Optimization of AVR in Micro-hydro Power Plant Using Differential Evolution (DE) Method

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Abstract

Micro-hydro Power Plant had three primary components: water (as the energy resource), turbine, and generator. Water that flew in a specific capacity was channeled from a certain height to the installation house (turbine house). In the powerhouse, the water installation pounded the turbine that made the turbine received direct energy from the water and turn it into mechanical energy and caused the turbine shaft to spin. Changes in the loading could cause fluctuation in the system's frequency and voltage. This problem could damage electrical equipment. Therefore, the Automatic Voltage Regulator (AVR) was used to control and stabilize the voltage. This research used PID controller to obtain the optimized control parameter in the Micro-hydro Power Plant. This research compared the simulations of without control method, with PID-ZN control method, and with PID-DE method to obtain the best control method. The comparison simulations showed that the best response in the micro-hydro plant and the AVR system was from the PID-DE controller. These results might be a reference for future research with other methods that might generate better results.

Keywords
AVR, Differential Evolution, micro-hydro, PID Controller

1. Introduction

Micro-hydro or Micro-hydro Power Plant is a small-scale power plant that uses water as the driving force such as irrigation channel, river, or natural waterfall, by utilizing the head and flow rate. Micro-hydro is a term that consists of the word micro, which means small and hydro, which means water. The common problem that occurred in the Micro-hydro Power Plant is inconstant generator rotation caused by changes in the connected load. Thus, it caused fluctuation in the system frequency and could damage the electrical equipment [1]. Electrical frequency and voltage generated by micro-hydro generators are heavily influenced by the rotation speed of the generator [2][3].

Meanwhile, the rotation speed of the generator is affected by the load. Therefore, frequency control is required in the working area. To date, Artificial Intelligent (AI) is often used to develop various knowledge such as vehicle steer control [4], wind turbine blade control [5], micro-hydro control [2][6], and DC motor speed control [7]. Some of those devices also use Differential Evolution (DE) method [8][9]. Hence, researchers were interested in experimenting with PID controller to optimize the AVR based on Differential Evolution (DE).

2. MICRO-HYDRO SYSTEM

2.1 Micro-hydro Power Plant

The Micro-hydro Power Plant system in this paper used an induction generator, a servo motor that served as the governor, modeled using the Matlab-Simulink program. Figure 1 shows the configuration of the micro-hydro plant in this research.
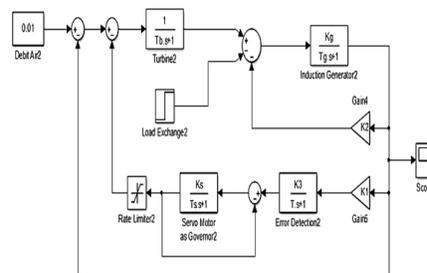

Figure 1.   Micro-hydro block diagram [10]

The Δω signal was passed on to the motor servo block, which served as the governor, from the error detection block. This block had Ks and Ts parameters. In the governor's output side, there was a signal that was fed back as the input value to the governor. The governor's output was passed on to the rate limiter that served to limit the sign at the highest and lowest saturation values. The output of the rate limiter, then forwarded as the input in the water turbine block [11][3].

2.2 Micro-hydro Power Plant Parameters

The above block diagram consists of parameters that display each part of the Micro-hydro Power Plant. The chart starts with the input system that obtained the value from the water flow rate to rotate the water turbine. The parameter continues to Water Turbine block with Tw parameter that converts the water energy that rotates the turbine into mechanical power, another input for the generator. From the error detection block, the signal is forwarded to the servomotor block that serves as the governor. This block has Ks and Ts parameters. In the governor's output side, there was a signal that was fed back as the input value to the governor. The governor's output was passed on to the rate limiter that serves to limit the sign at the highest and lowest saturation values. The output of rate limiter then forwarded as the input in water turbine block. Other than the pre-determined parameters, there is an input value to the generator from the load exchange or changes in load frequency. The input signal from the changes is a determining part of how the frequency controlling system works. Table 1 presents the micro-hydro parameter values.

TABLE I
Micro-hydro power plant parameters

	Value	Information
Tb	1	Water turbine response time (s)
Kg	1	Induction generator regulator reinforcement (s)
Tg	13.333	Induction generator response time (s)
K1	5	Error detection reinforcement constant
K2	8.52	Frequency deviation reinforcement constant
K3	0.004	Error detection regulator reinforcement
T	0.02	Error detection response time
Ts	0.1	Governor duration constant (s)
KS	2.5	Governor regulation reinforcement
Sg	40	Microhydro generator power rating (kVA)
pf	0.8	Power factor
Vg	400/231	The nominal voltage of the generator (V)
ω	1500	Nominal rotation speed (rpm)
fg	50	Nominal frequency of micro-hydro (Hz)

3. Method

3.1 PID Controller

PID controller is a combined control system between proportional, integral, and derivative control. In this method, the tuning is done in a closed-loop where the reference input uses step function. The controller in this method is only a proportional controller. Kp is increased from 0 up to the critical Kp, and thus, a continuous oscillating output is obtained with the same amplitude [12][13]. The critical Kp is called the ultimate gain. The ultimate period value, or Tu, is obtained after the system output reaches a continuous oscillating condition [14][6].

Ziegler Nichols Method

The first method is based on the plant's response to the open-loop input. Plant without integrator generates a response curve on the step input like the S curve in Figure 3. The plant's response curve is used to find the L delay time and T time constant [15].
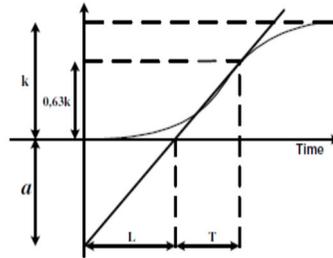
Figure 2.   S-shaped response curve

The parameters from the reaction curve are used to determine the parameters of the PID controller based on the Ziegler-Nichols empirical constant. Table 2 illustrates the formulas for controlling parameters using the reaction curve method.

TABLE 2
The first tuning from the Ziegler-Nichols method

Controller	Kp	Ti	Td
P	1/a	-	-
PI	0.9/a	3L	-
PID	1.2/a	2L	L/2

3.2 Differential Evolution (DE)

Differential Evolution (DE) is a method developed by Kenneth Price. This method is a mathematical optimization method of multidimensional functions and belongs to the evolutionary algorithm group. The DE method was started from the effort to solve the Chebychev polynomial fitting problem and generated the idea of using vector differences to randomize vector populations. In development, DE became one of the best genetical algorithms and could find multidimensional global optimum (i.e., shows more than one optimum value) with reasonable probability in the first ICEO (International Contest on Evolutionary Optimization). The advantage of DE compared to previous evolutionary algorithms is an evolution experienced by every individual in the population where differentiation and crossover occur sequentially at each random individual from the population at any time. Results of this variation are called a child or trial individuals that will replace parents in the population if the resulted fitness is better or same as what produced by the parents.

```
function hasil = DEport(N,D,CR,F)
%%% inisialisasi
    x = rand(N,D);
    while fnew > retTrue
fval = risk(x);
%%% mutasi−crossover
    v = r1 + F*(r2−r3);
    u(rd <= CR,:) = v(rd<=cr, :);
%%% seleksi
    fit = risk(u);
      if fit <= fval
      new_x = u;
      new_f = fit;
%%% update populasi
    fnew = minf;
    retTrue = xs’ * ret’;
    end
```

Figure 3.   DE pseudocode

4. Result

Micro-hydro or Micro-hydro Power Plant is a small-scale power plant that uses water as the driving force such as irrigation channel, river, or natural waterfall, by utilizing the head and flow rate. Micro-hydro is a term that consists of the word micro, which means small, and hydro, which means water. Technically, micro-hydro has three primary components, and they are water (as energy resource), turbine, and generator.
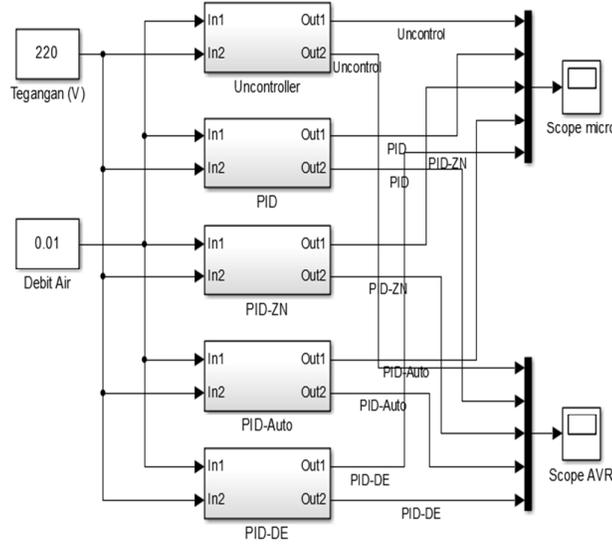
Figure 4.   Micro-hydro control design

Figure 5 presents the micro-hydro response system. Simulation without controller obtained 130 volts undershoots with 76 seconds settling time. Simulation with the standard PID controller gained 178 volts undershoots, 312 volts overshoots with 46 seconds settling time. Simulation with the PID controller using the Ziegler Nichols method obtained 218 volts undershoots, 228 volts overshoots with 22 seconds settling time. Simulation with PID controller with auto tunning obtained 219 volts undershoot, 243 volts overshoots with 28 seconds settling time. And simulation with PID-DE controller got 220 volts undershoots, 224 volts overshoots with 8 seconds settling time.

TABLE 3
Tuning Results Constants

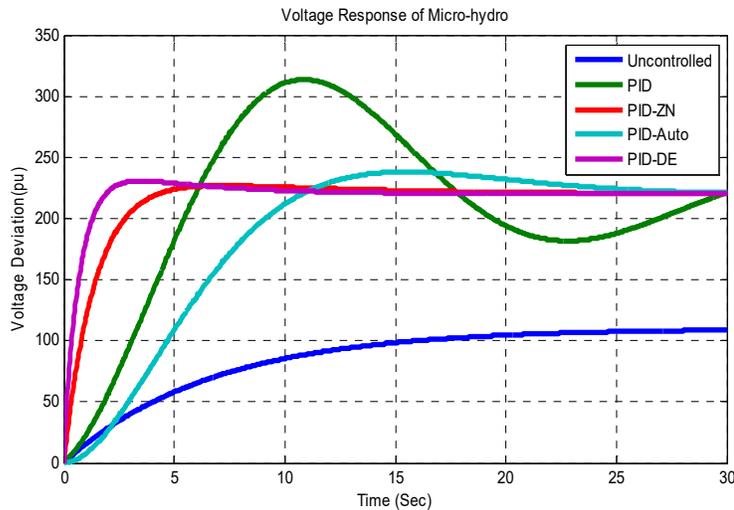|	Uncontrol	PID	PID-Auto	PID-ZN	PID-DE
Kp	-	1	15.664	10	31.212
Ki	-	1	21.619	1.21	0.711
Kd	-	0	2.711	0	0.943

Figure 5.   Microhydro response results

Figure 6 explains that simulation without controller obtained 118 volts undershoots with 81 seconds settling time. Simulation with the standard PID controller gained 182 volts undershoots, 311 volts overshoots with 44 seconds settling time. Simulation with the PID controller using the Ziegler Nichols method obtained

217 volts undershoots, 227 volts overshoots with 20 seconds settling time. Simulation with the PID controller with auto tunning obtained 219 volts undershoots, 239 volts overshoots with 26 seconds settling time. And simulation with the PID-DE controller received 220 volts undershoots, 225 volts overshoots with 11 seconds settling time.
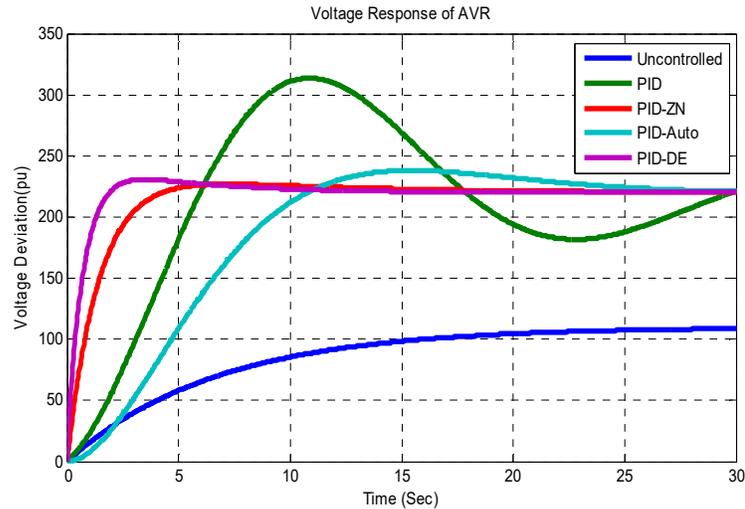

Figure 6.   AVR response results

5. Conclusion

In conclusion, the best response in Micro-hydro Power Plant was from the PID-DE controller model with 220 volts undershoots, 224 volts overshoots, and 8 seconds setting time. The best response in the AVR system was also from PID-DE controller with 220 volts undershoots, 225 volts overshoots in 11 seconds settling time. These results might be a reference for future research with other methods that might generate better results.

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