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Frequency stability improvement of micro hydro power system using hybrid SMES and CES based on Cuckoo search algorithm

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Abstract

Micro hydro has been chosen because it has advantages both economically, technically and as well as in terms of environmental friendliness. Micro hydro is suitable to be used in areas that difficult to be reached by the grid. Problems that often occur in the micro hydro system are not the constant rotation of the generator that caused by a change in load demand of the consumer. Thus causing frequency fluctuations in the system that can lead to damage both in the plant and in terms of consumer electrical appliances. The appropriate control technology should be taken to support the optimum performance of micro hydro. Therefore, this study will discuss a strategy of load frequency control by using Energy Storage. Superconducting magnetic energy storage (SMES) and capacitor energy storage (CES) are devices that can store energy in the form of a fast magnetic field in the superconducting coil. For the optimum performance, it is necessary to get the optimum tuning of SMES and CES parameters. The artificial intelligence methods, Cuckoo Search Algorithm (CSA) are used to obtain the optimum parameters in the micro hydro system. The simulation results show that the application of the CSA that use to tune the parameters of hybrid SMES-CES-PID can reduce overshoot oscillation of frequency response in micro hydro power plant.

Keywords: Micro hydro; superconducting magnetic-capacitive energy storage; Cuckoo; overshoot.

I. Introduction

Development of micro hydro power plant is one of the government policies for improving the economic and social conditions of rural communities. In this case, the provision of electric power in the countryside is one of the solutions to enhance the social and economic conditions in the rural area. Therefore, it is necessary to develop and utilize new and renewable energy sources by sticking to the principle of economically profitable, technically feasible, socially acceptable culture, and not causing environmental damage. Hence, micro hydro is one of the power plants that can achieve such as requirements.

One of the most important aspects of the power system is the frequency. The frequency has to be maintained according to the system requirement. The frequency generated by the micro hydro generator is greatly influenced by the rotational speed of the generator. Moreover, the rotational speed of the generator is affected by the load changing. At night (above 23:00), ninety percent of homes turn off the lights, that makes the burden of the micro hydro is decreased. As a result, the frequency of the system will increase significantly. If the deviation of frequency is not well maintained, it will damage the electronic devices. Therefore, it is necessary to control frequency and load demand automatically. This method can be called as load frequency control (LFC) [1]. The LFC of micro hydro can be done by arranging the wicket gate of micro hydro to control the water flow to the micro hydro. However, due to increasing load demand and uncertainty of it, LFC alone is not enough to handle the problems. Hence, utilizing

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energy storage as an additional device to increase the frequency stability of micro hydro power system is essential.

The integration of energy storages has been increased significantly over the past few decade. There have been many application of energy storage on power sectors such as for voltage stability, small signal stability, and frequency stability. As reported by Hung *et al.*, the battery energy storage is used to stabilize the voltage stability on distribution system by considering high penetration of uncertainty photovoltaic plant [2]. Impact of integration of battery energy storage system (BESS) on electromechanical oscillations on the power system is reported by Setiadi *et al.* [3]. In this research, the variation of BESS proportional gain controller could change the dynamic characteristic of the power system. The influence of the large-scale battery energy storage system in the small signal stability of power system is reported by Setiadi *et al.* [4]. In that research, battery energy storage has a significant influence on local and inter-area oscillation. The application of redox flow batteries to enhance the frequency performance of power system is reported by Shankar *et al.* [5]. This research reports that the RFB has a huge influence on stabilizing the frequency performance of the power system.

The application of capacitor energy storage (CES) to stabilize the frequency performance of power systems is reported by Kumar *et al.* [6]. Moreover, the application of superconducting magnetic energy storage (SMES) for enhancing small disturbance angle stability of multi-machine power system is reported by Lastomo *et al.* [7]. However, very scant attention has been paid to integrate two different energy storages at the same time and assess the performance on frequency stability. Hence, it is important to conduct a deeper study on how the frequency performance of power system, especially in micro hydro power plant when two different energy storage is integrating at the same time. Other major issues are how to design the parameter of the energy storage and make it secure and reliable for providing active power to the system. Hence, the utilizing metaheuristic algorithm as optimization method can be a solution for designing energy storage parameter.

Metaheuristic algorithm can be classified based on the inspiration. There are a socially based inspiration, a physically based inspiration, and a biological based inspiration. In recent years, the application of metaheuristic based on biological inspiration such as particle swarm optimization and ant colony optimization are increasing significantly [8, 9]. However, those algorithms still have several drawbacks including long computation process and stuck at local optimum [10]. Hence, the deployment of a new and optimum algorithm such as cuckoo search algorithm (CSA) is crucial [11]. Hence, the novelty of this paper are: Investigating the frequency performance of micro hydro power plant, enhancement of frequency stability of micro hydro power plant using hybrid superconducting magnetic energy storage (SMES) and capacitor energy storage (CES), and utilizing CSA as optimization method for designing SMES and CES.

II. Fundamental theory

A. Micro hydro power plant

The working principle of micro hydro power plant is utilizing the waterfall flow of a river. Micro hydro turbine can generate the mechanical energy using water flow power. This mechanical energy will spin the generator to produce electricity. The mathematical representation of electric power that can be generated from micro hydro can be described as given in equation (1) [12].

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

where P_{th} and Q are active power generated from micro hydro and the amount of water flow to the turbine. H and k corresponded to the high of the water flow and gravitational constant. Moreover, completed representation of active power from the systems considering turbine ($\eta_{turbine}$) and generator (η_{gen}) efficiency can be described using equation (2) [12].

$$P_{real}[W] = Q[m^3/s].H[m].k[N/kg].\eta_{turbin}.\eta_{gen} \quad (2)$$

For frequency stability study, the micro hydro power plant modelled as linear system (Figure 1)

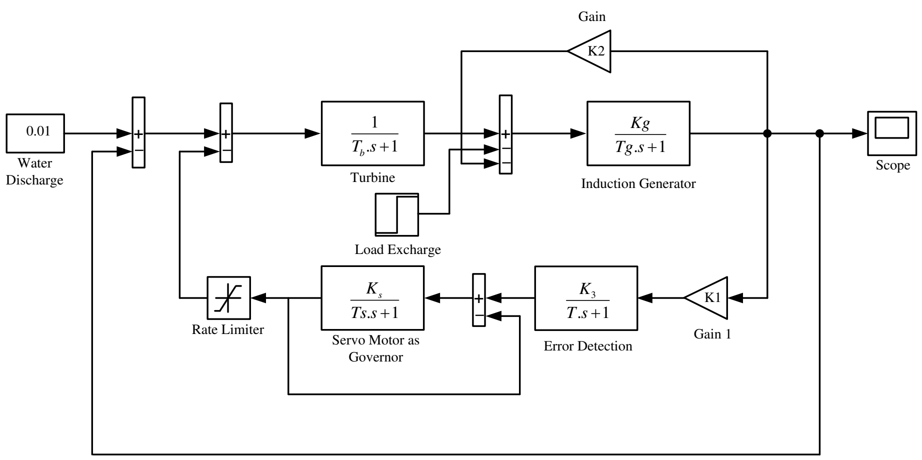

Figure 1. Block diagram of micro hydro

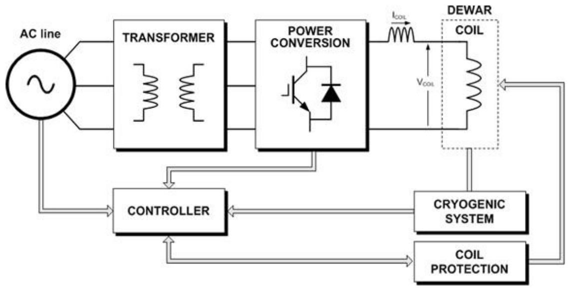

Figure 2. Schematic diagram of SMES

consists of induction generator, turbine, and servomotor as the governor [12].

B. Superconducting magnetic energy storage

Superconducting Magnetic Energy Storage (SMES) store energy in a magnetic field created by the DC current in superconducting coils cooled by cryogenic systems. SMES comprises of a superconducting coil, cryogenic cooling system, and a power conditioning system (PCS). PCS is referred as a power electronic interface between SMES coil and the grid. In principle, superconductors have losses almost zero at cold temperature. The cryogenic of SMES consist of liquid helium, which can maintain the temperature at 4 K. The PCS is used to transfer energy from the SMES coil towards the system. A dc link capacitor PCS uses to connect the source voltage of the SMES coil towards the system.

The working principle of SMES is divided into three, charging mode, standby mode, and discharging mode [13]. Setting performance of SMES is carried out by adjusting the duty cycle (D) of the converter which in this case using the Gate Turn Off (GTO) thyristors [14]. Figure 2 shows a schematic diagram of SMES while the mathematical representation of SMES can be described as given in equations (3) to (7).

$$V_{SM} = D * V_{DC} \quad (3)$$

$$-V_{SM} = (1-D) * V_{DC} \quad (4)$$

$$I_{SM} = \frac{1}{L_{SM}} \int_{t_0}^{t} V_{DC} d\tau + I_{SM0} \quad (5)$$

$$P_{SM} = V_{SM} I_{SM} \quad (6)$$

$$W_{SM} = \frac{1}{2} L_{SM} I_{SM}^2 \quad (7)$$

Equation (3) is SMES mode in charging mode, where V_{SM} is Voltage in SMES Coils, V_{DC} is Voltage in DC Link Capacitor and D is Duty Cycle. I_{SM0} is the initial current of the inductor. P_{SM} is power stored or transmitted by SMES. W_{SM} is the energy stored in the SMES coil. Then, equation (4) is a mathematical representation of SMES in discharging mode, while equation (5) is a representation of current SMES. Furthermore, equation (6) described energy from SMES, while equation (7) described the energy in SMES's coil. Figure 3 shows SMES configuration.

The parameters that are owned by the SMES is starting from the input side in the form of Δω. After that, the signal will enter the washout block where there is a washout time constant from SMES. It is then amplified by the SMES constantly reinforcing on the loop gain block. In this block, there is also a T_{DC} time delay constant from the SMES control device. The next step is to restrict the signal to the desired saturation conditions on the rate limiter. Next signal is forwarded to the transfer block function inductance SMES where there is a parameter of L_{SM}. The L_{SM} is then summed with I_{do} to produce the output. The resulting output, P_{SM}, is used as input (compensation) on the generator while waiting for the governor work.

SMES is placed at the bus terminal of the generator to control the balance of power in the generator effectively. The block diagram of SMES-PID can be made using several SMES equations from references, as shown in Figure 4 [14, 15].

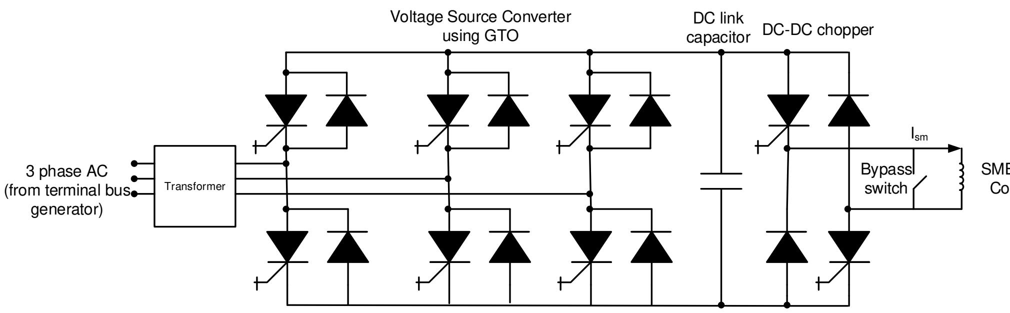

Figure 3. SMES configuration

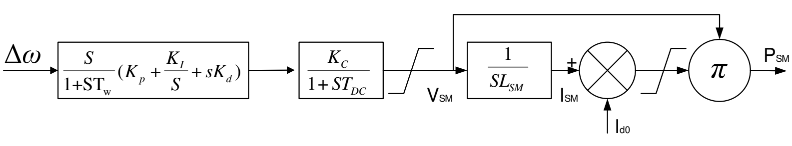

Figure 4. Block diagram of SMES-PID

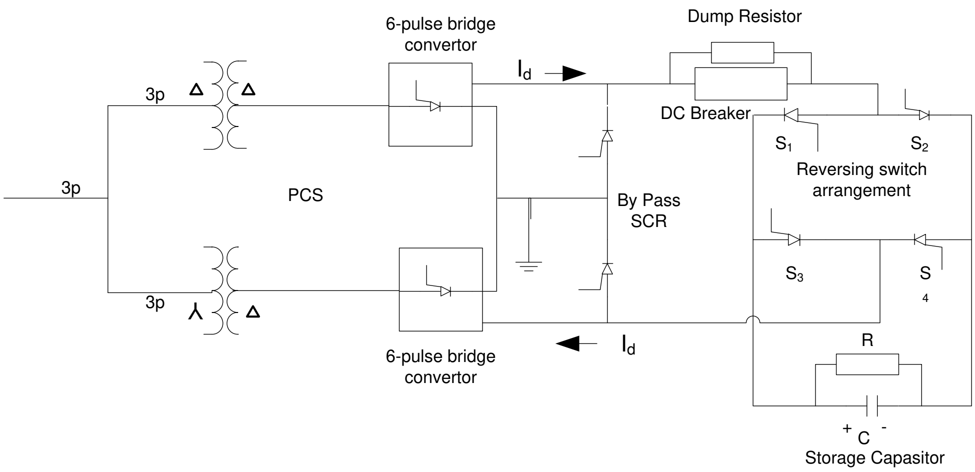

Figure 5. Schematic diagram of capacitor energy storage

C. Capacitor energy storage

Capacitor Energy Storage (CES) stores energy in the form of an electric field in the capacitor. A CES consists of a storage capacitor and PCS. Storage capacitor consists of several discrete capacitors connected in parallel with capacitance (*C*). Leaking losses and dielectric capacitor bank at CES modeled by a resistance (*R*) connected in parallel to the capacitor. Storage capacitor connected to the grid through the PCS 12-pulse. PCS consists of ac to dc rectifier and dc to ac inverter. Figure 5 shows the schematic diagram of CES [16, 17].

Thyristor bypass serves to provide a path for current flow (I_d) when converter failure occurs. DC breaker allows current (I_d) energy diverted to discharge energy of resistor R_D if the converter fails. By ignoring losses, bridge voltage (E_d) is as given in equation (8) and (9) [16, 17].

$$E_d = 2E_{d0}\cos\alpha - 2I_d R_D \quad (8)$$

$$E_{d0} = \frac{[E_{d\max}^2 + E_{d\min}^2]^{1/2}}{2} \quad (9)$$

In the case that perturbation occurs in the system, the capacitor voltage is too low and other disorders occur before the voltage back to normal values, the energy will be more withdrawn from the capacitor which can cause intermittent control. The limit for the capacitor voltage is 30% lower from the rating E_{d0} value to solve this problem. Hence, the mathematical representation can be described using equation (10) [16, 17].

$$E_{d\min} = 30E_{d0} \quad (10)$$

The operating point of the capacitor is such that the total energy absorbed which is equal to the amount of energy depleted. Initially, the capacitor is charged to its set E_{d0} value. The CES voltage must find the initial condition as soon as possible to maintain the performance of the system. Therefore, a negative feedback signal of capacitor voltage deviation is essential to achieve a fast response of CES. The block diagram of CES is depicted in Figure 6 [17, 18]. where the capacitor voltage deviation (ΔE_d) can be described as given in equation (11) [17, 18].

$$\Delta E_d = \left[\frac{1}{sC + 1/R}\right]\Delta I_d \quad (11)$$

Moreover, the CES power output injected into the system can be presented in equation (12) [17, 18].

$$\Delta P_{CES} = (E_{d0} + \Delta E_d)\Delta I_d \quad (12)$$

III. Design hybrid SMES and CES using Cuckoo search algorithm

This section provides a dynamic model of the overall system and Cuckoo search algorithm. At the end of this section, the objective function of the simulation is presented and the objective function will be achieved by using CSA.

A. Overall simulation

Based on the equations (1) to (12), the overall dynamic model of the entire system can be expressed in Figures 7 to Figure 9. Figure 7 illustrates the test system (micro hydro for frequency stability) with SMES and CES installed in the system. Figure 8 shows the dynamic model of CES in SIMULINK, while Figure 9 depicts a dynamic representation of SMES in SIMULINK.

In this research, all of the systems are expressed in the linear model. The parameter that will be optimized by CSA is the SMES and CES parameter.

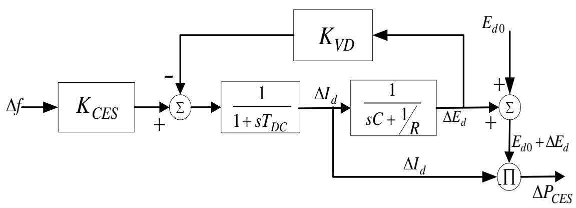

Figure 6. Block diagram CES

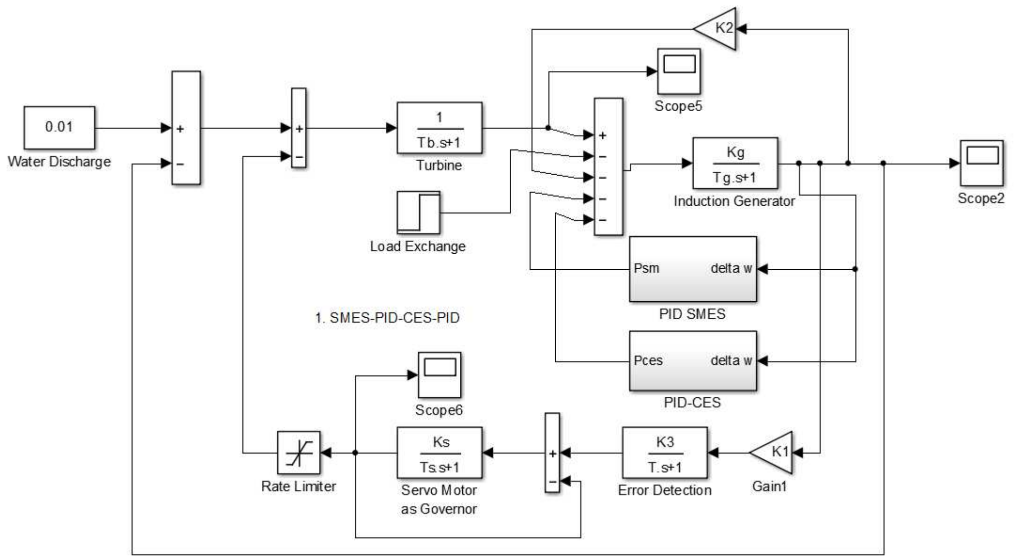

Figure 7. Simulink model of entire system

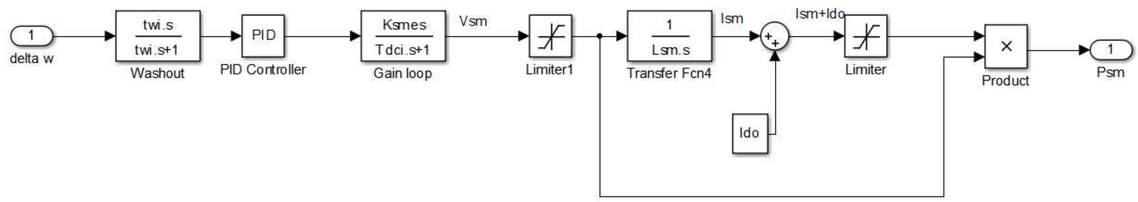

Figure 8. Simulink model of SMES

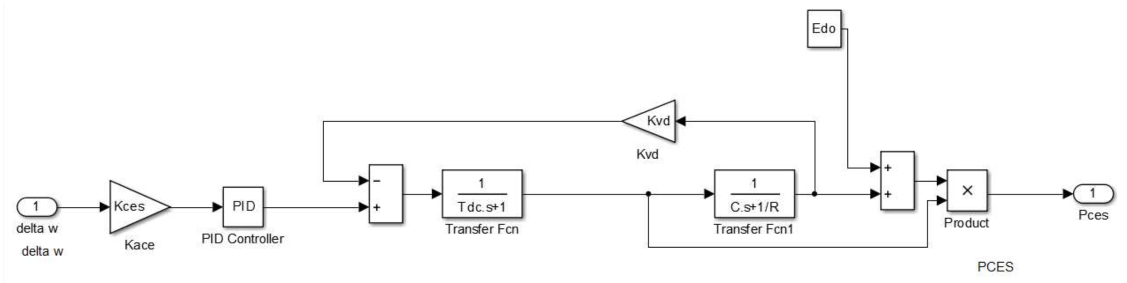

Figure 9. Simulink model of CES

B. Cuckoo search algorithm

The Cuckoo search algorithm is one of the metaheuristic algorithm developed by Xin She Yang *et al.* [19], inspired by the behavior of cuckoo bird in breeding. From all species of cuckoo, it is known that 59 of them are parasitic. They utilize breeding nests of other birds of different species to incubate their eggs. In fact, not infrequently cuckoo eggs were put on another cuckoo's nest [20, 21].

Several types of cuckoo throw eggs from the original parent at the nest to increase the likelihood of their eggs hatch. It may cause a conflict between the host and cuckoo birds when the cuckoo lays its eggs, so the bird hosts throw the cuckoo’s egg or leave their nests and then discard the new nest. Other parasitic behavior is when the cuckoo hatches, cuckoo eggs usually hatch earlier than the host bird eggs, the unhatched eggs were discharged from the cuckoo's nest for children to get more food [20, 21].

Figure 10 shows the Cuckoo algorithm process in finding the controller parameters. Starting from the initialization parameters, the optimization process, and finally the optimum parameter optimization results. The final rule can be simplified with the approach *pa* fraction of *n* nest replaced with a new nest (with new solutions at random). For maximizing problems, quality or fitness of a solution can be compared to the

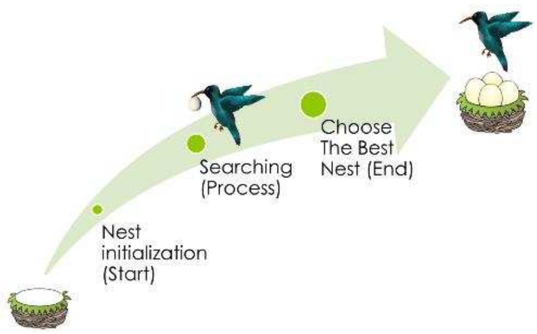

Figure 10. Cuckoo search algorithm process

value of the objective function. Other forms of fitness can be defined in the same manner as the fitness function in the genetic algorithm. For simplicity, it can use a simple representation that any eggs in the nest represent a solution, and the cuckoo egg represents a new solution, the aim is to use the potential of new and better solutions (cuckoos) to replace a solution that is not good on the nest. Then the eggs had to be evolved, the more eggs will replace other eggs as measured by fitness, like in GA [20, 21].

In a host nest, there can be two eggs, in other words, the nest can hold more than one solution only to simplify the problem, and a nest will only store one solution (eggs). Based on the three rules, the basic steps Cuckoo Search (CS) can be summarized as pseudo code below [20, 21].

```
Begin
   objective function f (x), x = (x
   1, ..., x) T
   Initialize the population of the
   target bird nest n xi (i = 1,2,
   ..., n)
While (t <generasiTotal) or (other
criteria to stop)
   Evaluation of the quality values
   of each cuckoo cuckoo
   Choose from randomly and do a
   random walk
if (Fi> Fj)
   Replace cuckoo cuckoo j with i
End If
   re Reset nests with the worst
   conditions (Pa)
   Save nests that survived sort and
   find the best solutions
End While
   process results and visualization
end
```

when the generation of new solutions $x (t + 1)$ for a i cuckoo, Levy flight is shown as follows: The mathematical representation to generate a new solution considering Levy flight can be described using equation (13) [20, 21].

$$x_i^{(t+1)} = x_i^{(t)} + \alpha \oplus Levy\ (\lambda) \quad (13)$$

In equation (13), $\alpha > 0$ is a measure of the stages that should be related to the scale of the problem of interest. In the most cases, the value of α is 1. Furthermore, the mathematical representation of Levy flight (random walk) can be defined using equation (14) [20, 21].

$$Levy \sim u = t^{-\lambda}, (1 < \lambda \leq 3) \quad (14)$$

C. Objective function

The Objective function that used is Integral Time Absolute Error (ITAE), where the CSA will be optimized all parameters by minimizing the frequency error of the micro hydro as described in equation (15).

$$ITAE = \int_0^t t\left|\Delta\omega(t)\right| dt \quad (15)$$

where $\Delta\omega$ is the frequency deviation of the system while t is the period of the simulation. Figure 11 shows the flowchart of the CSA for optimizing SMES and CES parameter. The parameter of SMES that will be optimized by CSA is K_{smes}, T_{dc}, T_w, K_p, K_i, and K_d, while the parameter of CES is K_{ces}, T_{dc}, K_p, K_i and K_d.

Table 1 shows the parameter of Cuckoo search algorithm (the parameter if Cuckoo search algorithm is a dimensionless parameter) on this paper while Table 2 shows the lower and upper limit of the SMES and CES parameter. The algorithm starts by initializing the micro hydro, SMES, CES, and CSA parameters followed by initializing the population of the host with the particular constraint. The next step is a random search of cuckoo by using Levy flight function. Evaluation of the objective function is done by using ITAE of the frequency micro hydro. The process is continued by finding the best nest by using random process. The cuckoo will remove the Pa from the worst nest and put that Pa to the new nest. If the criteria are not satisfied, then the algorithm will be back to the initializing process. The algorithm will loop the process until the criteria is satisfied, in this paper the criteria is the max generation.

Table 1.
Parameters of Cuckoo search algorithm.

Parameter	Value
Number of nests	25
Discovery rate of alien eggs/solutions	0.25
Tolerance	1.0e-5
Max Generation	50
Number of Variable (nd)	11

Table 2.
Constraints of CSA

Parameters	Lower	Upper
CES		
K_{ces}	80	90
T_{dc}	0.03	0.06
K_p	10	15
K_i	0.1	0.5
K_d	0	1
SMES		
T_{dc}	0.01	0.03
T_w	15	30
K_{smes}	70	90
K_p	35	40
K_i	0	1
K_d	0	0.1

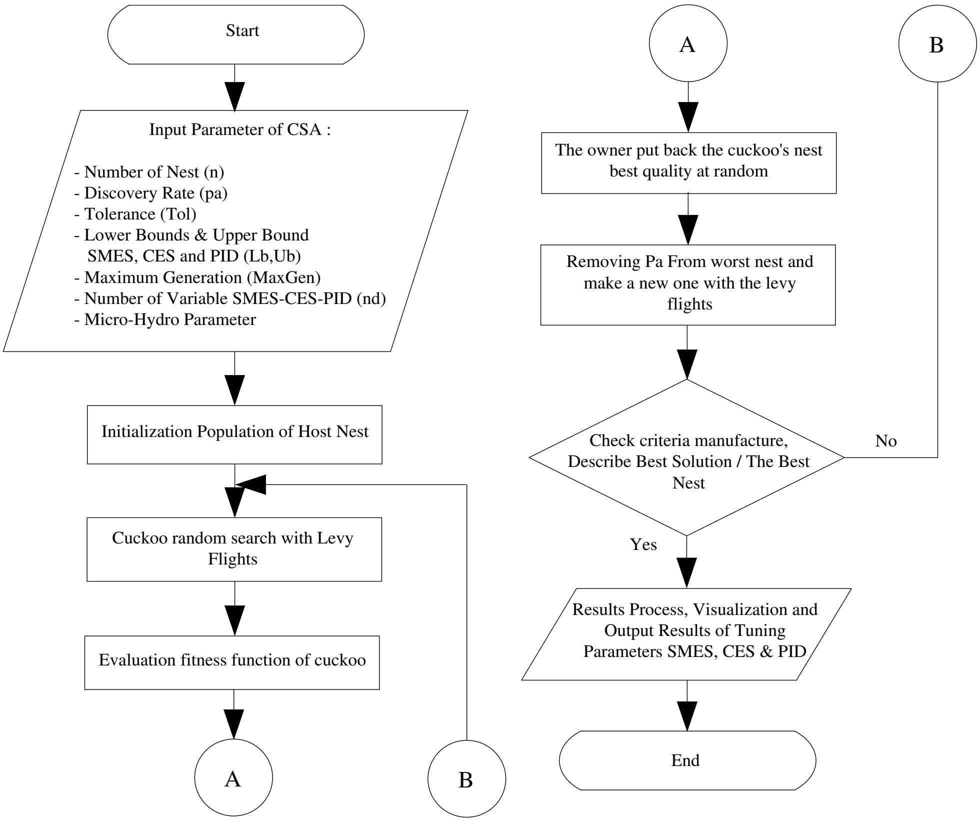

Figure 11. Flowchart of the CSA for optimizing CES and SMES

IV. Result and discussion

In this paper, three sections are reported in an attempt to investigate the enhancement of frequency stability using the proposed method. A load frequency control model of the micro hydro power system is used in this study. The case study was carried on MATLAB/SIMULINK environmental. Table 3 shows the dynamic data of micro hydro [22], SMES, and CES used in this paper while Table 4 illustrates the optimized parameter of SMES and CES using CSA.

Table 3.
Dynamic data of the test system [22]

Parameter	Value
Tb	1
Kg	1
Tg	13,333
K1	5
K2	8,52
K3	0.004
T	0,02
Ts	0,1
Ks	2,5
Sg	40
pf	0,8
Vg	400/231
ω	1500
fg	50

A. Governor time domain response

This section is focusing on analyzing the governor response of micro hydro under different scenarios due to the small load perturbation. Figure 12 illustrates the governor response of micro hydro under different scenarios. It can be seen that by adding additional devices such as SMES, and CES, the overshoot of the governor response was decreased.

Table 5 shows the detailed featured of overshoot of the micro hydro governor under different scenarios. It was observed that the best response was performed by system with SMES-PID-CES-PID indicated by smallest overshoot compared to the other scenarios.

Table 4.
Optimum parameter of SMES and CES

Parameters	CSA Result
CES	
K_{ces}	88.1472
T_{dc}	0.0572
K_p	10.6349
K_i	0.4654
K_d	0.6324
SMES	
T_{dc}	0.0120
T_w	19.1775
K_{smes}	80.9376
K_p	39.7875
K_i	0.9649
K_d	0.0158

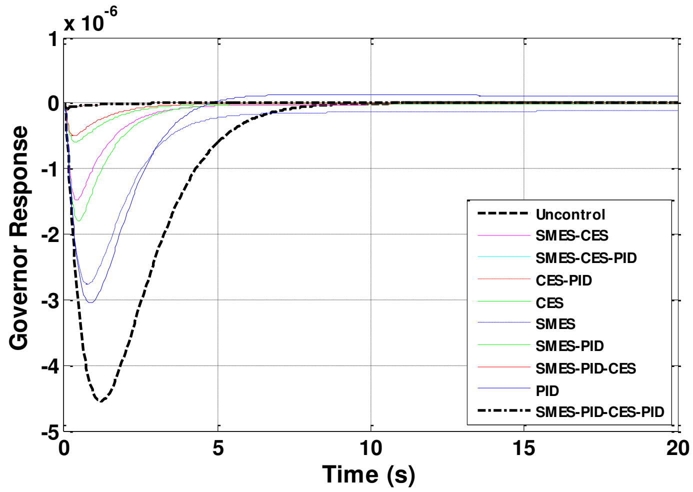

Figure 12. Governor response under different scenarios

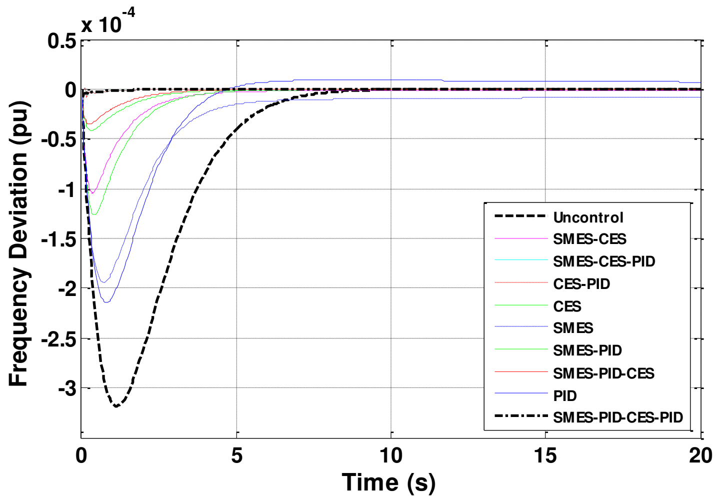

Figure 13. Frequency response under different scenarios

B. Frequency dynamic response

The time domain response of the frequency micro hydro could be performed by giving step input of small load disturbance in the system as shown in Figure 13. It was found that the frequency response of the system was increased when SMES and CES were installed on the system. This condition can be happened due to additional active power from CES and SMES.

It was also found that by adding PID controller on SMES and CES could also increase the frequency of the system. It could be happened due to additional control signals from PID that make SMES and CES able to give more detailed active power to the system when small perturbation occurs.

Table 6 illustrates the detailed features of overshoot of the micro hydro frequency response under different scenarios. It was observed that system

Table 5.
Overshoot of governor

Cases	Overshoot
Uncontrolled	-0.00000453
PID	-0.00000312
CES	-0.00000181
CES-PID	-0.00000023
SMES	-0.00000281
SMES-PID	-0.00000061
SMES-CES	-0.00000154
SMES-CES-PID	-0.00000013
SMES-PID-CES	-0.00000052
SMES-PID-CES-PID	-0.00000009

Table 6.
Overshoot of governor

Cases	Overshoot
Uncontrolled	-0.00031811
PID	-0.00021392
CES	-0.00012623
CES-PID	-0.00001604
SMES	-0.00019384
SMES-PID	-0.00004173
SMES-CES	-0.00010412
SMES-CES-PID	-0.00001581
SMES-PID-CES	-0.00003552
SMES-PID-CES-PID	-0.00000983

with hybrid SMES-PID and CES-PID experienced lower overshoot compared to the other scenarios. Moreover, SMES and CES could store and release active power from the system depending on the condition of the load. If the load was increased, then SMES and CES will release (discharging) active power to the system, so the burden of the system is decreased (the system will experience lower overshoot). In contrary, if the load was decreased, the SMES and CES will store (charging) surplus active power from the system.

V. Conclusion

This paper proposed a method to enhance the frequency performance of micro hydro power system using hybrid SMES and CES based on CSA. From the investigated case study, it is found that by adding SMES and CES can enhance the frequency performance of the micro hydro power systems. It is also observed that the best performance is shown by the system with proposed method (hybrid SMES and CES based on CSA) indicated by the smallest overshoot and fastest settling from all of the scenarios.

Further research needs to be conducted to analyze the impact of integrating SMES – CES hybrid in larger system, such as load frequency control of two or more power systems. High penetration of renewable energy sources in frequency stability domain can be considered to analyze the significant impact of integrating SMES – CES hybrid. Moreover, employing another metaheuristic algorithm such as grey wolf algorithm, whale algorithm, and social spider algorithm can be considered to get better parameter of SMES and CES.

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References

[1] M. Abdillah *et al.*, "Optimal selection of LQR parameter using AIS for LFC in a multi-area power system," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 7, pp. 93-104, 2016.

[2] D. Q. Hung *et al.*, "Integration of PV and BES units in commercial distribution systems considering energy loss and voltage stability," *Applied Energy*, vol. 113, pp. 1162-1170, 2014.

[3] H. Setiadi *et al.*, "Impact of Battery Energy Storage Systems on Electromechanical Oscillations in Power Systems," in *2017 IEEE Power and Energy General Meeting*, Chicago, USA, 2017.

[4] H. Setiadi *et al.*, "Influence of BES system on local and inter-area oscillation of power system with high penetration of PV plants," in *Applied System Innovation (ICASI)*, 2017 International Conference on, 2017, pp. 1-4.

[5] R. Shankar *et al.*, "Impact of energy storage system on load frequency control for diverse sources of interconnected power system in deregulated power environment," *International Journal of Electrical Power & Energy Systems*, vol. 79, pp. 11-26, 7// 2016.

[6] N. V. Kumar and M. M. T. Ansari, "A new design of dual mode Type-II fuzzy logic load frequency controller for interconnected power systems with parallel AC–DC tie-lines and capacitor energy storage unit," *International Journal of Electrical Power & Energy Systems,* vol. 82, pp. 579-598, 2016.

[7] D. Lastomo *et al.*, "Optimization of SMES and TCSC using particle swarm optimization for oscillation mitigation in a multi machines power system," *Journal of Mechatronics, Electrical Power, and Vehicular Technology*, vol. 8, pp. 11-21, 2017.

[8] D. Lastomo *et al.*, "Enabling PID and SSSC for Load Frequency Control using Particle Swarm Optimization," in *2017 3rd International Conference on Science in Information Technology (ICSITech)*, 2017.

[9] M. Taufik *et al.*, "Small-Disturbance Angle Stability Enhancement using Intelligent Redox Flow Batteries," in *2017 4th International Conference on Electrical Engineering, Computer Science and Informatics (EECSI 2017)*, Yogyakarta, Indonesia, 2017.

[10] D. Lastomo *et al.*, "Small Signal Stability Enhancement of Hybrid Power System using RFB Tune with Craziness Particle Swarm Optimization," in *2017 3rd International Conference on Science in Information Technology (ICSITech)*, Bandung, Indonesia, 2017.

[11] M. R. Djalal *et al.*, "Desain Optimal Kontroler PID Motor DC Menggunakan Cuckoo Search Algorithm," *Prosiding SENTIA,* 2015.

[12] S. Doolla *et al.*, "Load frequency control of an isolated small hydro power plant using multi-pipe scheme," *Electric Power Components and Systems,* vol. 39, pp. 46-63, 2011.

[13] H. Setiadi and K. O. Jones, "Power System Design using Firefly Algorithm for Dynamic Stability Enhancement," *Indonesian Journal of Electrical Engineering and Computer Science,* vol. 1, pp. 446-455, 2016.

[14] W. Yao *et al.*, "Adaptive power oscillation damping controller of superconducting magnetic energy storage device for interarea oscillations in power system," *International Journal of Electrical Power & Energy Systems,* vol. 78, pp. 555-562, 2016.

[15] H. Shayeghi and H. Shayanfar, "Application of PSO for fuzzy load frequency design with considering superconducting magnetic energy storage," *International Journal on "Technical and Physical Problems of Engineering"(IJTPE),* vol. 2, pp. 24-33, 2010.

[16] M. R. Djalal *et al.*, "Frequency Control PLTMH dengan Capacitive Energy Storage menggunakan Cuckoo Search Algorithm," in *SENTIA 2015*, 2015.

[17] A. Chatterjee *et al.*, "Transient performance improvement of grid connected hydro system using distributed generation and capacitive energy storage unit," *International Journal of Electrical Power & Energy Systems,* vol. 43, pp. 210-221, 2012.

[18] D. Lastomo *et al.*, "The Effects of Energy Storage on Small Signal Stability of a Power System," in *2017 International Seminar on Technology and Its Application (ISITIA)*, Surabaya, Indonesia, 2017.

[19] S. M. Abd Elazim and E. S. Ali, "Optimal Power System Stabilizers design via Cuckoo Search algorithm," *International Journal of Electrical Power & Energy Systems,* vol. 75, pp. 99-107, 2016/02/01/ 2016.

[20] A. H. Gandomi *et al.*, "Cuckoo search algorithm: a metaheuristic approach to solve structural optimization problems," *Engineering with computers,* vol. 29, pp. 17-35, 2013.

[21] X.-S. Yang, *Cuckoo search and firefly algorithm: Theory and applications* vol. 516: Springer, 2013.

[22] I. T. Yuniahastuti *et al.*, "Load frequency control (LFC) of micro-hydro power plant with Capacitive Energy Storage (CES) using Bat Algorithm (BA)," in *Technology of Information and Communication (ISemantic), International Seminar on Application for*, 2016, pp. 147-151.