Electronic Load Controller based on Modified Firefly Algorithm to Reduce Frequency Fluctuation of Generator in Micro Hydro Power Plants

Nur Iksan*‡, Muhammad Ubaid Firdaus*, Subiyanto*, Esa Apriaskar*, Anan Nugroho*, Erika Devi Udayanti**, Djoko Adi Widodo*

*Department of Electrical Engineering, Faculty of Engineering, Semarang State University, Indonesia

**Department of Information System, Faculty of Computer Science, Dian Nuswantoro University, Indonesia

(nur.iksan@mail.unnes.ac.id, ubaidfirdaus26@students.unnes.ac.id, subiyanto@mail.unnes.ac.id, esa.apriaskar@mail.unnes.ac.id, anannugroho@mail.unnes.ac.id, erikadevi@dsn.dinus.ac.id, djokoadiwidodo@mail.unnes.ac.id)

‡ Corresponding Author; Nur Iksan, Building E11 Department of Electrical Engineering, Faculty of Engineering, State University of Semarang, Sekaran Village, Gunung pati District, Semarang City, Central Java Province, Indonesia, Postal code 50229, Tel: +62 813-2600-3768 or nur.iksan@mail.unnes.ac.id

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Abstract- An overpowering condition generated by the PLMTH generator simulator will cause frequency instability which can result in some damage to electronic goods. So, it is necessary to design an optimal control system. One of the control systems used is the Electronic Load Controller (ELC) which can adjust the excess power to consumer loads and ballast loads. Development of an ELC that uses an electrical switch in the form of a Triac. This component will be controlled by a microcontroller with input data in the form of voltage, current, and frequency values. In the processing of microcontroller data, algorithms can be applied to obtain more optimal ELC performance. One of them is using the Modified Firefly Algorithm (MFA). With this method, a PID tuning approach is taken so that it will get PID parameters on the Electronic Load Controller (ELC) system. In this MFA tuning process, up to 100 iterations are repeated to achieve optimal or near-optimal PID parameters. The results of this study were to measure the performance of the MFA ELC which was tested with a PLTMH generator simulator. Based on the test results, shows that the performance of the MFA ELC can reduce frequency fluctuations so that the frequency value is more stable within the standard limits set by the Ministry of Energy and Mineral Resources of the Republic of Indonesia of 50.1Hz – 51.5 Hz. In addition, the generated voltage also becomes more stable, namely in the range of 222.2 – 223.6 Volts. These results when compared with testing the generator without using the MFA ELC are very different, because the frequency values produced are in the interval 46.7 – 51.5 Hz and the voltage values are in the interval 214.2 – 244.5 Volts. Thus, the performance of the MFA ELC is sufficient to help reduce frequency instability in the PLTMH generator simulator.

Keywords Electronic Load Controller (ELC), Frequency Fluctuation, Modified Firefly Algorithm, PID Controller.

1. Introduction

In everyday life, electrical energy has an important role, thus triggering the need for electrical energy which is increasing every year. The need for electrical energy is not only from individual homes but also from public buildings and medium and small industries [1, 2]. The condition of national electrical energy needs in Indonesia is still dependent on coal-fired steam power plants. Of the several power plants in Indonesia, steam power plants have a high growth rate of around 9.3% per year [3].

From a geographical point of view, Indonesia is a tropical country that is crossed by the equator so it has six new renewable energy resources (EBT) in the form of water energy, solar energy (sunlight), geothermal energy, wind, bioenergy and ocean currents. Currently, the production of fossil energy is also decreasing, thus encouraging the use of this new renewable energy. If this abundant potential for renewable energy is developed, it is estimated that the potential for electrical energy will be 441.7 Giga Watt (GW) [4 - 6].

One of the uses of NRE is a micro hydro power plant (PLTMH). The working mechanism of the MHP is very dependent on the rotational speed of the generator. This rotation is caused by a hydro turbine. Where the hydro turbine converts water pressure into mechanical energy in the form of a generator shaft rotation. In general, PLTMH distributes electrical power to people's homes around the power plant. Thus, the consumer's burden will always change dynamically. Dynamic changes will cause the generator to rotate faster. This will cause symptoms of frequency fluctuations so that the resulting frequency becomes unstable [7, 8].

This frequency instability disorder has many factors, one of which is the excess power supply generated by the generator than the load that must be met. This resulted in a frequency that was not included in the tolerance limit set by the Ministry of Energy and Mineral Resources of the Republic of Indonesia, namely 50 Hz. Conditions like this can cause damage to electronic devices. Therefore, every power plant must be equipped with a control system [9].

To deal with the phenomenon of frequency fluctuations, MHP must be equipped with a control system. There are several types of control systems in MHP, including Average Voltage Regulator (AVR) [10], Flow Valve Control (FVC) [11], PID Controller [12], and Electronic Load Controller (ELC) [13]. Meanwhile, the most popular control system is the ELC which is connected to the ballast load. Where this ballast load serves to remove excessive loads and adjust the frequency [9].

There are many types of generator control systems, this PLTMH generally uses the Average Voltage Regulator (AVR), which method is usually used on 3-phase electricity. However, for single-phase electricity, it is more possible to use an Electronic Load Controller (ELC) which has a working mechanism to share excess power between ballast loads or complementary loads. The general use of ELC uses a manual contactor to transfer power, so it requires an operator to check periodically [14].

This balancing process is carried out due to the emergence of several phenomena when the PLTMH operates without using a control system. One of the phenomena that arise is the frequency fluctuations that occur due to the unstable rotating PLTMH generator because it is driven by dynamic changes in consumer loads. Frequency fluctuations will produce unstable frequencies. So, it will cause damage to electronic goods [15].

Based on previous research, it was shown that ELC by applying PID control was able to provide an optimal response, this was shown from the transient response to a state that balanced. However, there are other studies that apply the Frequency Load Controller (FLC) control which produces good performance when compared to ELC that applies only PI control. In addition, there is an algorithm that helps in the process of producing an optimal control system. For example, the use of the Firefly Algorithm which adopts the life behavior of fireflies [16, 17].

In this study, the modified firefly algorithm method is used as a PID parameter tuning. Furthermore, the parameter values of Kp, Ki, and Kd are applied to the microcontroller by writing an ELC program based on PID-MFA. This is done with the aim that the ELC has an optimal response when carrying out the process of transferring power from the generator to the consumer load and ballast load. Thus, the frequency and voltage values produced will be more stable in the event of loading conditions by consumer loads.

This paper consists of 4 parts, namely: part 1 discusses Introduction, part 2 discusses Materials and Methods, part 3 discusses Result and Discussion, and part 4 discusses Conclusion.

2. Material and Method

This research begins by simulating the Modified Firefly Algorithm, which aims to get the PID Controller parameter value. The use of the MFA algorithm is not without reason, because when compared to the use of algorithms for optimization (for example Ant Colony Optimization (ACO), Bat Algorithm (BA) and so on) MFA is easier and simpler to do [18, 19].

2.1. Modified Firefly Algorithm

The firefly Algorithm is a new metaheuristic that adopts the life behavior of a colony of fireflies that are attracted to each other by the flickering of light. The basic purpose of this firefly blinking behavior is to attract other fireflies during the mating season and another purpose is to attract potential victims for prey. On the other hand, by blinking the firefly species can give a warning of danger [20].

This means that one firefly will always be attracted to each other but at the same time, the firefly colony moves in all directions (randomly). This movement creates a mutual attraction that is equal to the brightness of the firefly's light but the attraction will be opposite to the distance between the fireflies. On the other hand, the emergence of attraction between fireflies is obtained from the process of absorption of light by the surrounding environment which causes a reduction in light intensity and the attraction of fireflies. This attraction can be calculated in equation (1) below [20].

$$\beta_{(r)} = \beta_0 \, e^{-\gamma r^m}, \text{ with } m \geq 1 \tag{1}$$

In equation (1), r is the distance between firefly i and firefly j. In addition, β_0 is the initial attraction when distance = 0 In addition, to update the transfer of fireflies i that are attracted to fireflies j can be represented in equation (2) below.

$$X_{(i+1)} = \beta_0 e^{-\gamma r^2}\left(x_i - x_j\right) + \alpha\left(rand - \frac{1}{2}\right) \tag{2}$$

In equation (2), the first term is the initial position of firefly i, then for the second term, and then considers the attraction between firefly i and firefly j using equation (1). In addition, fireflies move randomly when there is no interest in the intensity of light (there are no brighter fireflies). Thus, the coefficient of this random movement can be determined from the distance between fireflies i and fireflies j at each position ($x_i \; dan \; x_j$). To clarify, it can be seen in the equation (3).

$$r_{i,j} = \|x_i - x_j\| = \sqrt{\sum_{k=1}^{d}(x_{i,k} - x_{j,k})^2} \quad (3)$$

In equation (3), the value of (x_i,k) is the value in the k-th order of equation (x_i) on firefly i as well as for firefly j. To understand the process of MFA tuning, see Fig.1 below

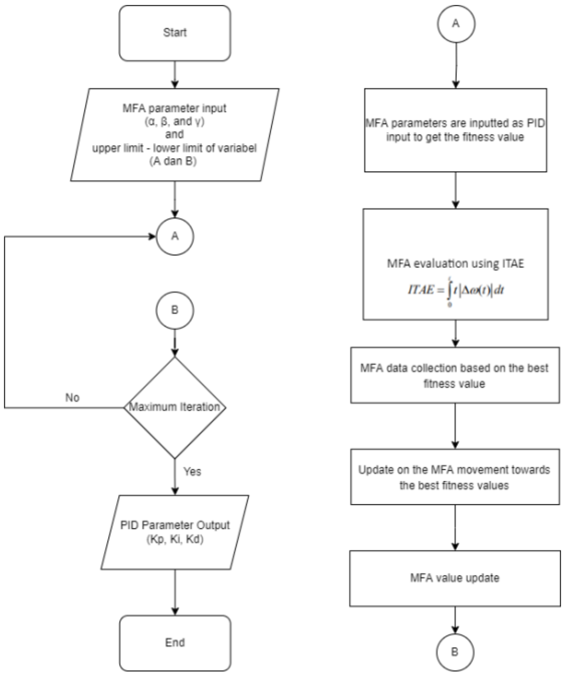


Fig. 1. MFA tuning flowchart

The parameters to be used, for example, the number of fireflies (m), the random parameter coefficient (α), the attractiveness at the start ($\beta 0$), the light absorption coefficient in the medium (γ), and the desired maximum iteration (maximum iteration). Doing data input by starting with preparing some input data based on the performance of the PLTMH, namely in the form of loading conditions, rotational speed values, frequency, and generator voltage. In generating the initial population of fireflies, it was carried out as many as n-populations. Each firefly represents the limit value of the generator frequency variable based on the generator rotational speed value. The initial generation of firefly elements is done by randomly generating real numbers with the interval [0,1].

The procedure for initializing these MFA parameters is as follows.

Parameter initialization procedure
Begin
nPop <- *Total population of fireflies;*
MaxIt <- *Maximum iterations;*
α <- *Firefly random coefficient value;*
β0 <- *The value of the initial attractiveness coefficient of fireflies;*
γ <- *The value of the coefficient of absorption of light by air;*
End

The procedure for inputting data is as follows:

Data entry procedures
Begin
For i <- *Generator loading conditions;*
For j <- *Consumer load conditions;*
Rho <- *Generator rotational speed value;*
F <- *Generator frequency value;*
V <- *Generator voltage rating;*
End For j
End For i
End

Raising the initial population of fireflies can be seen in the following procedure:

Procedure for generating an initial population of fireflies
Begin
For i <- *The first firefly (I1) goes to n-population;*
For j <- *The second firefly (I2) goes to n-fireflies;*
VarMin <- *Generator minimum variable frequency;*
VarMax <- *Generator maximum frequency variable;*
VarSize <- *Generator standard variable frequency (50Hz);*
Rho <- *Generator rotational speed variable;*
End For j
End For i
End

This study uses FA which has been modified on parameter values (α, β, dan γ) so that it is expected to produce a more optimal response. Theoretically, MFA has an objective function that can affect the stability response of the system, using the Integral Time Absolute Error (ITAE) equation will produce PID parameter values in the form of (Kp, Ki, and Kd) This ITAE equation can be understood in equation (4) below.

$$ITAE = \int_0^t t|e(t)| \quad (4)$$

This model has a function to perform manual or automatic tuning to generate PID Controller parameters. This PID tuning automatically adjusts the PID parameters and also models the process which consists of several computational models and compares the output so that it can be seen that there are process variations. In this process, there is a repetition of the PID parameter values so that they can provide the desired output.

Furthermore, the scheme of this MFA tuning process by changing the parameter values (α, β, dan γ) simultaneously [21]. The schematic explanation can be understood in the following details.

a. The value α will be modified in each iteration using thefollowing equation (5):

$$\alpha = 0,9 + \left(0,8 \times \frac{kg}{Maximum\ Generatioan}\right) \quad (5)$$

The value α will decrease in each iteration starting from 0.8 in the first iteration to 0.1 in the last iteration. In the first iteration alpha (flexibility) is given a maximum value (0.8), in the next iteration the alpha value is reduced until the final target is seen. Because the targetis clearly visible, the alpha value is given a minimum value.

b. The value β using the following equation (6).

$$\beta = 0{,}9 + \left(0{,}8 \times \frac{kg}{Maximum\ Generatioan}\right) \qquad (6)$$

The beta value in each iteration will change (increase)from 0.1 in the first iteration to 0.8 in the last iteration.In the first iteration, a beta value of 0.1 is given to provide a firefly stance in finding targets.

c. The value γ in this modification process is made to 0 because this value is not used temporarily for the case of ELC.

After performing according to the scheme, it will produce the best value for each iteration that is run. After reaching iteration maximum, will return the PID parameter value. With this will be applied in the microcontroller program. Based on the modification scheme described above and to make it easier to understand the pseudocode [22], it can be seen in Figure 2 below.

Begin
determine the value of the upper limit A and lower limit B of the design variable
defines multiple parameter variables (α, β, γ) and objective function
  fireflyrandom parameter value (α)
  the value of attraction between fireflies (β)
  absorption coefficient value (γ)
  the objective function value is f(x) where x is $(X_1, \ldots, X_n)$
generating the initial population of fireflies (X_i) for i (1,..,n)
sort the fireflies according to the response of the objective function f(x)
While t = 1 < maximum iteration
  $y_i = x_i$ where (i =1,2,...,n)
  For i = m_1 *to* $(n - m_2 - k)$
    For j = 1 to n
      If $(f(x_i) < f(x_j))$ **Then**
      move the firefly i towards firefly j according to equation (1)
      end if
      the attractuin valeu of fireflies varies with distance r through-the equation $\beta = \beta_o . \exp(-\gamma r^2$
      evaluate the latest solution then make an update the light-intensity of the fireflies
    end for j
  next i
    check the lower bound value for firefly X_i
      for i =$(n - m_2 - k) + 1$ *to* $(n - k)$**Then**
        $x_1 = y_{1-n+m_2+k}$
  next i
      for i = $(n - k) + 1$ *to n*
        $x_1 = \boldsymbol{B} + rand\ x\ (\boldsymbol{B} - \boldsymbol{A})$
  next i
  evaluate the value of the objective function $f(x_i)$ for fireflies which has-been updated
  sort the fireflies according to the objective function f(x)
  determine the best solution from fireflies in on going iterations
  end while
  determine the results and visualization after the process is complete
End begins

Fig. 2. Pseudo code of the firefly algorithm modification that will be carried out

2.2. Electronic Load Controller (ELC)

After tuning the MFA which will produce the PID controller parameter values in the form of Kp, Ki, and Kd, then the next step is to implement it in the ELC control system. It begins with designing a schematic of the ELC. The control system that is built is a prototype that will be tested using a stand-alone synchronous generator, which has constituent components including the Switch PCB, Microcontroller, and also the Pzeem-004T module. In this study, ELC uses an electric switch in the form of a Triac. To be able to clarify can be seen in Fig.3 below

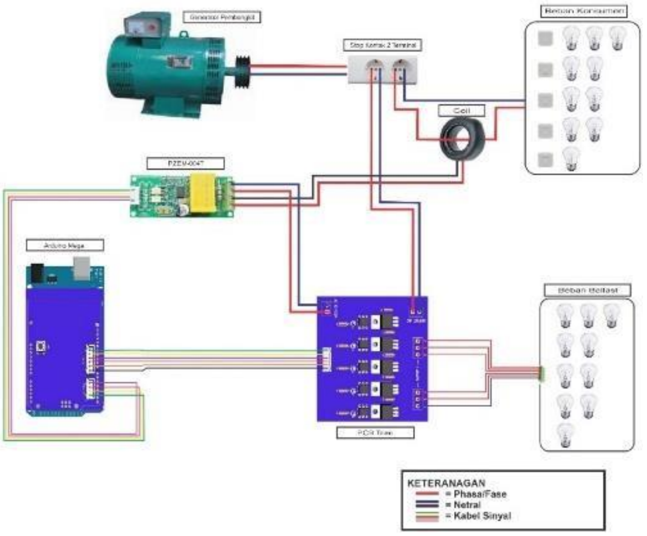


Fig. 3. Control system schematic circuit

Fig.3 shows that the generator will be connected consumer load and ballast load by using a socket with 2 terminals. One terminal is connected to the consumer load and added with a coil for monitoring using the Pzem-004T module. Then one other terminal is connected to the switching PCB as input voltage which is then forwarded to the Pzeem-004T module, which will later become the reference for the microcontroller to send the Triac corner opening signal. With the corners of the Triac open will do the power transfer.

The working mechanism of this ELC when there is excessive current from the generating source, the ELC diverts the excess current to the ballast load, in other words, the ballast load is a place to dispose of the excess current. With this generator can still operate optimally. The application of MFA to the ELC is to optimize the ELC response so that it can send a transfer signal precisely and reliably [17, 23].

In this study, the ballast load used is in the form of a series of incandescent lamps with an estimated total power of 1000 W as well as the consumer load using incandescent lamps which are assembled to have a power of 1000 W.

2.3. ELC MFA Circuit Test Plan

The schematic circuit will be tested as a whole using a stand-alone synchronous generator to obtain data in the form of measurement results of frequency values that arise in several conditions. This ELC MFA test has three loading conditions, to see the response of the application of ELC

MFA. In this study, researchers took data from various conditions on a synchronous generator. These conditions are divided into 3 (three) including:

a. Conditions when the generator is only connected to the load consumer,

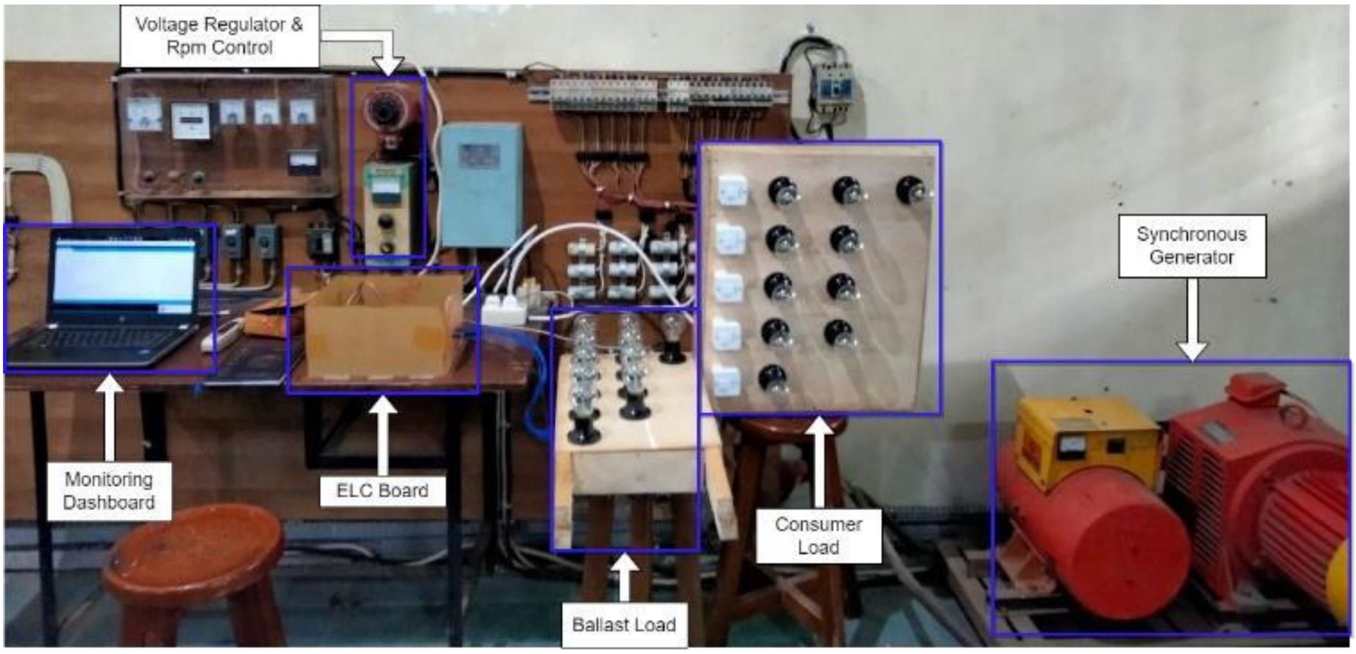
b. Conditions when the generator is only connected to the ballast load

c. Conditions when the generator is connected to the ELC MFA, the consumer load and ballast load

The data is presented in a comparison table between the condition of the generator without ELC-MFA and the generator equipped with ELC MFA. This is done in order to ensure that the application of MFA to the ELC can optimize the performance of the ELC as a control system in the MHP.

In this research, data analysis of a control system that has been created and tested is carried out by providing several loading conditions on the synchronous generator. Initial analysis was carried out for tuning the PID parameter values using the Modified Firefly Algorithm.

Further analysis is carried out to test the ELC MFA control system that has been made by looking at the frequency, voltage, and current response to the consumer load or ballast load. In this study, using equipment such as generator, consumer load, ballast load and ELC board. In order to understand the alignment used, it can be seen in Fig.4 below.



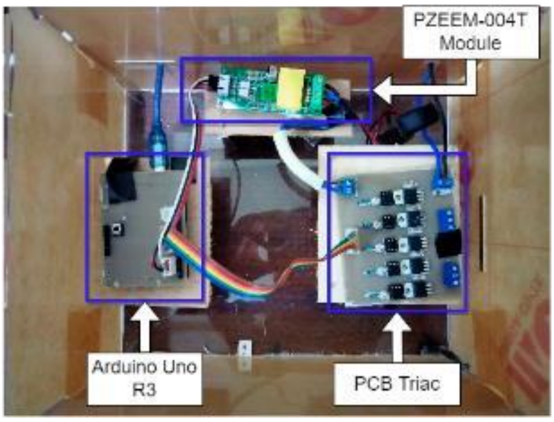


Fig. 4. Micro-hydro simulator for ELC-MFA testing

3. Result and Discussion

3.1. Tuning Parameters of PID MFA

In this study, a simulation is carried out that aims to generate PID parameter values in the form of Kp, Ki, and Kd. The tuning process begins with writing a program, after that, it is continued to create a Simulink model to run the program, to make it easier to understand can be seen in Fig. 5. An MHP system without a control system so that there is no feedback in the form of error detection. This affects the PLTMH system, if an error condition occurs, the system cannot return to work optimally.

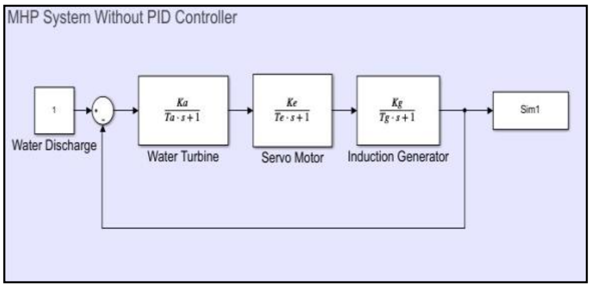


Fig. 5. Model Simulink MHP system without PID Controller

In addition, this study compares a system that has feedback with a system that is equipped with feedback. To make it easier to understand the system can be seen in Fig. 6.

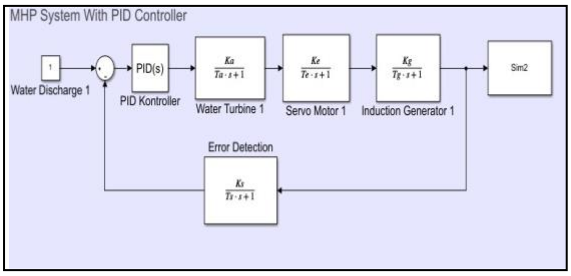


Fig. 6. Model Simulink MHP system with PID Controller

Fig.6 shows that the second system is equipped with feedback in the form of an error detector. In addition, this system is equipped with a PID controller, to make the MHP system able to work optimally. After that, run the program to see the tuning results in the form of a response graph as shown in Fig. 7. The response values of Kp,Ki, and Kd in each iteration. There is the stability of the system when entering iteration number 30, this stability occurs until iteration number 100. This process also combines the programwith the Simulink model, so that it will produce a response graph when running the program.

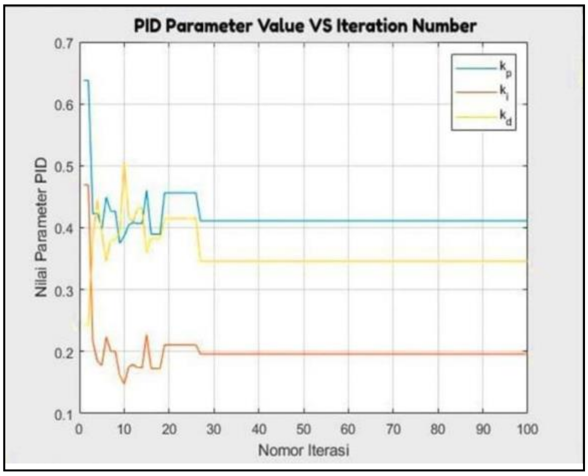


Fig. 7. Graph of PID parameters value response to iteration number

The graph of the system response using PID MFA and without using PID MFA can beseen in Fig. 8 and Fig. 9 below. Fig.8 shows the frequency response of the system without using a PID Controller, which takes about 8 seconds to produce a stable frequency. It is characterized by an increasingly small and stable amplitude area.

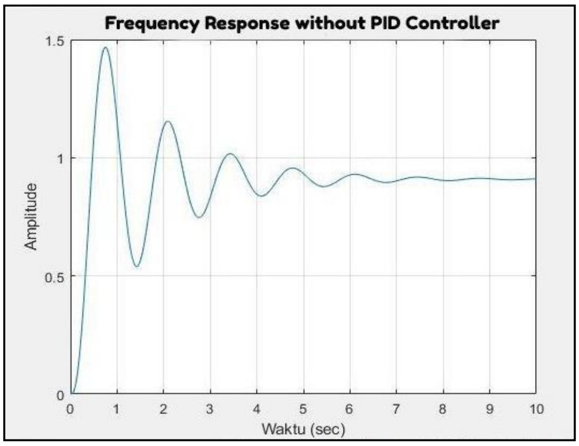


Fig. 8. Graph of frequency response without PID Controller

Figure 9 shows that the frequency response using a PID controller is faster to get a stable value. This is shown when the 5-second chart has started to stabilize. Based on Fig.8 and Fig. 9 which are sinusoidal waves resulting from tuning the PID Controller by MFA. The difference between the two is that a system with PID-MFA has faster performance to become stable than a system without PID-MFA.

From the results of this experiment, the best function value is 2.2116 e-06 while the PID parameter value is Kp = 0.36469, Ki = 0.20913, kd = 0.19928.

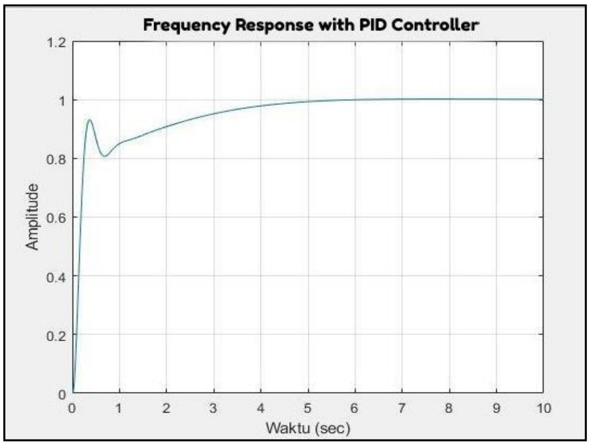


Fig. 9. Frequency response graph with PID Controller

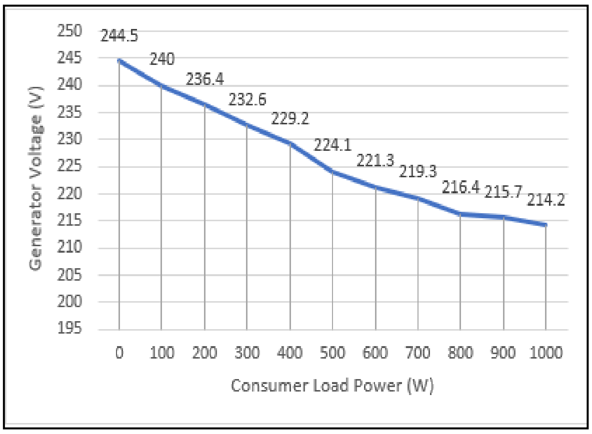


Fig. 10. Graph of generator voltage response to changes in consumer load

3.2. Testing Generator with Consumer Load

This test looks at the response of the generator when it is connected using a consumer load. After that, the consumer load is given several conditions in the form of an increase in the amount of power. This illustrates when PLTMH operates without using any control system and the power generated is directly distributed to consumers. The loading in this test is done by providing a resistive load on the generator in the form of an incandescent lamp which is assembled to have an input power of 1000 W. Then several conditions are carried out starting from a load of 0 W, then increased to have an input power of 1000 W with an increase of every 100 W. per each condition. The results can be seen in Table 1 below.

Table 1. Generator test data connected to consumer loads

Consumer Load Power (W)	Generator Voltage (V)	Frequency (Hz)
0	244.5	51.5
100	240	50.8
200	236.4	50.1
300	232.6	49.8
400	229.2	49.6
500	224.1	48.7
600	221.3	48.3
700	219.3	47.5
800	216.4	47.2
900	215.7	47
1000	214.2	46.7

Table 1 shows the results of measuring the voltage and frequency generated by the generator using consumer loads without using the ELC MFA circuit. The recorded data shows a change in the value of voltage and frequency. For changes in the value of the generator rotational speed can be seen in Fig. 10. There is a decrease in the generator output voltage. This decrease occurs continuously until the consumer's load is 1000 W. This is because the greater the consumer's load, the greater the current that flows, but with the large current, the voltage value will be small.

Then there is a decrease in the value of the output frequency of the generator due to changes in the consumer load which triggers the rotational speed of the generator to become unstable. This unstable speed affects the frequency generated by the generator. The decrease in frequency can be seen in the following Fig.11. the frequency response that decreases continuously when the generator is loaded by the consumer load. The initial frequency value when 0W consumer load is 51.5 Hz then drops to 46.7 Hz when the consumer load is worth 1000 W.

Based on the description of the generator test on changes in consumer load, it can be understood that, if the rotational speed of the generator gets faster, it will produce a voltage and frequency that is higher than the standard value. Conversely, if the rotational speed of the generator is slower, the voltage and frequency produced will also be lower. In addition, the consumer load connected to the generator also affects the rotation of the generator. When the rotational speed of the generator is unstable, it will produce an unstable frequency as well. Testing the generator using this consumer load, has been able to describe the condition of the PLTMH which does not have a control system so that the electrical power produced is directly distributed to surrounding consumers. In Fig. 11 also shows a fairly high decline and has passed the standards set in Indonesia.

3.3. Testing Generator with Ballast Load

Based on the description of the previous test, the generator is tested by connecting this ballast load. This test data is shown in Table 2 where the generator output power is connected to the ELC board circuit without turning on the consumer load. This will later aim to make the ELC balance the power needs of the consumer load that must be borne by the generator. Steps are taken by adjusting the size of the power to the ballast load, in the form of the number of lights on the ballast load that are life. The test result data in Table 2 shows the response of the ballast load when it receives the output power from the generator and uses it as heat energy. This transfer process will later be regulated by the Arduino Uno R3 microcontroller which sends an ignition signal to the Triac.

Table 2. Test results using ballast load

Ballast Load Phase R		BallastLoad Power (Watt)
Voltage(Volt)	Current(A)	
0	0	0
220	0.45	100
219	0.91	200
219	1.37	300
218	1.83	400
218	2.29	500
219	2.74	600
218	3.22	700
217	3.68	800
217	4.14	900
217	4.61	1000

After observing and recording each of these loading conditions, it has data in the form of voltage and current values that enter the ballast load. This represents when excess current is transferred to the ballast load. To clarify can be seen in Fig. 12 below.

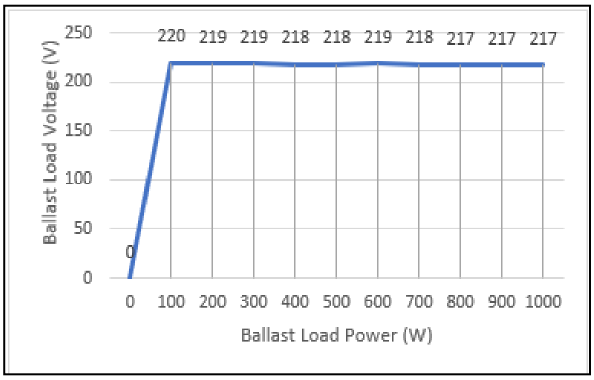


Fig. 12. Ballast load voltage graph

Based on Fig. 12, indicates that the input voltage value leads to the ballast load when the ballast load is active, whichis 217-220 Volts. There is a relatively small decrease when given loading conditions with this ballast load. However, the current flowing to the ballast load will be even greater. Thus, the greater the active ballast load, the lower the input voltage toward the ballast load. This is inversely proportional to the value of the current flowing, as shown in Fig.13 below.

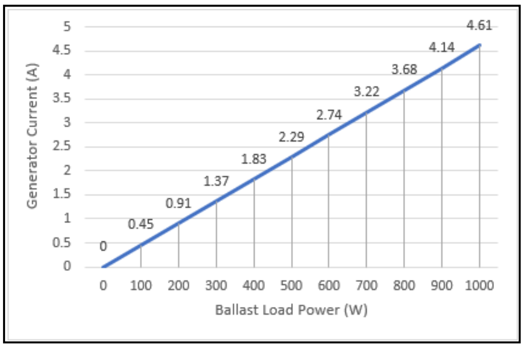


Fig. 13. Ballast load current graph

Fig. 13 This shows that the current flowing in the ballast load will always increase as the ballast load increases. An increase in the current value of the ballast load, will shift the generator output power. This test describes how the conditions when the generator output power will be transferred to the ballast load first. When the consumer load requires input power, the current and voltage to the ballast load will decrease according to the needs of the consumer load.

3.4. Testing Generator with ELC MFA

This test aims to see the response of the voltage, current, and frequency generated by the generator using the ELC MFA control system. The use of MFA is devoted to finding more optimal PID Controller parameter values Then the PID Controller parameter value will be applied to the Arduino UNO R3. After testing the generator using ELC MFA, it has been proven that power transfer occurs so that the resulting frequency is more optimal. The transfer of power occurs between the consumer load and the ballast load, where the power that has been generated will go to the ballast load, and when there is a loading condition by the consumer load, the power that goes to the ballast load is reduced according to the power required by the consumer. To understand the results, see Table 3 below.

Table 3. Generator test data using ELC MFA

Consumer Load Power (W)	Generator Voltage (V)	Frequency(Hz)	Ballast Load Phase R		Ballast Load Power(W)
			Voltage(V)	Current(A)	
0	222.4	50.1	220	4.54	1000
100	222.7	50.3	219	4.11	900
200	229.1	51.5	217	3.68	800
300	223.5	50.6	218	3.21	700
400	223.6	50.7	218	2.75	600
500	223.5	50.8	218	2.29	500
600	222.8	50.8	218	1.83	400
700	222.2	50.8	217	1.38	300
800	222.4	50.8	217	0.92	200
900	222.6	50.9	217	0.46	100
1000	222.5	50.9	0	0	0

Based on Table 3, it is known that the effect of ELC using PID-MFA is better able to maintain the frequency value so that stable. Where the Triac component is able to send a power transfer signal from the consumer load to the ballast load. So that the voltage and frequency values are more stable when compared to the previous test. After observing and recording the test results, the data is presented in the form of a graph that can be seen in Fig. 7 below.

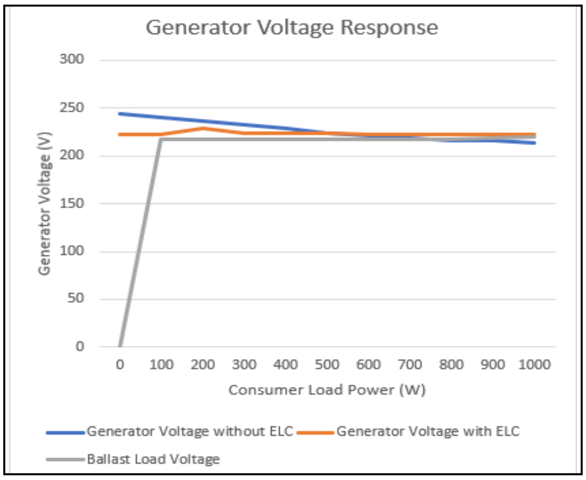


Fig. 14. Graph of voltage response to changes in consumer load

Based on Fig.14, it shows that the ballast load voltage is 0 volts when the ballast load is 0 W. This shows that when the ballast load is 0 W, no current flows, and all the power from the generator is absorbed by the consumer load. Then there is an increase when the ballast load is worth 100 W, in this condition there has been a power transfer which divides the power flowing to the consumer load by 900 W and the power flowing to the ballast load by 100 W. This power transfer condition occurs continuously until the load consumer of 1000 W. Based on Fig.7 also, it shows that the voltage generated by the generator after entering the ELC circuit PCB does not experience a large decrease, approximately only 2 – 5 Volts.

Table 4. Power measurement data generated by the generator

Consumer Load Power (W)	Nominal Power (W)	Rated Power of Consumer Load (W)	Rated Power of Ballast Load (W)	Total Power (W)
0	1000	0	998.8	998.8
100	1000	88.91	900.09	989
200	1000	194.1	789.56	983.66
300	1000	283.6	699.78	983.38
400	1000	373.3	599.5	972.8
500	1000	471.9	499.22	971.12
600	1000	568.5	398.94	967.44
700	1000	656.8	299.6	956.4
800	1000	750.2	199.64	949.84
900	1000	852.3	99.82	952.12
1000	1000	941.2	0	941.2

In addition, this test measures the power consumption leading to consumer loads and ballast loads. The data are collected in Table 4 assuming (cos $\varphi = 1$ due to resistive load). The data that has been collected in Table 4 is processed into a comparison chart. This can show the power consumption of consumer loads and ballast loads when compared to nominal loads. To clarify can be seen in Fig. 15, below.

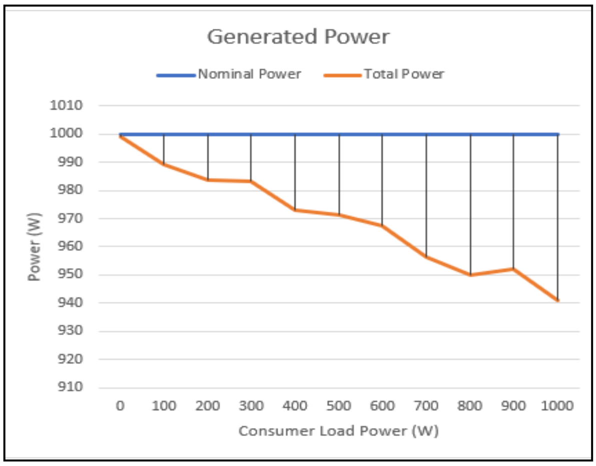


Fig. 15. Graph of the comparison of the power generated bythe generator

Fig. 15 This shows a decrease in the total power when compared to the nominal power (standard power). This decrease occurred due to the distribution of power from the generator to the load, both consumer and ballast loads. In addition, Fig.15 shows the existence of contradictory values between the power at the consumer load and the ballast load. This indicates the occurrence of the power transfer process by Arduino Uno R3. In addition, the change in the frequency value can be seen in Fig. 16 following.

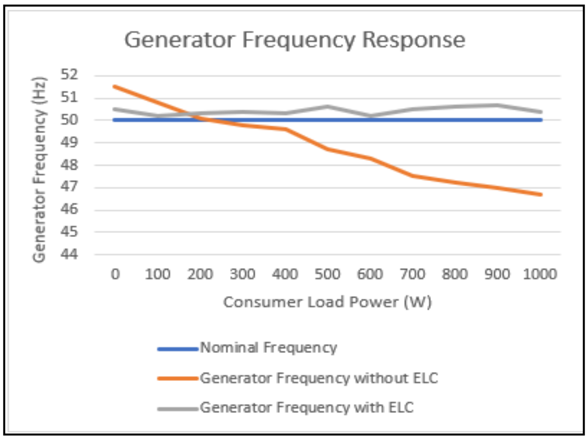


Fig. 16. Graph of frequency to changes in consumer load using the ELC MFA control system

Fig.16 shows a graph of the frequency response when given the loading conditions of the consumer load. The graph shows values that have increased and decreased but are still above the normal limit that applies in Indonesia, namely 50 Hz. However, the change in the frequency value is still within the tolerance, which is no more than 1 Hz.

Based on the test results of the three conditions and the data analysis above, the load control test using ELC MFA is able to switch power between consumer loads and ballast loads. This results in the voltage (v) and frequency (f) not experiencing instability with a large interval value and still within a tolerable value. In addition, this ELC control system can send a Triac ignition signal that activates and turns off the ballast load to keep the frequency within the standard value of 50 Hz

4. Conclusion

Based on the results of the tests that have been carried out in this study, conclusions can be drawn including:

a. The design of the MFA ELC using the BTA 12-600B series Triac component can regulate the transfer of electrical power between consumer loads and ballast loads. The performance of the MFA ELC is shown by a frequency comparison graph between the generator frequency and the reference frequency. Thus, the ELC MFA can reduce the possibility of frequency fluctuation phenomena.

b. Using the Modified Firefly Algorithm to find PID parameter values applied to the microcontroller program has given optimal results. So that the performance of the MFA ELC which can transmit the Triac gate opening signal is more optimal. This is necessary so that when experiencing frequency fluctuations, the ELC-MFA can switch on time and reduce the risk of damage to electronic devices.

c. Testing the generator without the MFA ELC showed unfavorable results, where the resulting frequency value always decreased when there was loading by consumer loads. The highest frequency value is generated when the load is 0 W which is 51.5 Hz and the smallest frequency value when the load is 1000 W is 46.7 Hz. Likewise, the largest generated voltage value when the load is 0 W is 244.5 Volts, and the smallest when the consumer load is 1000 W is 214.2 Volts.

d. Generator testing using the MFA ELC showed good results with quite optimal power transfer, where the largest frequency value produced was 51.5 Hz at a load of 200 W and the smallest frequency value was 50.1 Hz at a load of 0 W. In addition, the voltage response also showed good results. well, where the largest voltage is 223.6 Volts when the load is 400 W and the smallest voltage is 222.2 Volts when the load is 700 W. Besides that, the resulting frequency values are in the range of 50.1 – 51.5 Hz and the voltage values are within the range 222.2 – 223.6 Volts

e. As a further research development, there are several suggestions for improvement, namely: in conducting a tuning simulation of PID parameter values using more iterations. With more iterations, it will produce more optimal parameter values. Next, apply other metaheuristic methods so that there will be comparisons and use those that are more optimal for application in ELC

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