Superconducting Magnetic Energy Storage Optimization for Load Frequency Control in Micro Hydro Power Plant using Imperialist Competitive Algorithm

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Abstract

This research proposes an additional controller for load frequency control at a micro hydro power plant using PID-SMES. The PID-SMES parameters are optimized using smart methods, Imperialist Competitive Algorithms (ICA), which can find the optimal value of PID-SMES. From the analysis results, obtained on the P controller, overshoot of -0.0002176, with PI Controller -0.0002167, with PD Controller -0.0002128, with PID controller -0.0002118, with SMES controller -0.0001951, and with PID-SMES -4.11e-05. ICA optimization results obtained fitness function value of 1.79846040002633e-08, with 40 iterations. The minimum value of the system performance function at each iteration is plotted on the convergence graph shown. In the Figure it can be seen that the ICA algorithm can quickly converge on the 14th iteration or find the most optimal value at the 7th iteration. The PID-SMES controller proposed in this study has a significant influence in the damping of the oscillations. Therefore, it is proposed to be applied to micro-hydro.

1. Introduction

LFC mechanism is designed using Superconducting Magnetic Energy Storage (SMES). SMES provides energy storage systems that can operate quickly and automatically. Optimal optimization of SMES parameters is required for optimal SMES performance. Therefore, this research is proposed using Imperialist Competitive

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Algorithm (ICA) method for tuning PID-SMES parameters.

In some previous studies, many researchers have discussed the application of SMES on electric power systems, such as [1], [2] which discussed SMES applications on wind turbines. [3] discusses SMES applications on smart grids. The SMES application as a frequency controller in power system has also been discussed, such as [4], [5], [6]. [7] on thermal power plants. Optimization of SMES parameters using intelligent methods discussed by [8], [9] using Fuzzy Logic. From some of the studies above, it can be concluded that the SMES application is very good at controlling, and by tuning the right parameters that is by using smart methods, it will get an optimal system control performance. For this reason, this study will discuss the application of SMES controllers for regulating the load frequency in micro hydro generators using tuning using ICA-based intelligent methods. The application of smart methods is increasing and shows satisfactory results [10-12].

The Imperialist Competitive Algorithm (ICA) method is a computational algorithm that is inspired by the royal competition in seizing power from a region. The ICA algorithm will work based on Objective Function, which minimizes Integral Time Absolute Error (ITAE). Implementation of ICA has also been widely used, because the results are very optimal in doing the computation process, some of these studies [13] for Power System Stabilizer, [14] for pendulum control, [15] for SMES control.

2. System Modeling

2.1. Hydro Micro Power Plant

Micro hydro power plant is one of the renewable power plant, which utilizes the height difference and the amount of water discharge. Water discharge can be sourced from irrigation channel, river or waterfalls. This water flow will rotate the turbine shaft to produce mechanical energy. This energy then drives the generator and generates electricity. The best location for the installation of micro hydro power plants is the location that has a source of water whose water flow always flows throughout the year. Theoretically, the value of electric power that can be generated by a micro hydro power plant depends heavily on the value of the water discharge passing through the pipe Q and also the high waterfall H. The equation is as follows:

$$P_{th}[W] = Q[m^3/s].H[m].k[N/kg] \qquad (1)$$

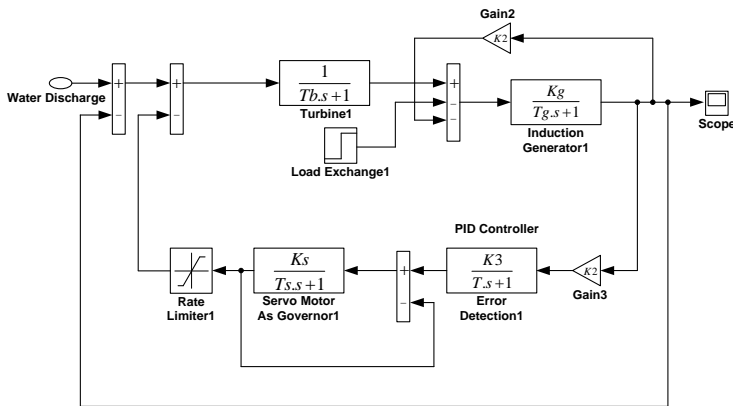The following figure shows the configuration of the designed micro hydro power plant.

Fig.1. Micro Hydro Block Diagram [16]

Superconducting Magnetic Energy Storage Optimization for Load Frequency Control in
Micro Hydro Power Plant using Imperialist Competitive Algorithm

3

From the error detection block, the signal Δω will be forwarded to the servomotor block used as the governor. In this block there are parameters that is Ks and Ts. As for the output side of the governor there is a signal that is fed back as an input value to the governor. Also the output of the governor is passed to a rate limiter which serves to limit the signal at the highest and lowest saturation value that has been determined. From the output of this limiter rate, it is forwarded as input on the water turbine block. Table 1 below shows the micro hydro parameters used in this study.

Table 1. Micro Hydro Parameters [16]

Parameters	Values	Notes
Tb	1	Water turbine time response (s)
Kg	1	Strengthening the generator regulator (s)
Tg	13,333	Response time induction generator (s)
K1	5	Error Detection confirmation constant
K2	8,52	Frequency deviation constant
K3	0.004	Strengthening Error Detection
T	0,02	Time response Error Detection
Ts	0,1	The governor's time constant (s)
Ks	2,5	Strengthening governor
Sg	40	Micro hydro power generator rating (kVA)
pf	0,8	Power factor
Vg	400/231	Nominal voltage generator (V)
ω	1500	Nominal rotational speed (rpm)
fg	50	The nominal frequency of micro hydro (Hz)

2.2. Superconducting Magnetic Energy Storage (SMES)

SMES is an equipment that can store and release large amounts of power simultaneously. SMES stores energy in magnetic fields created by DC currents on superconducting coils. SMES consists of superconducting coils, cyrogenic cooling systems, and power conditioning systems (PCS) with control and protection functions. PCS is also referred to as a power electronics hub of the SMES coil. Figure 2 shows the schematic diagram of SMES.

In principle, superconductors have near-zero losses at cold temperatures. The coolant used is Helium liquid which is able to cool to 4 K. PCS is used to transfer energy from the SMES coil to the system. A PCS uses a dc link capacitor to connect the voltage source from the SMES coil to the system. The working principle of SMES is divided into three, namely the mode of charging, standby mode and discharging mode. The SMES performance setting is performed by adjusting the duty cycle (D) of the converter which in this case uses a Gate Turn Off (GTO) thyristor.
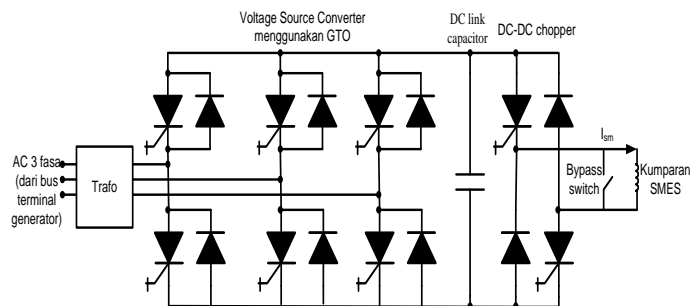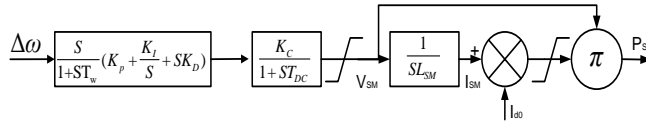

Fig.2. SMES Configuration

Fig.3. Block diagram of PID-SMES

3. Imperialist Competitive Algorithm (ICA)

Empire Initialization

In the optimization process, ICA forms an array of variable values to be optimized. In other intelligent algorithms, such as GA, this array is called a chromosome, so in ICA there is a state term. In a state defined as 1 x Nvar array. Some of the best countries will be chosen as imperialists to lead the empire.

The rest of the previous population will form colonies owned by the empire. An empire will consist of one imperialist and several colonies. The most powerful imperialist has the largest number of colonies. The ICA country initialization equation is as follows.

$$country = [P_1, P_2, P_3...P_{N_{var}}] \tag{2}$$

The above equation is the variable that will be optimized in this case PID. The cost of each country can be determined by evaluating the position of each country shown in the following equations,

$$cost = f(country) = f(P_1, P_2, P_3...P_{N_{var}}) \tag{3}$$

The division of the colony should be based on the strength of the imperialists. To divide the colony must be based on the proper imperialist, therefore the imperialist cost must be normalized first using the following equation.

$$C_n = c_n - \max_i \{c_i) \tag{4}$$

With cn is the cost of the nth imperialist, and C_n is the normalized cost. After that, the strength of each imperialist is defined as follows,

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \tag{5}$$

Number of initial colonies for n empire:

$$N.C._n = round\{P_n.N_{col}\} \tag{6}$$

$N.C._n$ is the initial number of colonies of the nth empire and N_{col} is the number of early colonies. The colony with the n imperialist will soon form the n empire. The empire will further form the initial empire as shown in Figure 4.
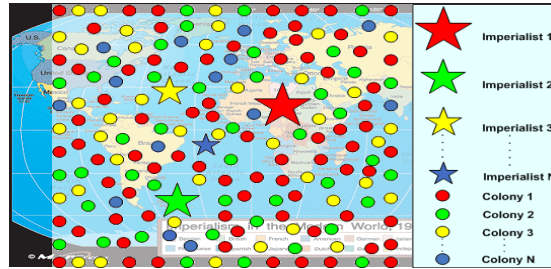
Superconducting Magnetic Energy Storage Optimization for Load Frequency Control in
Micro Hydro Power Plant using Imperialist Competitive Algorithm

5

Fig.4. Early Empire [15]

4. Result of Simulation and Analysis

The objective function used in this study is to minimize Integral Time Absolute Error (ITAE).

$$ITAE = \int_{0}^{t} t \left| \Delta\omega(t) \right| dt \tag{7}$$

SMES-PID parameters tuned by ICA are Kp, Ki, Kd, Tdci, twi, and Ksmes. The ICA parameter data and the ICA convergence graph are shown in Table 2 and Figure 5 below.

Table 2. ICA Parameter

Parameters	Values
Jumlah Countries	50
InitialImperialists	6
Decades	50
RevolutionRate	0.3
AssimilationCoefficient	2
AssimilationAngleCoefficient	0.5
Zeta	0.02
Damp Ratio	0.99
Uniting Threshold	0.02

ICA optimization results obtained fitness function value of 1.79846040002633e-08, with 40 iterations. The minimum value of the system performance function at each iteration is plotted on the convergence graph shown in Figure 5. In the Figure it can be seen that the ICA algorithm can quickly converge on the 14th iteration or find the most optimal value at the 7th iteration. Table 3 shows the value of SMES-PID parameter optimization results after tuning by ICA.

Table 3. Results of Tuning of SMES-PID Parameters

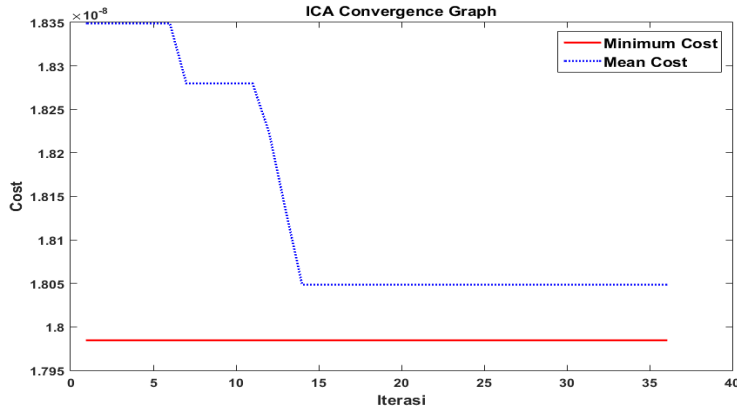| Parameter	Limits		Results
	Lower limit	Upper limit	
Kp	0	100	10.9266
Ki	0	1	0.4515
Kd	0	1	0.6588
Tdci	0	1	0.0196
twi	0	100	19.6067
Ksmes	0	100	80.2835

Source: Result Analysis

Fig.5. ICA Convergence

The first control design is to use a proportional controller for frequency control on micro hydro. Proportional controller parameters will be optimized using ICA methods. From the simulation results show a better response compared to the system without control, where the overshoot on this system is -0.0002176. Settling time is also increasingly showing good results, because the system returns to steady state conditions faster than before.

The next controller design uses a proportional-integral controller for frequency control on micro hydro. The proportional-integral controller parameters will be optimized using the ICA method. From the simulation results show a better response compared to the system without control and proportional, where the overshoot on this system is -0.0002167. Settling time is also increasingly showing good results, because the system returns to steady state conditions faster than before.

The proportional-derivative controller parameters will be optimized using the ICA method. From the simulation results show a better response compared to the previous controller, where the overshoot on this system is -0.0002128. Settling time is also increasingly showing good results, because the system returns to steady state conditions faster than before.

Based on the performance response of the frequency controller with the previous PI and PD, the performance of the controller can still be increased again with PID combination. The next controller design uses a proportional-integral-derivative (PID) controller for frequency control on micro hydro. The PID controller parameters will be optimized using the ICA method. From the simulation results show a better response compared to the previous controller, where the overshoot on this system is -0.0002118. Settling time is also increasingly showing good results, because the system returns to steady state conditions faster than before. It can be concluded that the combination of PID shows more satisfactory performance.

The next controller design uses Superconducting Magnetic Energy Storage (SMES) controllers. The SMES controller parameters will be optimized using the ICA method. The simulation results show a more satisfactory response than some previous controllers, where the overshoot on this system is -0.0001951. Settling time also shows good results, because the system returns to steady state conditions faster than before.

The next controller design uses a Superconducting Magnetic Energy Storage (SMES) based controller. From the results of the previous discussion, we can see a good response from the PID controller. Therefore, in this study, we proposed a new control method for micro hydro frequencies using a combination of PID-SMES. The PID-SMES controller parameters will be optimized using the ICA method. From the simulation results show a more satisfactory response than some previous controllers, where the overshoot on this system is -4.11e-05. Settling time also shows good results, because the system returns to steady state conditions faster than before. It can be concluded that the combination of PID-SMES shows more satisfactory performance. Comparison of micro hydro frequency response of all control methods, can be seen in Figure 6.

Superconducting Magnetic Energy Storage Optimization for Load Frequency Control in
Micro Hydro Power Plant using Imperialist Competitive Algorithm

7

Tabel 4. Overshoot and Settling Time Value

Characteristics	Overshoot (pu)
Uncontroll	-0.0003179
Proportional	-0.0002176
Proportional-Integral (PI)	-0.0002167
Proportional-Derivative (PD)	-0.0002128
Proportional-Integral-Derivative (PID)	-0.0002118
Superconducting Magnetic Energy Storage (SMES	-0.0001951
PID-SMES	-4.11e-05

The PID-SMES controller proposed in this study has a significant influence on the oscillation damping and is suitable for use in micro-hydro plants. The ICA method as an intelligent method inspired by power competition, can be a method for parameter optimization of PID and SMES. With optimal PID and SMES parameters, micro hydro performance will be more optimal in controlling the dynamics of load changes.
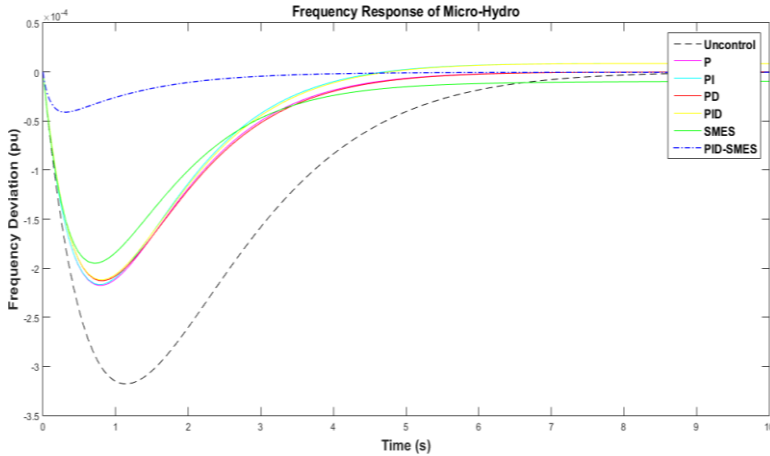

Fig.6. Micro Hydro Frequency Response Comparison

5. Conclusions

The PID-SMES parameters are optimized using smart methods, ICA algorithms, which can find the optimal value of PID-SMES. From the analysis results, obtained on the P controller, overshoot of -0.0002176, with PI Controller -0.0002167, with PD Controller -0.0002128, with PID controller -0.0002118, with SMES controller -0.0001951, and with PID-SMES -4.11e-05. The PID-SMES controller proposed in this study has a significant influence in the damping of the oscillations. Therefore, it is proposed to be applied to micro-hydro.

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