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Intelligent Coordinated Control of PID-SMES and AVR based on Hybrid PSO-DE for Small Signal Stability Enhancement

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***Abstract*—Dynamic disturbances in the electric power system occur due to changes in the load that can change important parameter values, this results in loss of synchronization in multi-machine power systems, so a controller in the power system is needed to maintain a stable condition during dynamic disturbances. In this final project, a Proportional Integral Differential (PID)-Superconducting Magnetic Energy Storage (SMES) controller is useful for supplying or absorbing active power when there is a load change so that the frequency can be maintained continuously, and an Automatic Voltage Regulator (AVR) is in charge of regulating the voltage on the system. The PID controller in SMES is useful for setting the output parameters of SMES. Hybrid Differential Evolution - Particle Swarm Optimization (DE-PSO) optimization method is used to optimize the oscillation damping process. The results indicate that the use of PID SMES and AVR optimized using the DE-PSO hybrid algorithm has a better response. In the Suralaya generator unit, the overshoot is -0.0001395 pu, and the settling time is 12.4 seconds by using the optimal controller. Meanwhile, when it is not using the additional controller, the overshoot is -0.0004228 pu, and the settling time is more than 16 seconds.**

***Keywords*—AVR, DE-PSO, Dynamic Stability, Energy efficiency, Multimachine, SMES.**

I. Introduction

An electric power system requires a stable state so that the quality of power supplied to consumers is maintained. However, in reality, the stable state of an electric power system cannot always be maintained due to disturbances and dynamics of load changes [1]. Therefore, additional controllers are needed to maintain system performance. In its application, the controller parameters must be determined carefully so that the controller can play an effective role in maintaining the stability of the generator [2]. However, this is not easy if implemented in a multi-machine power system, where several generators are interconnected so that the level of system complexity increases [3].

A multi-machine power system is a system consisting of several generators that operate simultaneously and are interconnected [4]. If one generator or subsystem is disturbed, the entire system will be affected (oscillate) [5]. To overcome the above problems, an additional controller is needed that is useful to assist the system in dampening oscillations. Superconducting Magnetic Energy Storage (SMES) is an additional controller that can dampen oscillations in the system by supplying or absorbing active power. To optimize the performance of additional controllers, artificial intelligence algorithms are used to determine controller parameters [6], [7].

One of the artificial intelligence algorithms that can be implemented is the Hybrid Differential Evolution (DE) – Particle Swarm Optimization (PSO) algorithm. Parameter tuning is performed on the PID SMES controller and the AVR controller. The SMES PID acts as an active power oscillation damper, and the AVR acts as a voltage oscillation damper. In this final project, the performance of the system is determined by looking at the value of overshoot and settling time on the frequency response, rotor angle response, and voltage response. The conclusion is presented by analyzing the comparison results from the simulation results of the system with and without tuning.

II. System Model

A. Test System

Java Bali system data is obtained from PT. PLN as of April 19, 2011 [8] consists of 25 buses, 30 channels, 1 slack bus, 17 load buses, and 7 bus generators. The single-line diagram for the Java Bali 500 kV electrical system is shown in Figure 1. In this paper, all modeling of multi-machine, starting from the turbine, governor, excitation system, field equations, and torque equations are modeled linearly. Multi-machine linear modeling in terms of one machine can be seen in Figure 2 [9].

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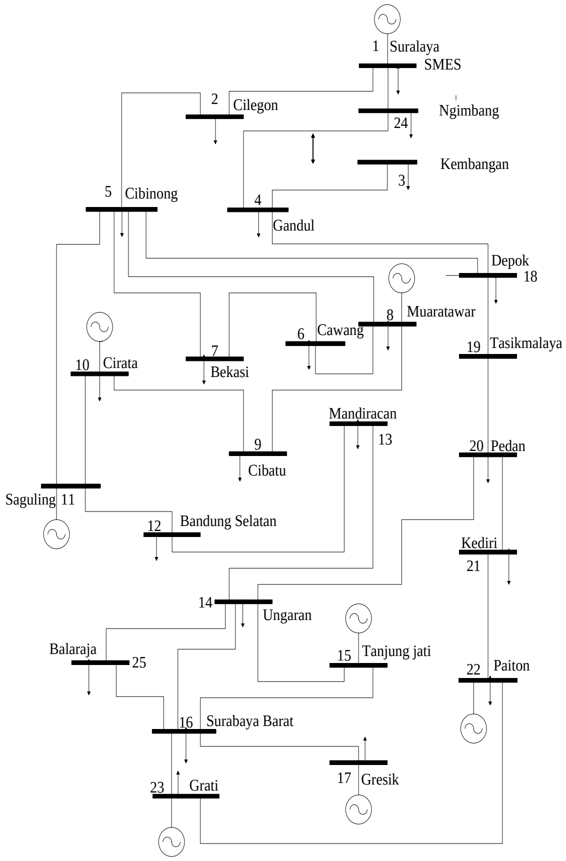

Figure 1. Single line diagram of the Java Bali 500 kV system

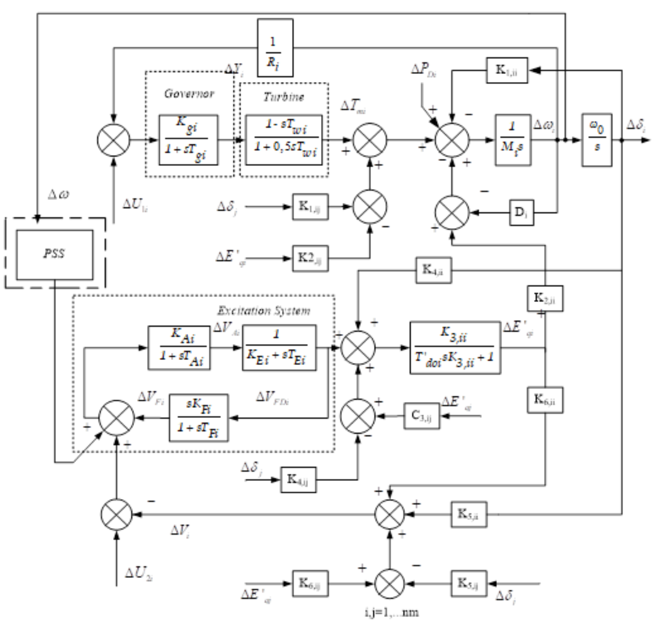

Figure 2. Multi-machine system viewed from one machine

B. *Superconducting Magnetic Energy Storage*

SMES is a device for storing and releasing large amounts of power at the same time. SMES stores energy in a magnetic field which is created by a DC current in a cryogenic cooled superconducting coil. A SMES which is connected to an electric power system consists of a superconducting coil, a power conditioning system (PCS), and a cryogenic cooling system with control and protection functions. PCS is also known as the power electronics connector of the SMES coil. Figure 2 shows a schematic diagram of the SMES [10].

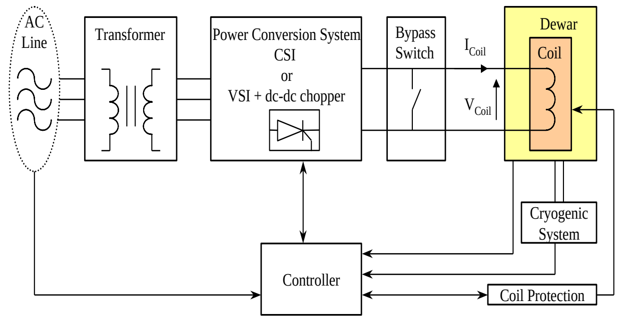

Figure 3. SMES schematic diagram

In principle, superconductors have near-zero losses at cold temperatures. Liquid Helium is used because it is capable of cooling to a temperature of 4 K. A PCS uses a dc-link capacitor to connect a voltage source and transfer energy from the SMES coil to the system. Various types of controllers used for SMES have been developed by many researchers. In this paper, SMES uses a PID controller to assist the performance of SMES in damping oscillations.

SMES is installed on the bus terminal of the generator in the model electric power system which is used to control the power balance effectively of the synchronous generator during the dynamic period. Figure 4 shows the basic SMES configuration consisting of a transformer, a voltage source converter (VSC) using a GTO thyristor, a DC-DC chopper using a GTO, and a superconducting coil. The converter and DC-DC chopper are connected by a DC link capacitor [11].

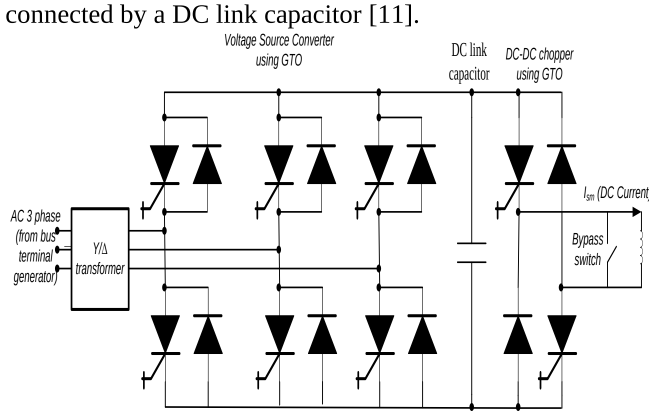

Figure 4. SMES Configuration

To control the power balance effectively of the generator, SMES is located at the bus terminal of the generator. The relationship between current and voltage in SMES is [12],

$$I_{SM} = \frac{1}{L_{SM}} \int_{t_0}^{t} V_{SM} d\tau + I_{SM\,0} \qquad (1)$$

I_{SM0} is the starting current of the inductor. The power stored or transmitted by SMES is [12],

$$P_{SM} = V_{SM} I_{SM} \qquad (2)$$

If V_{SM} *is* positive, then power will be transferred from the system to SMES. Meanwhile, if VSM is negative, then power will be released from SMES to the system. The energy stored in the SMES coil is [12],

$$W_{SM} = \frac{1}{2} L_{SM} I_{SM}^2 \quad (3)$$

L_{SM} is the inductance of the SMES. The voltage on the SMES coil V_{SM} is continuously controlled depending on the change in the generator rotor speed, i.e. [12],

$$\Delta V_{SM} = \frac{K_c}{1+sT_{dc}} \Delta\omega \quad (4)$$

K_c is the gain of the control loop, and Tdc is the time delay constant of the control device. Due to the limitations of hardware implementation, the coil current has a maximum and minimum limit. During operation, the upper limit of the coil current is set 1,38I_{sm0}, and the lower limit 0,31I_{sm0}. The limit of the terminal voltage is ± 0,2352 p.u.

From the above equation, a block diagram of the PID SMES controller used can be made, as shown in Figure 5[13].

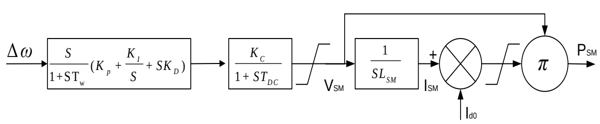

Figure 5. Block diagram of PID SMES

In this study, the SMES PID was installed on the Java Bali 500 kV system. The location of the SMES PID installation is at the Suralaya generator terminal bus when there is a load change disturbance.

III. METHOD

A. Hybrid DEA-PSO

DE-PSO is an optimization method consisting of a combination of two algorithms, namely DE and PSO. The basic program of DE-PSO uses the algorithm of PSO. The selection process on DE is combined with PSO to increase the speed of convergence. Technically this process can minimize the search function space. When viewed on PSO, birds or particles can be led directly into a better solution space [14].

The DE-PSO algorithm begins with the initialization of PSO parameters, which include the number of particles, the upper search limit, the lower search limit, and several other PSO parameters. Afterward, each particle is distributed in a randomly determined solution space. The randomly dispersed particles start to move based on the information from the particle with the best position. The fitness function of each particle is evaluated, and the best value of the movement of each particle (Pbest) and the best value of the swarm (Gbest) can be obtained. By getting the best swarm value, a second iteration process will be carried out with the additional role of the DE algorithm. In the second and subsequent iterations, DE first selects some of the best particles before the particles in the swarm continue the process of finding the solution. DE performs a particle selection process such as mutation, recombination, and evaluation stages. After passing through the DE process, the particles will be more collected or focused on a smaller search space so that this can speed up finding the best solution. Furthermore, the particles in the swarm perform the same procedure as the PSO algorithm in general [15].

When viewed from the process, DE-PSO does not have a wider solution possibility than PSO due to the narrowing of the solution search area. However, with this narrowing of the solution area, the best solution will be achieved more quickly [16].

B. PID SMES and AVR Parameter Optimization using DE-PSO

Hybrid DEA-PSO is an optimization method consisting of a combination of two algorithms, DEA and PSO. The basic program of DEA-PSO uses an algorithm from PSO and the selection process in DEA to increase convergence speed. Technically this process can minimize the search function space. When piloted on PSO, birds or particles can be lead directly into the solution space.

In this final project, the PID SMES and AVR controllers are tuned using DE-PSO. For the evaluation of the fitness function, the Comprehensive Damping Index (CDI) objective function is used, which is formulated with the equation [17].

$$CDI = \Sigma_{i=1}^{n}(1 - \xi_i) \quad (5)$$

with,
ξ_i = Damping ratio to-i
n = Number of eigenvalues

Several controller parameters are used so that the oscillations can be well damped, including Ksmes, Tdc, tw, Kp, Ki, Kd, Ka, Ta. Table 1 shows the parameters of Hybrid DE-PSO.

Table 1. Algorithm parameters

Number of particles	30
Number of variables	8
C2	2
C1	0.9
W	0.9
F	0.8
CR	0.5
Maximum iteration	30

The optimization of PID SMES and AVR parameters was carried out for 30 iterations. The fitness value is the error value of the frequency response. In the picture above, DE-PSO has achieved convergence in the ninth iteration. This can be caused by the role of DE, which functions to minimize the search space so that fast convergence is achieved. The optimal parameters of PID SMES and AVR can be seen in Table 2.

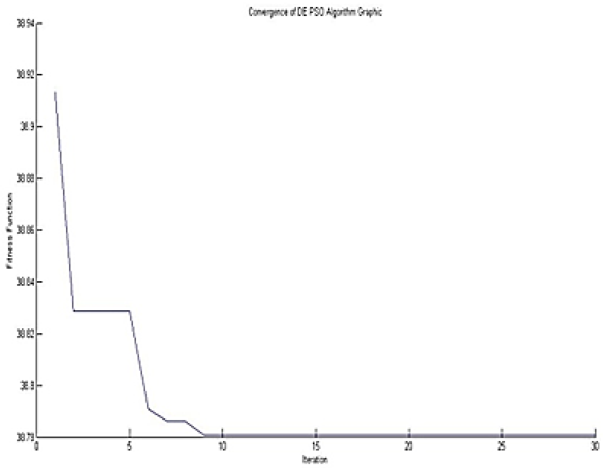

Figure 6. Convergence graph

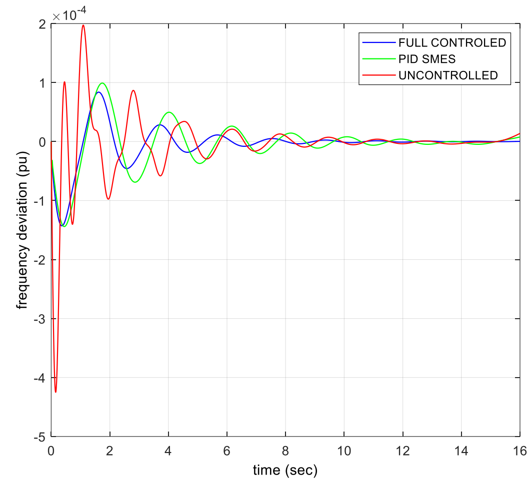

Figure 7. Frequency response at PLTU Suralaya

Table 2. Results of optimization of PID SMES and AVR. parameters

K_{smes}	t_{dc}	t_w	K_p	K_i
78.5639	0.0282	6.3991	7.8639	5.8537
K_d	**Ta**	**Ka**		
4.0864	0.0582	416.1448		

Table 3. Data on the frequency response of Suralaya PLTU

Control Method	Conventional	PID SMES	PID SMES and AVR with DE-PSO
Overshoot (pu)	-0.0004228	-0.0001439	-0.0001395
Settling time	> 16 seconds	> 16 seconds	12.4 seconds

IV. Results and Discussion

A. Frequency Deviation at PLTU Suralaya

Changes in the load of 0.05 that occur at the Suralaya generator caused frequency oscillations. The frequency oscillations that occur at the Suralaya generator are the largest when compared to the frequency oscillations in other generating units. Figure 7 shows the dynamic response of the rotor speed under different cases. This is because the disturbance of 0.05 pu only occurs in the Suralaya unit. Based on Table 3, the generating unit without using an additional controller has an overshoot of -0.0004228 pu. By using the PID SMES controller, the overshoot is reduced to -0.0001439 pu. Moreover, by using the PID SMES and the optimal AVR, the overshoot value can be reduced to -0.0001395 pu. For settling time, Table 4 shows that the conventional form of settling time cannot be achieved in 16 seconds. Similar to the conventional method, the SMES PID has not yet reached the settling time of 16 seconds. With optimal PID SMES and AVR, settling time can be achieved in 12.4 seconds. The results of this simulation show that DE-PSO can optimize the performance of the SMES, AVR, and PID controllers,

B. Rotor Angle Deviation at PLTU Suralaya

For the second case study, the load torque was considered to investigate the impact of load torque fluctuation on PSMS speed response and analyze the proposed method's effectiveness. The load torque was 1.2 N/m. Fig. 7 depicts the PSMS speed response due to load torque variation. It was noticeable that the overshoot of all of the cases increased due to external load torque. It was monitored that the best response was the system with the proposed method (PI controller based of hybrid DEA-PSO) indicated by small overshoot fastest settling time and precise final value. Table 4 shows the overshoot and settling time of the PSMS speed response.

Figure 8 shows the dynamic response of the rotor angle under different cases. Similar to what happened in the frequency response, the response to changes in the rotor angle at PLTU Suralaya has a greater overshoot when compared to other generators. This is because the location of the disturbance of 0.05 pu occurred in the Suralaya PLTU unit itself. In the initial state or without using an additional controller, PLTU Suralaya has an overshoot response of -0.03362 pu, and until the 16th second, the settling time has not been achieved. By adding PID SMES, the overshoot response decreased to -0.03258 pu and the settling time was more than 16 seconds. After adding the DE-PSO tuning method to the PID SMES and AVR, a smaller overshoot is obtained, namely -0.02981 pu, and the settling time can be achieved at 12.1 seconds. The simulation results show that the use of the DE-PSO tuning method can reduce the disturbances that occur in this problem.

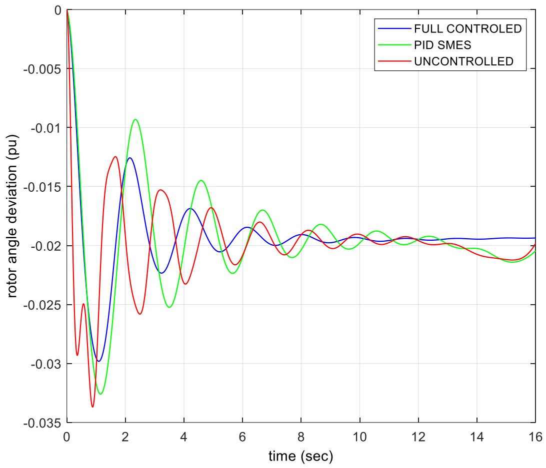

Figure 8. Rotor angle response at PLTU Suralaya

V. Conclusion

From the results of the research conducted, several conclusions were obtained as follows:

- Disturbances that occur in a generator can affect other plants if it occurs in a multi-machine power system.
- SMES can be implemented in multi-machine power systems to reduce system oscillations.
- The Hybrid DE-PSO algorithm can be used to optimize the SMES PID controller. Thus, it is obtained K_{smes} as much as 78.5639, t_{dc} as much as 0.0282, t_w as much as 6.3991, K_p as much as 7.8639, K_i as much as 5.8537, and K_d as much as 4.0864.
- The Hybrid DE-PSO algorithm can be used to optimize the AVR controller. Thus, it is obtained T_a as much as 0.0582 and k_a as much as 416.1448.
- Optimal PID SMES and AVR controllers can dampen system oscillations at the generator better when compared to without using PID SMES and using PID SMES without optimization methods.

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