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SMIB stability enhancement using capacitive energy storage and PID based on ant colony optimization

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Abstract. This research proposes a control method in the Single Machine Infinite Bus (SMIB) system by using energy storage based on Capacitive Energy Storage (CES) and Proportional Integral Derivative (PID). The CES-PID parameter is optimized using the Ant Colony Optimization (ACO) algorithm. From the results, the ACO algorithm can quickly converge, the ACO obtained the fitness function value of 2.5054e-07, with 50 iterations. ACO found the most optimal value at the 19th iteration. With elapsed time is 59.179148 seconds. To investigate the stability of the SMIB system with CES-PID control, two case studies are applied, namely increasing and load shedding. The system analysis reviewed is time domain simulation frequency response and rotor angle, Eigenvalue analysis, and damping system. From the simulation result, it can be obtained optimal SMIB system performance with a control method based on Capacitive Energy Storage-PID.

1. Introduction

Studying the dynamic behavior of the system means studying the dynamic behavior of all components of the electric power system such as generation, transmission and distribution. Learning the dynamic behavior of the system could not be separated from learning the control system with the main goal of managing the system to achieve the most desired dynamic behavior.

Improved dynamic performance of the Single Machine Infinite Bus (SMIB), which includes the frequency and angle of the rotor, due to changes in load and load shedding can be done by adding Capacitive Energy Storage (CES) based energy storage equipment and Proportional Integral Derivative (PID) controller. Therefore, a CES-PID-based control is proposed in this study to improve the stability of the SMIB electric power system. To obtain the optimal performance from the control method used, the CES-PID parameter was optimized using the Ant Colony Optimization (ACO) algorithm. ACO algorithm is an optimization method that is inspired by ant behavior in finding food sources in groups [1-3]. Implementation of ACO for optimizing control parameters in the SMIB has been carried out and resulted in optimal performance, as studied in [4]. References [5,6] also discuss the optimization of the power system stabilizer on SMIB using ACO.

Energy storages have been widely used in electric power systems, for example, Superconducting Magnetic Energy Storage (SMES) [7-11] and CES [12,13]. CES is a device that could store and release large amounts of power simultaneously. CES stores energy in the form of an electric field on a capacitor. In this study CES will be used to assists the SMIB system stability. The application of CES in the SMIB system has also been proposed in [14], where the study is focused on optimization of CES parameters using Particle Swarm Optimization with a case study of load changes in the SMIB.

2. Research Methods

2.1. System Modeling

System modeling consists of modeling SMIB, excitation, governor, turbine, CES. The system is modeled using Simulink Matlab.

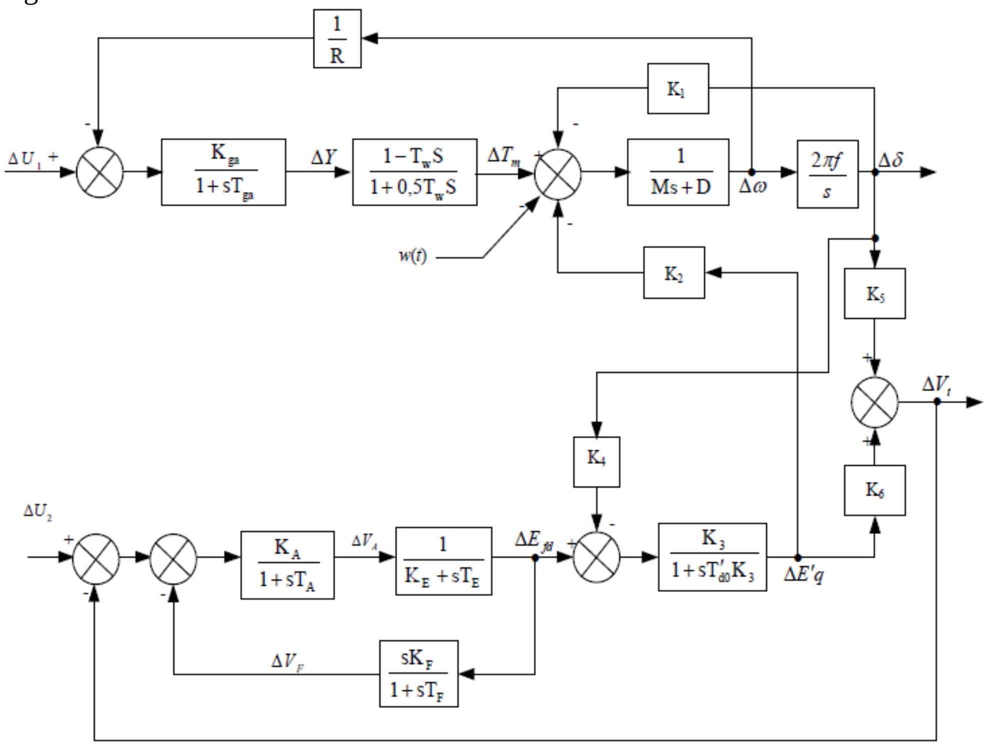

Figure 1. SMIB Model

Modeling CES is shown in Figure 2. CES is a device for storing and releasing large amounts of power simultaneously, in this study the CES-PID combination is used as a control for the SMIB system.

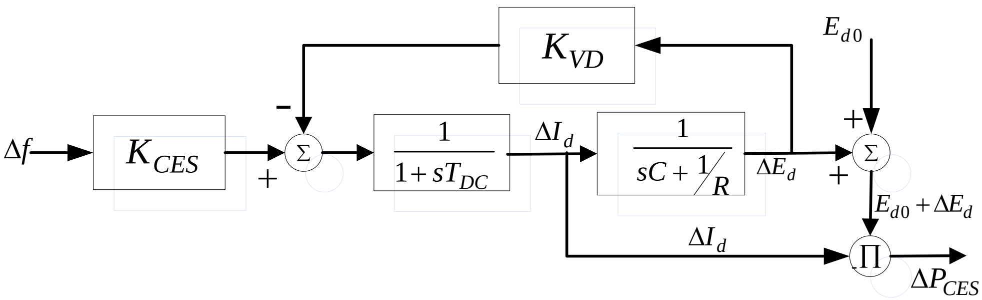

Figure 2. Block Diagram CES

2.2. Objective Function

To optimize problem using ACO, the problem must be converted to a combinatorial form. A graph generated to represent the problem into combinatorial form. To optimize the PID parameters, a graph generated as in Figure 3, where each parameter have specific constraint.

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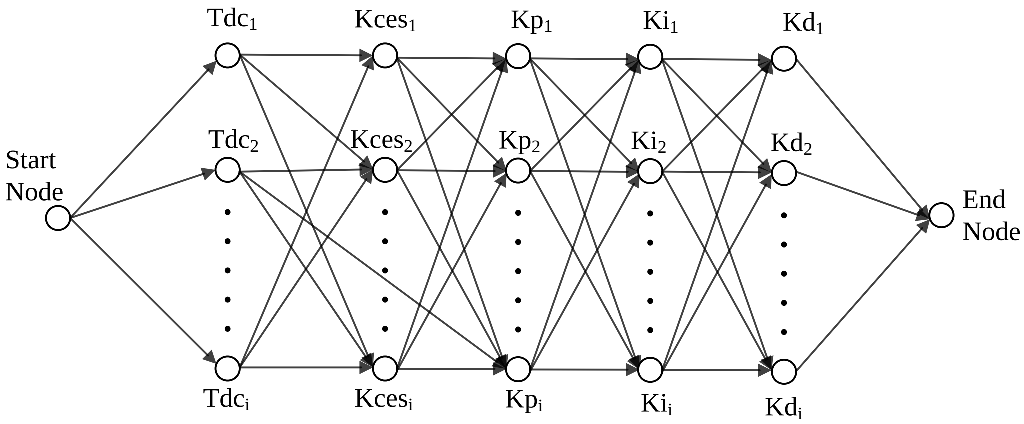

Figure 3. Graph of an ACO

PID parameters are assumed as the nodes that must be visited by the ants. The shortest path is assumed as the best combination of PID parameters. To get the best combination of PID parameters, it should be evaluated. The evaluation was done by calculating the value of objective function of the system response. In ACO, objective function is assumed by tour length of ants. The objective function has used in this research is Integral of Time Absolute Error (ITAE). ITAE is defined as follows:

$$\mathrm{ITAE} = \int_{0}^{t} t\left|\Delta\omega(t)\right|dt \tag{1}$$

3. Results

In this study the CES-PID controller parameters are optimized using ACO. To test the stability of the SMIB, the system is tested with the addition and load shedding on the SMIB system. The objective function used in this study is to minimize Integral Time Absolute Error (ITAE). CES-PIDS parameters tuned by ACO are Tdc, Kces, Kp, Ki, and Kd.

ACO optimization results obtained fitness function value of 2.5054e-07, with 50 iterations. The minimum value of the system performance function at each iteration is plotted on the convergence graph shown in Figure 4. In the figure it can be seen that the ACO algorithm can quickly converge on the 19^{th}iteration or find the most optimal value at the 19^{th} iteration. Elapsed time is 59.179148 seconds. From the results of ACO optimization, the optimal parameters are Tdc = 0.052, Kces = 85.7273, Kp = 1.7745, Ki = 0.0999, Kd = 0.0196.

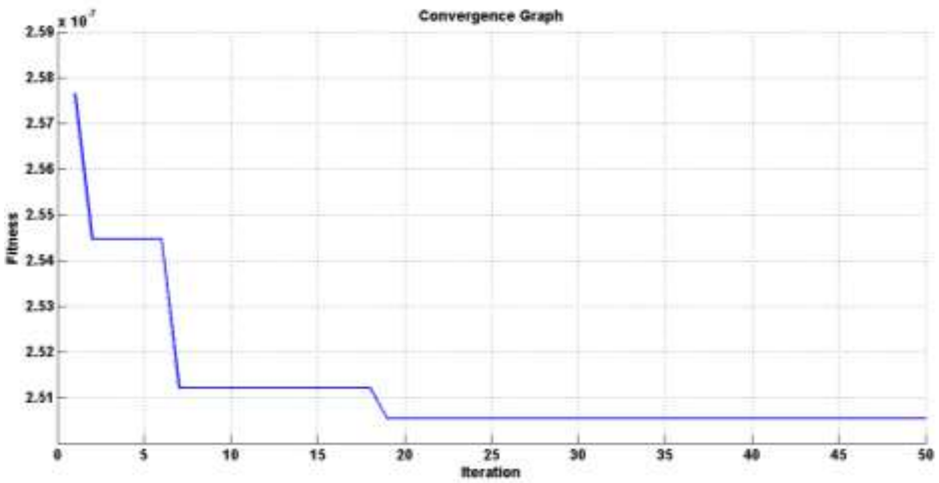

Figure 4. Ant colony optimization convergence process

3.1. Frequency Response

In this study, a control method in SMIB is proposed by using a combination of energy storage based on CES and PID. The CES-PID parameter is optimized using the ACO algorithm. To test the stability of the SMIB system with CES-PID, a load shedding case study was used.The system analysis reviewed is time domain simulation frequency response and rotor angle, eigenvalue analysis, and damping system.

The SMIB system was given a load change disturbance of 0.01 pu, then load shedding occurred in the 20th second of 0.005 pu. This causes the electrical power (Pe) to change. When load shedding occurs, the electrical power is not the same as the mechanical power (Pm) Pe<Pm, so the electrical torque and mechanical torque are not balanced. This condition causes the electrical frequency (Δf) to also change. During this instability the rotational speed of the rotor (Δω) becomes out of sync. In this condition the frequency response graphs go up before returning to steady state. The function of the control system is then needed to return to steady state. Figure 5 is a graph of the electrical frequency response of the system (Δf). From the graph shown it can be seen the comparison of overshoot and settling time of the system. Comparison of overshoot and settling time of the electrical frequency response of the system can be seen in Table 1.

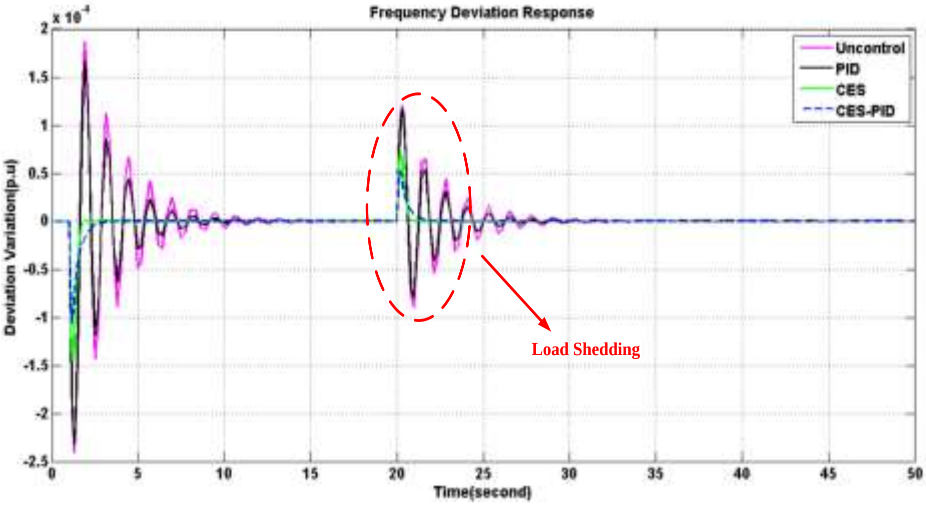

Figure 5. SMIB frequency response against load shedding

Table 1. Frequency deviation response

Frequency Deviation	Overshoot (p.u)	Settling Time (s)
SMIB	-0.0002405 & 0.0001869	15.09
PID	-0.0002322 & 0.000167	11.78
SMIB-CES	-0.0001449 & 7.26e-05	2.334
SMIB-CES-PID	-0.000106 & 5.195e-05	3.334

From the simulation results, the SMIB performance with CES-PID has the best overshoot and settling time values from other methods. An uncontrolled SMIB system has an overshoot of -0.0002405 to 0.0001869 pu with a settling time of 15.09 s. SMIB system with PID control obtained overshoot of -0.0002322 to 0.000167 pu with 11.78 s settling time. The SMIB system with CES control obtained overshoot of -0.0001449 to 7.26e-05 pu with a 2.334 s settling time. Then with the proposed method using CES-PID, the smallest overshoot is obtained from -0.000106 to 5.195e-05 pu with a settling time of 3.334 s.

3.2. Rotor Angle Response

In the rotor angle response, if the mechanical power of the generator is less than the electrical power, it can cause a slowdown in the rotor, slowing the rotor will also affect the rotor angle changes, so that the rotor angle response will rise or positive from the condition before the disturbance. This happens because the magnetic coupling will push the stator field with the rotor field, so that the rotor angle of the generator will rise, as shown in Figure 6. The observed response of the change in rotor angle is the overshoot value and settling time, as shown in Table 2. Eigenvalue characteristics and the resulting damping system for each method is shown in Table 3.

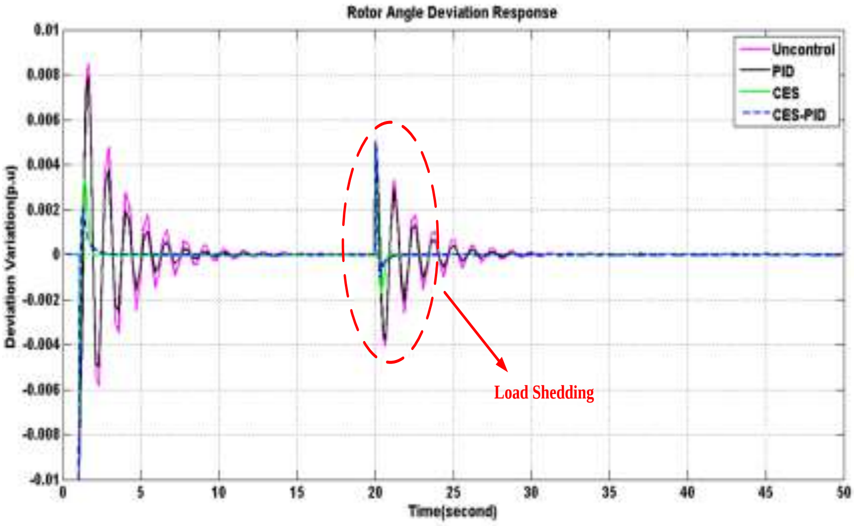

Figure 6. SMIB rotor angle response against load shedding

Table 2. Rotor angle deviation response against load shedding

Frequency Deviation	Overshoot (p.u)	Settling Time (s)
SMIB	-0.01 & 0.008482	15.57
PID	-0.01 & 0.00786	11.78
SMIB-CES	-0.01 & 0.005	2.334
SMIB-CES-PID	-0.01 & 0.005001	2.7

From the simulation results, the SMIB performance with CES-PID has the best overshoot and settling time values from other methods. An uncontrolled SMIB system has an overshoot of -0.01 to 0.008482 pu with a settling time of 15.57s. SMIB system with PID control obtained overshoot of -0.01 to 0.00786 pu with 11.78 s settling time. The SMIB system with CES control obtained overshoot of -0.01 to 0.005 pu with a 2.334 s settling time. Then with the proposed method using CES-PID, the smallest overshoot is obtained from -0.01 to 0.005001 pu with a settling time of 2.7s.

3.3. Eigenvalue Analysis

Table 3 shows the acquisition of damping ratio for each SMIB control method. From the simulation results obtained by the CES-PID method produces a good damping ratio compared to other methods. System analysis is also reviewed from the characteristics of the eigenvalue system, where from the analysis results we get a more negative eigenvalue, which indicates the system is more stable, as shown in Table 4.

Tabel 3. Damping ratio

Uncontrol	PID	CES	CES-PID
7.87e-02	9.59e-01	9.79e-01	6.14e-01
7.87e-02	9.59e-01	9.79e-01	6.14e-01
9.59e-01	1.03e-01	6.30e-01	9.36e-01
9.59e-01	1.03e-01	6.30e-01	9.36e-01
	1.00e+00	1.00e+00	1.00e+00
		1.00e+00	1.00e+00

1.00e+00

Tabel 4. Eigenvalue

Uncontrol	PID	CES	CES-PID
-3.97e-01 + 5.03e+00i	-9.64e+00 + 2.84e+00i	-1.26e+01 + 2.61e+00i	-7.83e+00 + 1.01e+01i
-3.97e-01 - 5.03e+00i	-9.64e+00 - 2.84e+00i	-1.26e+01 - 2.61e+00i	-7.83e+00 - 1.01e+01i
-9.66e+00 + 2.85e+00i	-5.19e-01 + 5.03e+00i	-4.99e+00 + 6.14e+00i	-1.10e+01 + 4.13e+00i
-9.66e+00 - 2.85e+00i	-5.19e-01 - 5.03e+00i	-4.99e+00 - 6.14e+00i	-1.10e+01 - 4.13e+00i
	-6.94e-18	-4.85e+00	-2.23e+00
		-1.13e-01	-1.13e-01
			-2.61e-17

4. Conclusion

From the analysis results, the optimal SMIB system performance is obtained by installing a Capacitive Energy Storage-PID-based control that is optimized using the Ant Colony Optimization (ACO) algorithm. ACO optimization results obtained fitness function value of 2.5054e-07, with 50 iterations. ACO algorithm can quickly convert, ACO finds the most optimal value at the 19th iteration. Elapsed time is 59.179148 seconds. System performance with the proposed method, can reduce frequency overshoot oscillation and rotor angle oscillation, with two case studies used namely, the addition of load and load shedding. From the simulation results obtained by the CES-PID method produces a good damping ratio compared to other methods. The system analysis is also reviewed from the characteristics of the eigenvalue system, where the results of the analysis show a more negative eigenvalue, which indicates the system is more stable.

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