Optimal Coordination PID-PSS Control Based on Craziness Particle Swarm Optimization In Sulselrabar System

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***Abstract*—The combination of a Power System Stabilizer (PSS) and PID control in a multiengine system provides additional control action on the excitation side of the generator. Optimal coordination is required to use the two controllers. The Sulselrabar system is a complex system that connects large load centers. A study is needed regarding generator stability to support system performance. This study proposes an artificial intelligence optimization method based on Craziness Particle Swarm Optimization (CRPSO) to optimize the PID-PSS parameters. CRPSO is a refinement of the premature convergence of the conventional PSO method. The optimal PID-PSS parameter results in optimal generator excitation performance. The combination of PID-PSS and excitation reduces the oscillations in the system. From the analysis, results obtained optimal performance compared to other control schemes in terms of the excitation output response that gives a maximum signal. The speed response produces a minimum overshoot of -0.01187 & 0.00019pu. Besides that, it is also viewed from the increase in eigenvalues and the maximum damping system, 0.601826596. This increase results in optimal system performance, faster system heading to a steady state and faster settling time.**

Keyword: PID, PSS, CRPSO, Damping, Overshoot

I. Introduction

The role of electrical energy in supporting daily human activities is very vital. The significant growth of load every year requires electrical energy providers to be able to adapt. An electric power system that can adapt well is reliable. One form of reliability is system stability. Stability is the ability of the system to maintain a synchronous condition when a disturbance occurs [1]. In the system's operation, there are two types of disturbances: transient and dynamic. Transient disturbances are related to large-scale disturbances such as transmission line breaks or lightning strikes. At the same time, dynamic disturbances are related to small disturbances that often occur and can disrupt system stability. One of the causes of dynamic disturbances such as changes in system load.

Power supply conditions change from load and power requirements on the system. So that the shift in the operating point occurs, marked by the appearance of oscillations, in a stable system condition, the oscillations that occur can be damped in a short time. This indicates that the system has survived the new operating conditions. Meanwhile, an unstable system cannot suppress oscillation for a long time. This stability disturbance occurs in all system parts, from distribution and transmission networks to power plants. This condition is hazardous because instability that cannot be overcome will cause synchronization loss, and the possibility of system blackout is challenging to avoid [2].

One part of the large-scale electric power system is that the interconnection system is also very vulnerable to disturbances that can affect the stable condition of the system. The same condition also occurs in the 150 kV Sulselrabar interconnection net. This network bears a significant burden, for example, industries with large power machines. Changes in the load in the system can cause oscillations and disrupt stable conditions [3].

To overcome the oscillations that can be placed auxiliary equipment that serves to dampen the oscillations. One of the pieces of equipment currently widely used is the Power System Stabilizer (PSS) placed on the side of the generator. In addition, conventional controllers such as PID are also often used in power plants. PID can reduce system disturbances, so that the system remains stable.

PSO is an optimal value search method inspired by the foraging patterns of birds and fish. PSO is a population-based optimization technique known as a swarm. PSO is similar to a Genetic Algorithm (GA) which has population initialization and random value search but does not have evolutionary operators such as crossover and mutation. The PSO algorithm is then refined by making changes to the mathematical equations to improve the particles' velocity (velocity update) and position (position update). This method was later called Craziness Particle Swarm Optimization (CRPSO). CRPSO can produce a better system response than PSO [4, 5]. Application of CRPSO to optimize controller parameters, such as [6] application of CRPSO to PSS in multi-machine systems, and [7] application of CRPSO to optimization of automatic generation control. These studies show optimal results with the application of CRPSO.

The lack of a PSS controller in providing additional damping must be combined with conventional PID-based control. This is indicated by research that combines PID-PSS simultaneously, such as [8] application of PID-PSS on uncertain power systems, [9] application of PID-PSS to increase the stability of multi-machine systems, [10] application of PID-PSS PSS for stability improvement of grid-tied HydroTurbine generator, and [11] application of PID-PSS for transient stability improvement. This research shows the optimal performance of PID-PSS for dynamic systems. The Sulselrabar system is a dynamic multi-machine system that shows rapid development. It is necessary to study system performance analysis to optimize system performance. Several studies on the South Sulawesi system include economic dispatch [12-14], and small signal stability analysis [15]. In this study, the effect of tuning PID and PSS parameters with CRPSO on the dynamic stability of the system was analyzed. The plant used is the Sulselrabar electrical system. To analyze the dynamic stability, the system will be modeled linearly. The simulation results will compare plant response using PID and PSS with CRPSO tuning.

In the second part of this article, we discuss modeling the Sulselrabar system and the PID-PSS controller. The third part discusses the research method used and the objective function used. The fourth section discusses the analysis of the PID-PSS installation in the Sulselrabar system. The last part is the conclusion of the research.

II. System Model

A. Generator Model

To analyze the system's performance against small disturbances, the system needs to be modelled linearly. The linear modelling of the generator is shown in equation (1) below [1].

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

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

From equation 1, the parameters are obtained, V_{dq} is Stator Voltage dq axis, V_F is Rotor Field Voltage, V_{DQ} is Rotor Voltage dq axis, r is stator Resistance, L_{dq} is Rotor Inductance dq axis, λ_{qd} is Initial flux dq *axis,* kM_F is Rotating Magnetic Field, M_{DQ} is Mutual Inductance, Δi_d Δi_q is Stator Current d q axis, Δi_F is Rotor Field Current, Δi_{DQ} is Rotor Current d and q axis, $\Delta\omega$ is Generator Speed Change, $\Delta\delta$ is Generator Rotor Angle Changes.

B. Fast Exiter Model

Excitation equipment functions as a regulator of voltage, current and power factor on the generator. In this study, the type of excitation used is the fast exciter [1].

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

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.

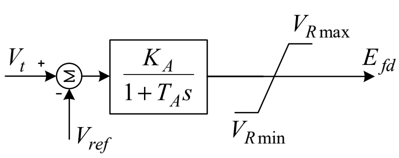

Fig. 1. Fast Exciter Block Diagram

C. Governor Model

The governor equipment serves to provide feedback for the balance of the system, if there is a change in the rotation of the generator rotor. Figure 2 below shows the governor model used [1].

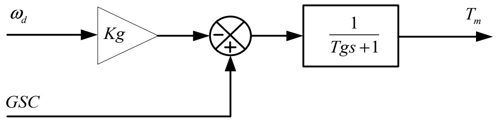

Fig. 2. Governor Modeling

Figure 2 shows the modeling of the governor, with T_m is Mechanic torque, ω_d is Change in speed, GSC is Governor Speed Changer (GSC=0), K_g is Gain Constant=1/R, T_g is Governor time constant, and R is Droop governor constant.

D. PSS Model

Equation 3 shows the PSS model [1].

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

Equation 3 shows the PSS model, with Vs is PSS Output, K_{PSS} is PSS Gain, T_w is Washout Filter, T_A, T_B, T_C, T_D are Lead-Lag Gain, and V_{Smax} V_{Smin} = Limiter. PSS provides an additional signal to the generator's excitation, thereby increasing the damping system. Figure 3 shows the PSS model used [1].

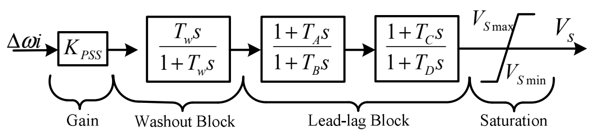

Fig. 3. PSS Block Diagram

Gain as amplifier. washout filter as a steady-state bias from the PSS output. The lead-lag compensates for the phase lag of the AVR and generator field circuit. Limiter as PSS output limiter.

E. PID Model

Control parameters P, I and D, can cover each other by combining all three in parallel. The controller components P, I, and D are each aimed at speeding up the reaction of a system, eliminating offsets and producing significant initial changes. The PID model is shown in figure 4.

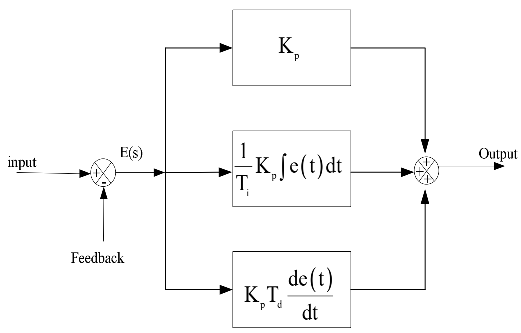

Fig. 4. PID controller block diagram

The PID controller output is the sum of the proportional, integral, and differential controller outputs. PID performance characteristics are influenced by parameters P, I and D. Determination of the right Kp, Ki, and Kd constants will produce optimal output. These constants can be set according to the system used.

F. Craziness Particle Swarm Optimization

Particle Swarm is a population optimization method, starting with spreading the particle population [16]. his particle stores information about its existence and the potential value generated by that existence. Each particle will provide information to the other so that the particle can occupy an optimal location in a movement. Other particles move to that location based on a velocity motion function from this information. During the flight process, each particle determines its position based on experience (Pbest) and other particles' experience (Gbest). The Pbest and Gbest optimization processes can be illustrated in Figure 5.

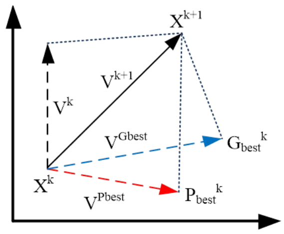

Fig. 5. The concept of CRPSO

The particle velocity is defined by (4).

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

Pbest and Gbest can be calculated by equation 4 based on particle velocity, while the current position can be calculated using equation 5.

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

X^k is current search point, X^{k+1} is modified search position, V^k is current speed, V^{k+1} is modified speed, Vpbest is speed based on P_{Best}, Vgbest is speed based on Gbest, n is number of particles in a group, m is the number of members in the particle, $pbest_i$ is Pbest from k, $gbest_i$ is Gbest from group, w is weight, c_i is weight coefficient.

The conventional particle swarm algorithm has the disadvantage of reaching convergence prematurely, so the solution obtained is a local optimum. At the same time, the CRPSO algorithm has an updated velocity function so that the particles move outside the speed rules for a certain iteration. The craziness swarm value is influenced by changes in weight that occur in each iteration as shown in Equations (6) and (7) below.

$$w^k = (w_{max} - w_{min}) \times \frac{iter_{max} - iter^k}{iter_{max}} + w_{min} \quad (6)$$

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

The update speed changes based on the Pcraz value shown in (8) as follows.

$$v_i^k = \begin{cases} rand\ (0, v_{max}) & if\ \ P_{craz} \leq rand\ (0,1) \\ v_i^k & other \end{cases} \quad (8)$$

III. Research Method

In this study, the stability of the Sulselrabar system was analyzed using eigenvalue analysis, time domain analysis, and a damping system. Equations 9 and 10 show the system modelling in state space to analyze the eigenvalue system.

$$\Delta\dot{x} = A\Delta x + B\Delta u \quad (9)$$

$$\Delta y = C\Delta x + D\Delta u \quad (10)$$

Δx is state matrix, Δy is output variable matrix with $m \times 1$, u is input variable matrix with $r \times 1$, A is system matrix ($n \times n$), B is input matrix with $n \times r$, C is measurement matrix with $m \times n$, D is input matrix for output with $m \times r$.

Stability can be determined from the matrix A system, shown in equation 11.

$$\det(sI-A)=0 \quad (11)$$

Equation 12 shows I is the identity matrix, s indicates the eigenvalue of the matrix A.

$$\lambda_i = \sigma_i + j\omega_i \quad (12)$$

The system frequency is:

$$f = \frac{\omega}{2\pi} \quad (13)$$

λ_i is *eigenvalue -i,* σ_i is real component, and ω_i is imaginary component eigenvalue system.

The stability of the power system can be seen from the eigenvalue matrix A. It is said to be stable if the real eigenvalue part is negative. The stable system is an indicator for the installation of the controller. The real part of the eigenvalue shows the system attenuation, and the imaginary part shows the system oscillation. Equation 14 shows the determination of the damping value of the system, and equation 15 shows the damping of the whole system.

$$\zeta_i = \frac{-\sigma_i}{\sqrt{\sigma_i^2 + \omega_i^2}} \quad (14)$$

$$CDI = \sum_{i=1}^{n} (1 - \zeta_i) \quad (15)$$

ζ_i is damping ratio and n is eigenvalue number.

The CRPSO algorithm works with an objective function to maximize system attenuation. Optimization of PID-PSS parameters based on the constraints shown in table 1.

TABLE I. CONSTRAINT PARAMETERS [17]

No	Parameter	Lower	Upper
1	Kp	0	20
2	Ki	0	20
3	Kd	0	20
4	K_{pss}	10	50
5	T_1	0	0.05
6	T_2	0	0.05
7	T_3	0	1
8	T_4	0	2
9	Tw	10	

IV. Simulation and Analysis

Figure 6 shows the convergence process of the algorithm, where the minimum global CRPSO can be achieved in the 7th iteration to find the optimal PID-PSS parameter, with a fitness function value of 74.35334956274994. The results of the PID-PSS parameter tuning are shown in table 2 below. To test the system performance with CRPSO, a trial error method of PID-PSS tuning is used. For the test scheme used without control, PID and PID-PSS.

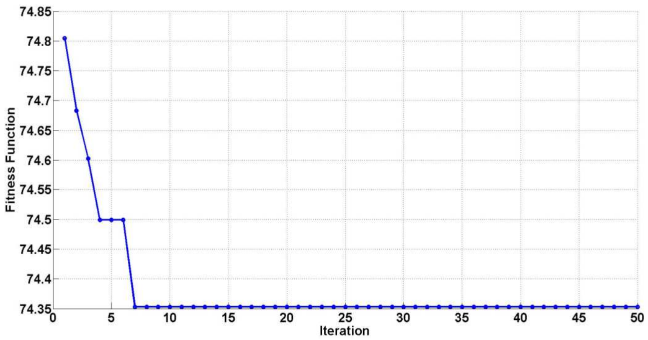

Fig. 6. Convergence Graph

TABLE II. Optimization Results

Trial-Error			CRPSO		
Parameter		Value	Parameter		Value
PID	Kp	0.1370	PID	Kp	12.7451
	Ki	1.3197		Ki	1.5119
	Kd	0.0026		Kd	0.0057
PSS	Kpss	15.3452	PSS	Kpss	48.5843
	T1	0.0161		T1	0.0343
	T2	0.0405		T2	0.0441
	T3	0.3562		T3	0.6175
	T4	0.1096		T4	0.3052

A. Excitation Voltage Response

In this study, the case study used is to test the reliability of the Bakaru generator due to changes in load. The Bakaru generator is tested for a PID-PSS-based control scheme. After getting the optimal PID-PSS parameters, the next step is to test the system's reliability by observing the speed response and rotor angle. The installation of PID-PSS control on the fuel generator provides an additional excitation signal, which can be seen in the EFD response of the generator excitation.

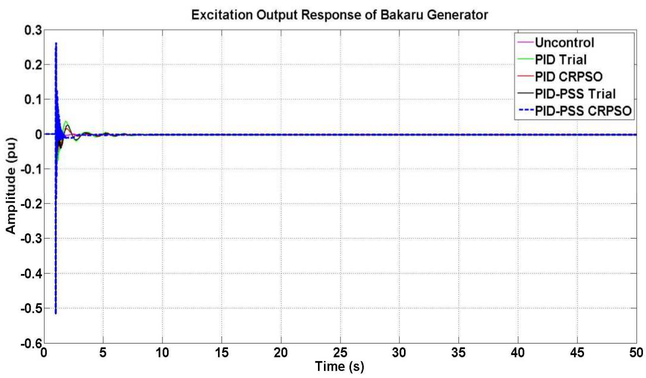

Fig. 7. Excitation output voltage (E_{fd}) of Generator Bakaru

Figure 7 shows the generator excitation voltage output characteristics of each control scheme. The simulation results obtained optimal signal performance using PID-PSS, compared with other control schemes.

B. Generator Speed Response

The following performance analysis of the PID-PSS installation will review the generator speed characteristics. Table 3 shows a comparison of the speed response of the fuel generator for each control scheme.

TABLE III. Bakaru Generator Speed Overshoot

No PSS	PID Trial Error	PID CRPSO	PID-PSS Trial Error	PID-PSS CRPSO
-0.02242 & 0.005246	-0.02003 & 0.001408	-0.01547 & 0.0002803	-0.01668 & 0.001037	-0.01187 & 0.00019

Table 3 shows the speed response characteristics of the Bakaru generator, from the simulation results obtained optimal performance with PID-PSS with optimization based on CRPSO, the minimum overshoot response compared to other schemes -0.01187 & 0.00019pu. While the worst system response is the system without control, namely -0.02242 & 0.005246pu. Meanwhile for trial-error PID -0.02003 & 0.001408pu, CRPSO PID -0.01547 & 0.0002803pu, and trial-error PID-PSS -0.01668 & 0.001037pu. Figure 8 shows the speed response of the fuel generator with various control schemes. The first response of the generator shows a downward response, and this is because the increase in load causes Pe > Pm, so the graph in the first response shows an increase in load.

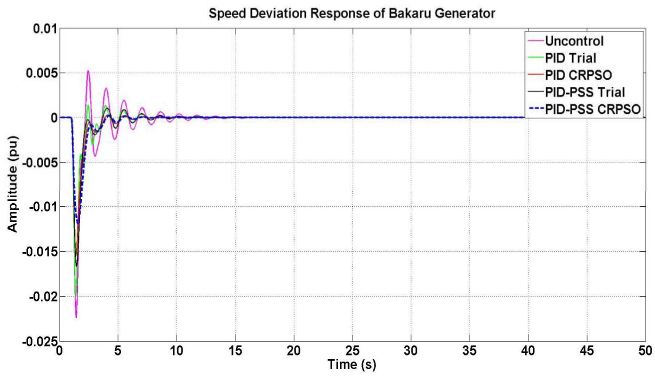

Fig. 8. Speed Response (Δω) of Generator

C. Generator Rotor Angle Response

The following system analysis reviews the performance of the combustion generator rotor angle response with several control schemes. Figure 9 shows the angular response of the fuel generator rotor.

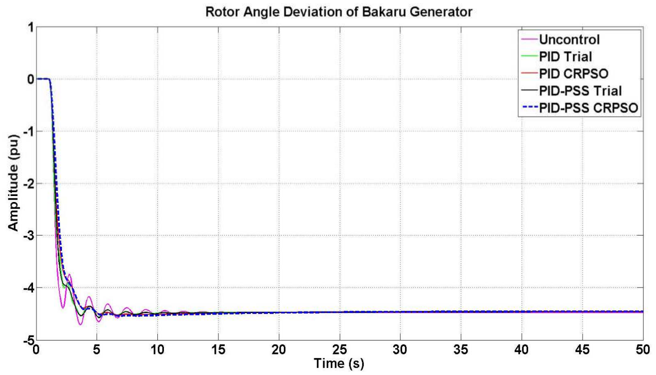

Fig. 9. Bakaru Generator Rotor Angle Variations

Figure 9 shows rotor angle response. Because Pe > Pm, the rotor slows down, and the rotor angle response becomes negative. Table 4 shows the total damping of the overall system with several control schemes.

TABLE IV. DAMPING SYSTEM

No PSS	PID Trial Error	PID CRPSO	PID-PSS Trial Error	PID-PSS CRPSO
0.449786111	0.58002918	0.5786897	0.588917021	0.601826596

Table 4 shows the damping eigenvalue system for the proposed control scheme based on PID-PSS CRPSO produces the maximum damping value, which is 0.601826596. While the system with minimum damping is without PSS of 0.449786111, the system with PID trial-error damping of 0.58002918, the system with PID CRPSO damping of 0.5786897, and trial-error PID-PSS of 0.588917021.

V. CONCLUSION

This study proposes an additional control scheme for the generator excitation based on PID-PSS based on CRPSO in the Sulselrabar system. From the analysis, results obtained optimal performance compared to other control schemes in terms of the excitation output response that gives a maximum signal. The speed response produces a minimum overshoot of -0.01187 & 0.00019pu. Besides that, it is also viewed from the increase in eigenvalues and the maximum damping system, 0.601826596. From these indications, it produces optimal system performance. The system goes faster to steady-state conditions and faster settling time.

This research develops the implementation of intelligent algorithms for controller optimization. In future studies, other algorithm models can be designed to optimize the system controller.

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