response and rotor angle. As for the condition of the frequency response settling time showed an acceleration of achieving a stable condition than without using PSS and PSS conventional.

The critical eigenvalue showed an increase with increasing eigenvalue damping ratio. Damping values greater than 0.1 indicate that the eigenvalue condition is secure and allows stable higher. The proposed of method can be improved stability system south of Sulawesi.

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