Optimal Design Capacitive Energy Storage (CES) for Load Frequency Control in Micro Hydro Power Plant Using Flower Pollination Algorithm

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Abstract— **The use of micro hydro power generation is increasingly chosen, because it has advantages economically, technically, and environmentally friendly. Operation of micro hydro requires appropriate control technology. Micro hydro is very suitable for use in areas that are difficult to reach the central power grid. A common problem with micro-hydro systems is the unstable turbine spin, caused by changes in loads from consumers. This causes a change in the frequency fluctuations in the system that can cause damage from the factory side and from the side of the consumer electrical appliances. Therefore, in this research we will discuss the strategy of load frequency control based on Capacitive Energy Storage (CES). CES is a tool that can store energy quickly and release energy in a certain time. In its use required proper adjustment for CES parameters. To obtain optimum CES parameter on micro hydro artificial intelligence method based on Flower Pollination Algorithm (FPA). The simulation results show that FPA application to test CES parameter add Proportional Integral Derivative (PID) controller to micro-hydro, can accelerate response time of change of frequency change and also increase overshoot frequency response system, that is equal to -2.325e 06 to 5,197e-07 pu.**

Keywords—CES, Flower Pollination Algorithm, Micro Hydro, PID, Overshoot

I. INTRODUCTION

Stability is a major concern in the planning of micro-hydro plants. The system must be in a stable state, the rotation speed of the generator is constant. The frequency generated by the micro-hydro generator is affected by load fluctuations. Load power will decrease at night, consequently will cause the wheel to spin faster. Electrical frequency will increase If the increase in frequency exceeds the standard limit will harm consumers. Setting or controlling system frequency due to load changes is necessary. Micro-hydro control will be carried out automatically by adjusting the governor's opening position. The falling water which has a potential energy of an elevation (H) with the flow of water (Q) flowing through the inlet pipe into the turbine house. Inside the turbine potential energy is converted into mechanical energy. The mechanical energy is converted into electrical energy by the generator. Changes in load power will affect the rotation of the generator so that the frequency of the generator will change. To reduce frequency oscillation, technology is needed to optimize micro-hydro power generation operations. Load Frequency Control will be designed using PID and CES, which has the ability to provide electric power compensation and reduce frequency oscillations. CES can store energy used as a power supply quickly. To obtain good frequency damping, optimal CES parameters are needed so that they can be used correctly on micro-hydro plants.

Therefore, this research is proposed using Flower Pollination Algorithm (FPA) method to set CES. As a complementary control, conventional Proportional Integral Derivative (PID) conventional controllers are used. Some conventional methods of controlling generators have been widely practiced, such as[1]. Several methods of Artificial Intelligence (AI) have been used as optimization [2,3]. In this study it has been proposed to optimize the value of control parameters, namely by conventional methods and artificial intelligence methods Particle Swarm Optimization (PSO) and Imperialists Competitive Algorithm (ICA), Firefly Algorithm [4], Particle Swarm Optimization [5], and Cuckoo Search Algorithm [6], but still has some weaknesses such as the old computing process. In this research will be used a new method with computation fast enough, that is by tuning method using FPA method. FPA is the metaheuristic algorithm that is inspired by pollination of flowers. This algorithm was first discovered by Dr. Xin-She Yang [7].

Application of Flower Pollination method in performing optimization shows good results, among others [8]. In this study, FPA is used to tune the optimal CES-PID parameters with the objective function to minimize the value of Integral Time Absolute Error (ITAE). Then analyzed the effect of the installation of PID-CES with FPA against dynamic stability in micro-hydro power plant system. CES is mounted on the induction generator feedback found on the micro-hydro system. The simulation results show the comparison of system

frequency response without the controller, using PID controller, and using CES controller. As a method of comparison used the intelligent method Particle Swarm Optimization (PSO). So that can be obtained by an optimal controller for micro-hydro.

II. SYSTEM MODELING

A. Micro Hydro Model

Micro-hydro power plants in terms of discharge per second available in irrigation channels, river or waterfalls [5]. The potential energy of the water flow will rotate the turbine shaft to produce mechanical energy. The mechanical energy of the turbine coupled with the generator drives the generator and generates electrical energy. The location of a good hydro-hydro power plant is a location that has a water source that always flows and has a large water discharge. Theoretically, the value of electric power generated by the generator depends on the value of the water discharge passing through the fast Q pipe and also the waterfall height H. The equation is as follows [5]:

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

The turbine efficiency in this research is 0.8 and the generator efficiency is 0.85. causes the value of the resulting electric power to be lower.

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

For pumps used as turbines, the efficiency values vary from 0.6 to 0.8. For cross-flow turbines, values vary from 0.5 to 0.7. While the generators used in micro hydro power systems here use induction generators, servo motors operated as governors, and some components are modeled on simulations using the MATLAB-SIMULINK program. The following figure shows the designed micro-hydro power plant configuration.
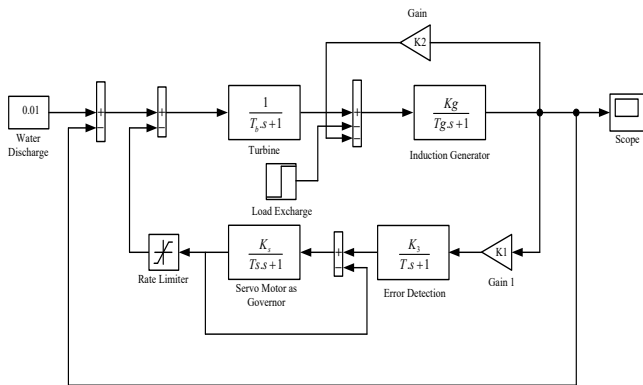

Fig. 1. Block diagram of Micro-hydro System

The signal change (Δω) will be forwarded to the servo motor block functioned as governor. The parameters required for signal strengthening are Ks and Ts. Output from the governor is passed to a limiter to limit excessive signals. Limiter is used to limit the highest and lowest saturation values in order not to exceed the specified value. The limiter output goes to the turbine block. The parameters used in this study; such as Strengthening governor, generator rating, power

factor, nominal voltage, nominal rotational speed, and nominal frequency can be seen on Table 1. [5]

TABLE I.   MICRO HYDRO PARAMETER

Parameter	Value	Item
Tb	1	Water turbine time response (s)
Kg	1	Reinforcement of inductor generator regulator (s)
Tg	13,333	Response time induction generator (s)
K1	5	Error Detection confirmation constant
K2	8,52	Frequency of 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)

B. Capacitive Energy Storage (CES)

CES is a device used to store and release large amounts of electrical power quickly. CES consist of Storage Capacitors (SC) and Power Conversion Systems (PCS)[9].
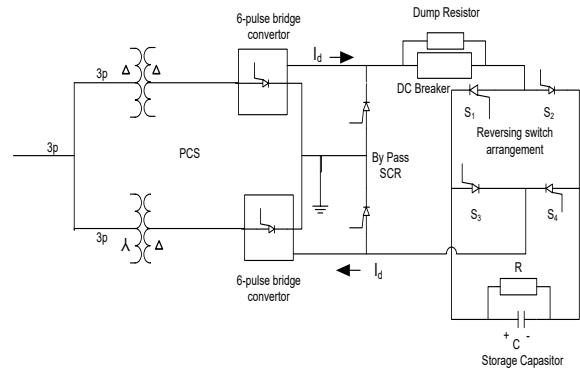

Fig. 2.   Capacitive Energy Storage

SC consist of discrete capacitors arranged in parallel. SC are connected via a 12-pulse Power Conversion System (PCS) to Mesh. The leakage and dielectric energy losses of the bank capacitor at CES are modeled by resistors R in parallel with the capacitor (C). PCS converts to DC and from DC to AC Inverter. Bypass Thyristor serves to provide the current path (Id) when the converter fails. The DC current breaker allows the current Id to be diverted to the resistor point of the Rd resistor if the converter fails. Regardless of the disadvantage, Ed's bridge voltage is like an equation,

$$E_d = 2E_{d0}\cos\alpha - 2I_d R_D \tag{3}$$

$$E_{d0} = \frac{[E_{d\max}^2 + E_{d\min}^2]^{1/2}}{2} \tag{4}$$

During interruption, the capacitor voltage becomes too low and the voltage will return to its normal value quickly. The energy will be absorbed by the capacitor and can cause the control to be disconnected. To solve this problem, the

lower limit for the capacitor voltage, taken 30% of the rating value (Ed0). Thereby,

$$E_{d\min} = 30 E_{d0} \qquad (5)$$

The change of voltage by the load at CES, should immediately return to its initial value so that it is ready to work for the next load power fluctuation.. Therefore, the voltage deviation of the capacitor is used as a negative feedback signal in the CES control loop so that fast voltage recovery is achieved.
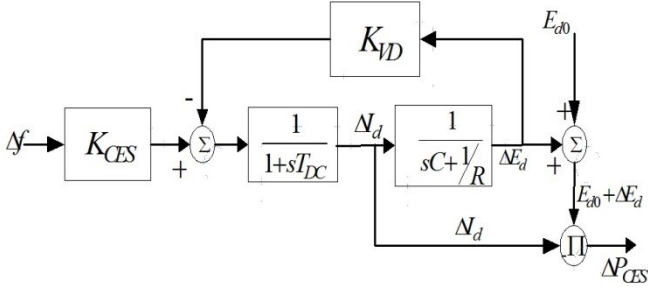

Fig. 3. CES Block diagram

The voltage deviation of the capacitor ΔE_d,

$$\Delta E_d = \left[\cfrac{1}{sC + \dfrac{1}{R}} \right] \Delta I_d \qquad (6)$$

CES output power released to the system during load changes is as follows,

$$\Delta P_{CES} = (E_{d0} + \Delta E_d).\Delta I_d \qquad (7)$$

III. FLOWER POLLINATION ALGORITHM (FPA)

FPA can be applied to maximize or minimize optimization problems. The rules of interest pollination algorithm are as follows [6]: Biotic pollination and cross-pollination are seen as global pollination, Abiotic pollination and self-pollination are seen as local pollination. The steps of the algorithm, ie; global pollination and local pollination. At the global pollination step, pollen from flowers is carried by pollinating animals like insects, and pollen can be carried away so that it moves into large areas. Flower constancy phenomenon can be represented mathematically as follows.

$$x_i^{t+1} = x_i^t + \gamma L (\lambda) (x_i^t - g^*) \qquad (8)$$

x_i^t is the pollen i or the solution vector x_i on the iteration t, and g^* is the best solution in the iteration. L is the power of pollination, which is basically a great step.

The PID and CES parameters tuned by FPA are *Kces_pso, Tdc, Kp, Ki,* and *Kd*. As for the flowchart, the process of tuning the parameters of PID-CES by using the FPA method is shown by a flowchart in Figure 4, as a comparison method used Particle Swarm Optimization (PSO) method.
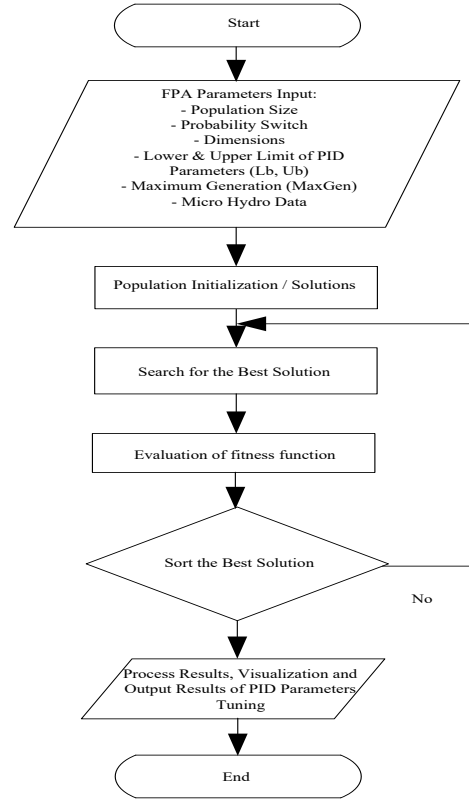

Fig. 4. Flowchart FPA Optimization

TABLE II.   ANALYSIS OF INTEREST ALGORITHM WITH OPTIMIZATION [6,7]

Optimization Problems:	
$\max or \min f(x_i), x_i = (x_1, x_2, ..., x_3) \in S^d \subset R^d, i = 1,2, ..., n$	
Pollination Phenomenon	Optimization Issues
Areas of Pollination Coverage	Value interval $S^d, x \in S^d$
Population of Interest	Solution Candidate $(x_1, x_2, ..., x_3)$
Interest rate match rate	Objective Function f
The event of pollination effort	Iteration
Flower Pollination Motion	Solution Search on Regional Definitions
Selected Individuals that match	Optimum State

TABLE III.   PSEUDO CODE FPA

Objective min or max $f(x), x = (x_1, x_2, ..., x_d)$
Initiation of n flower population as a random solution
Find the best solution g_* in the initial population
Define the switch probability $p \in [0,1]$
Define stop criteria (accuracy or maximum iteration)
    While (t < Maximum Iteration)
        For i=1:n(all n interest from the population)
            If rand < p,
Take a dimensionless step vector L that meets the global Pollination Levy distribution
$x_i^{t+1} = x_i^t + \gamma L (\lambda) (x_i^t - g^*)$
            Else
Take $\in$ from the uniform distribution (0,1)
Do local pollination $x_i^{t+1} = x_i^t + \in (x_j^t - x_k^t)$
            End if
Evaluate new solutions
If the new solution is better, update this solution into the population
        End for
Find the best solution g_*
    End while
Show the best solution found

A. CES Optimization with Flower Pollination Algorithm

Figure 4 shows FPA flow chart used in this study to tune Proportional Integral Derivative (PID) and Capacitive Energy Storage (CES) control parameters. Objective functions will be used as system stability testers with Integral Time Absolute Error (ITAE)[9]. The objective function will look for the correct parameters by minimizing Integral Time Absolute Error (ITAE).

$$ITAE = \int_0^t t|\Delta\omega(t)|dt \qquad (9)$$

As a comparison method used PSO method. PSO parameters are shown in the following table.

TABLE IV. PSO PARAMETER

Parameter	Value
Number of Particles	30
Max Iteration	50
Number of Variables	5
C2 (Social Constant)	2
C1 (Cognitive Constant)	2
W (Inertia Momentum)	0.9

The following optimization results with PSO method. [16]

TABLE V. PID OPTIMIZATION RESULTS WITH PSO

```
fitness =  1.6540e-10
Kces_pso = 69.4785
Tdc_pso = 0.01430
Kp_pso =  11.7909
Ki_pso =  1.7165
Kd_pso =  0.09166
```

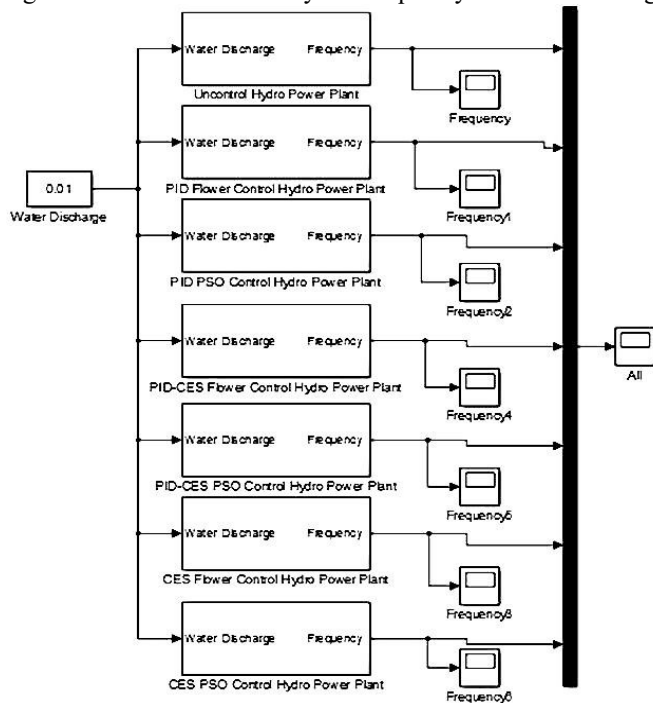Figure 5 shows the overall hydro-frequency control modeling.
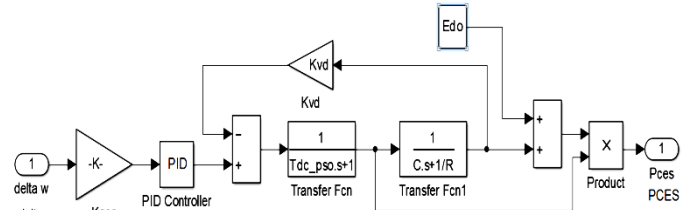
Fig. 5.   Micro hydro controller design

Fig. 6.   PID-CES controller design

Each without control, with PID, and with PID-CES combined. Each is optimized using FPA and PSO methods. Figure 6 shows the PID-CES controller modeling design on Matlab Software. This PID-CES parameter will be set using the FPA algorithm and the PSO comparison method.

IV. RESULTS AND ANALYSIS

Data from the following parameters, shown in Table 5, are used to optimize CES and PID parameters. For optimization results with FPA given in table 6.

TABLE VI. FPA OPTIMIZATION RESULT FOR CES-PID

```
Total number of evaluations: 100
bestsolution =
    88.8378  0.0563  63.6297  43.7886  9.6385
ans =
    88.8378  0.0563  63.6297  43.7886  9.6385
```

The result of FPA optimization is obtained by the value of fitness function 1.7085e-10, with 50 iterations, the best solution value is the best of pollination, which is known as CES and PID optimization parameter, ie *Kces, Tdc, Tw, Kp, Ki* and *Kd* for CES-PID parameters, Table 7 shows constraints and results.

TABLE VII. CONSTRAINTS AND TUNING RESULTS OF CSA

Parameter	Lower	Upper	FPA Result
Kces	0	100	88.8378
Tdc	0	10	0.0563
Kp	0	100	63.6297
Ki	0	100	43.7886
Kd	0	10	9.6385

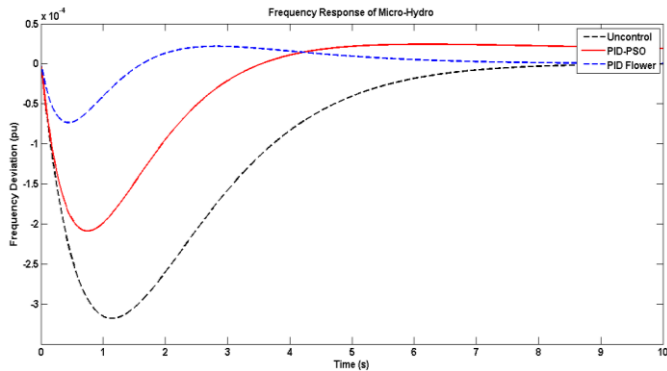Figure 7-10 shows the micro-hydro frequency response for each control design.

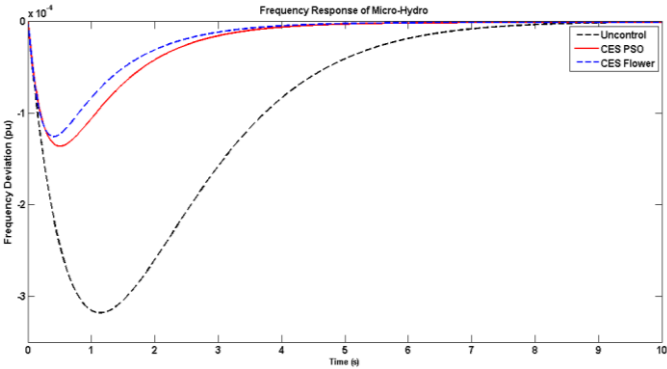Fig. 7. Micro Hydro Frequency with PID

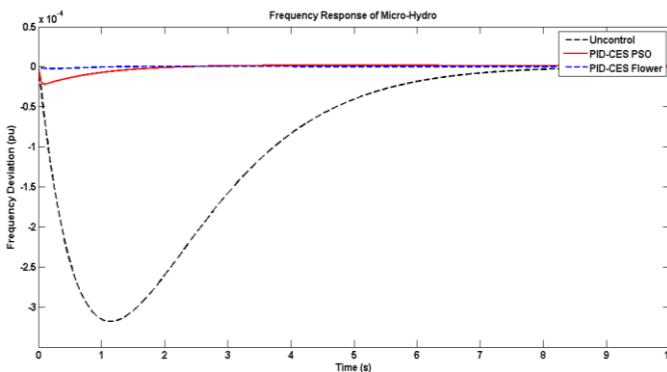Fig. 8. Micro Hydro Frequency with CES
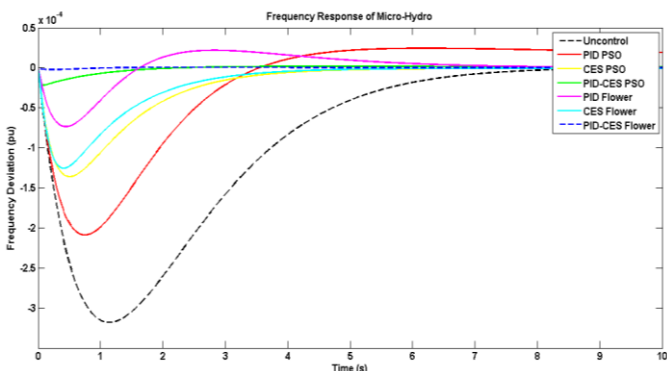

Fig. 9. Micro Hydro Frequency with PID-CES

Fig. 10. Plot All Graphic of Control Model

From Table 5, we can see the results of CES and PID tuning parameters. The simulations were performed using several control strategies for Micro-Hydro, ie without control, PID-PSO, PID-Flower, CES-PSO, CES-Flower, PID-CES-PSO and PID-CES-Flower. Figure 7-10 shows the frequency response of each micro hydro control strategy. where the best control strategy is Control Hybrid PID-CES-Flower. As shown in Figure 18, the proposed PID-CES-Flower method is given the best result to maintain the load frequency control of Micro Hydro Power Plant. The value obtained is a very small overshoot compared to other control models, which is about -2.325e-06 to 5,197e-07 pu, and completion time of about 1.5 seconds to go to steady state. The worst frequency response is shown in Figure 3, where the Micro-Hydro control is an open-loop or no-control system, where the overshoot is generated by -0.000318 to 0 pu and the settling time is about 8 seconds. Table 8 below shows the comparison of each type of control.

The development of further research is to combine several energy storage controllers such as Superconducting Magnetic Energy Storage (SMES) and combined with intelligent methods.

TABLE VIII. Overshoot Result of Each Model

Control	Overshoot
Uncontrol	-0.000318 & 0
PID PSO	-0.0002088 & 2.425e-05
PID Flower	-7.357e-05 & 2.174e-05
CES PSO	-0.000136 & 0
CES Flower	-0.0001255 & 0
PID-CES PSO	-2.18e-05 & 1.724e-06
PID-CES Flower	-2.325e-06 & 5.197e-07

V. Conclusion

By using Flower Pollination Algorithm (FPA) as the method of tuning the Capacitive Energy Storage (CES) controller, the result of tuning of CES parameter for Kces 88,8888, Tdc is 0.0563, Kp is 63.6297 and Ki is 43.7886, and Kd is 9.6385.

From the simulation result, it can be concluded that by using Capacitive Energy Storage (CES) controller in the designed Load Frequency Control (LFC) system, it can improve the frequency response of a Micro Hydro Power Plant system. This is indicated by the fast settling time value, as well as the overshoot value of -2.325e-06 to 5.197e-07 pu which is the smallest overshoot value of the other model.

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