CAPACITIVE ENERGY STORAGE OPTIMIZATION FOR LOAD FREQUENCY CONTROL IN WIND-DIESEL HYBRID POWER PLANT USING IMPERIALIST COMPETITIVE ALGORITHM

By Marhatang Marhatang

CAPACITIVE ENERGY STORAGE OPTIMIZATION FOR LOAD FREQUENCY CONTROL IN WIND-DIESEL HYBRID POWER PLANT USING IMPERIALIST COMPETITIVE ALGORITHM

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ABSTRACT

This research proposes an additional controller for load frequency control at a Wind-Diesel power plant using Proportional Integral Derivative (PID) – Capacitive Energy Storage (CES). The PID-CES parameters are optimized using smart methods, that is the Imperialist Competitive Algorithm (ICA). From the findings, it can be concluded that the proposed PID-CES controller in this study can successfully damp the oscillation of Wind-Diesel frequency, by tuning the parameters using the smart method.

KEYWORDS: *Wind-Diesel; PID; ICA; frequency; overshoot; settling time*

1. INTRODUCTION

Utilization of renewable energy as a source of electrical energy, is increasingly being used. Wind energy is widely used as a source of generator for generating electrical energy. However, the utilization of wind energy is highly dependent on wind conditions in an area, therefore wind power plants can be combined with diesel generators. The Wind-Diesel hybrid can serve consumers optimally, because its performance is more optimal compared to Wind Stand Alone. Hybrid system is a controlled network of several energy sources such as wind turbines, photovoltaic, microhydro, and so on. However, due to differences in the regulation of frequency fluctuations, this will affect the quality of power supply in the hybrid system.

The Imperialist Competitive Algorithm (ICA) method is a computational algorithm that is inspired by the royal rivalry in seizing power from a region. The ICA algorithm will work based on Objective Function, which minimizes Integral Time Absolute Error (ITAE). Implementation of ICA has also been widely used, because the results are very optimal in doing the computation process, some of these studies (Djalal, Ajiatmo, Imran, & Robandi, 2015) for Power System Stabilizer, (Lastomo, Setiadi, & Djalal, 2017) for pendulum control. Several studies have discussed the frequency setting in Wind-Diesel, (Bhatti, Al-Ademi, & Bansal, 1997a, 1997b; Citraningrum, Ashari, & Pamuji, 2015; Dapis, 2017; Dhundhara & Verma, 2017; El-Fergany & El-Hameed, 2017; Fadaee & Radzi, 2012; Garimella & Rajan, 2014; Junrui, Yuchun, & Wen, 2012; Ko, Niimura, & Lee, 2003; NUKALA & SUDHA, 2014; Raju & Ali, 2012; Soedibyo, Pamuji, & Ashari, 2015), but the wind-diesel performance can still be improved. Capacitive energy storage (CES) is a control device capable of storing and releasing energy. CES can be used as a tool to control the electrical frequency at a plant. Therefore, in this research will be

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discussed about the application of CES in regulating the load frequency at the Wind-Diesel hybrid generator.

2. HYBRID SYSTEM

Diesel-wind turbine hybrid power plant is a common power plant applied to a remote area, such as in mountainous areas or islands where wind speed is significant enough to drive generators in producing electricity (Figure 1). So it is expected that the generation of electrical energy from the Wind Turbine Hybrid system can provide good service to the consumers. Frequency control becomes an important topic for this plant as it is separated from the center of electricity. Therefore, a good control is necessary to improve the performance of wind-diesel generators. This means that the variation of the frequency system must be kept stable so that the equipment can operate properly and efficiently. The problem that occurs in the generation is the occurrence of low oscillation frequency. This comes about due to (i) high gain setting and low constant time in Automatic Voltage Regulator (AVR) and (ii) too many long transmission lines.
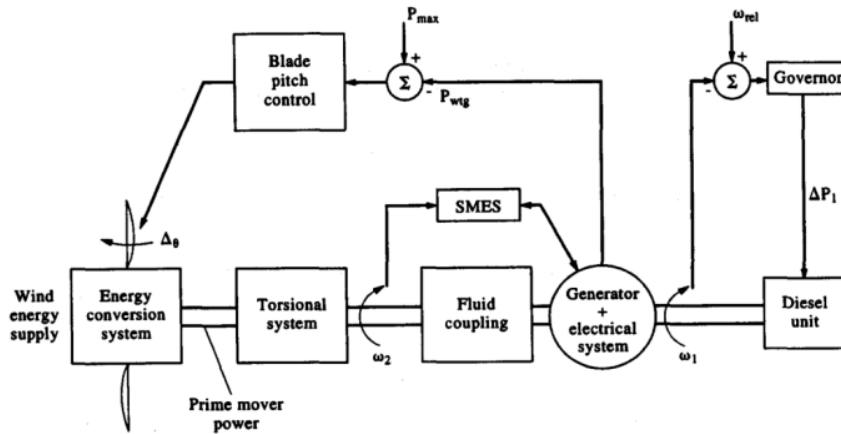

Figure 1. Concept Model of Diesel and Wind Turbine

In this case study, the model consists of wind turbine dynamics model, diesel dynamics model, wind turbine blade speed control and dynamic generator model. The block diagram of a Wind Turbine transfer function is as given in Figure 2.
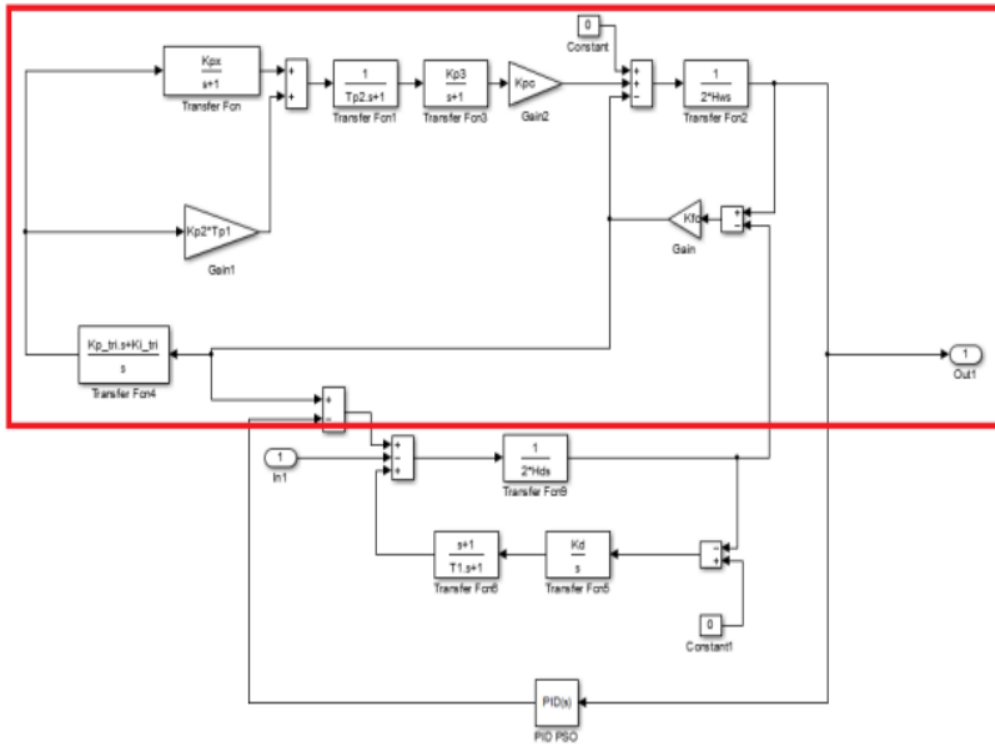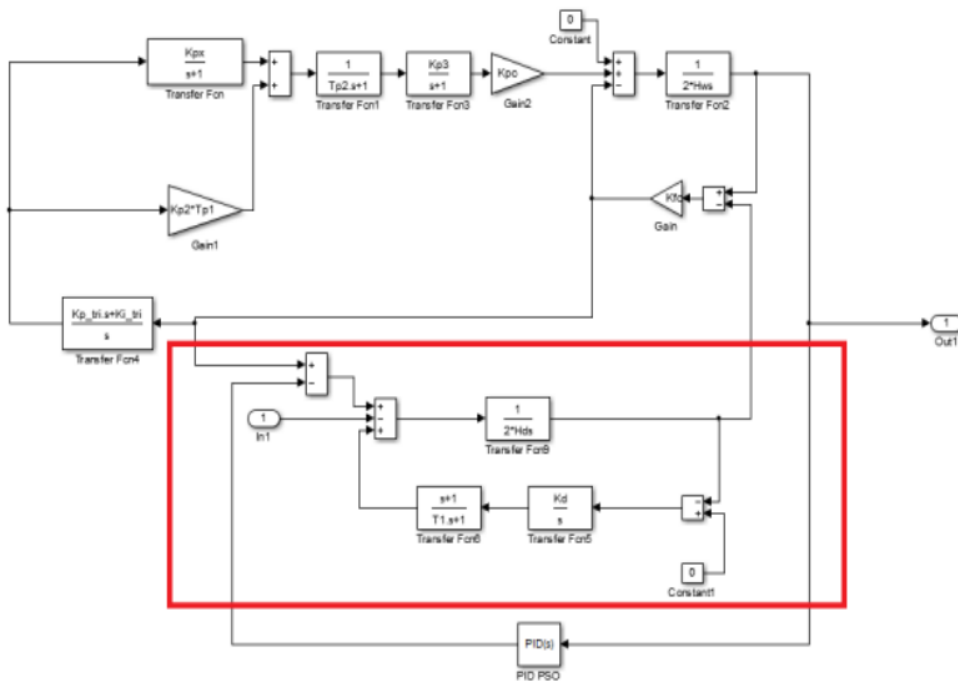
Figure 2. Modeling of Wind Turbine Power Plant

Figure 3. Modeling of Diesel Power Plant

3. IMPERIALIST COMPETITIVE ALGORITHM (ICA)

The method used to optimize the PID parameters of CES is Imperialist Competitive Algorithm (ICA) method. ICA is an evolutionary algorithm inspired by power competition. The algorithm was introduced by Esmaeil Atashpaz in 2007. In solving the optimization problem, ICA has several operations, including:

3.1. Empire Initialization

In the optimization process, ICA forms an array of variable values to be optimized. In other intelligent algorithms, such as GA, this array is called a chromosome, so in ICA there is a state term. In a state defined as 1 x Nvar array. Some of the best countries will be chosen as imperialists to lead the empire. The rest of the previous population will form colonies owned by the empire. An empire will consist of one imperialist and several colonies. The most powerful imperialist has the largest number of colonies. The ICA country initialization is expressed in Equation (1) as follow: -

$$country = [P_1, P_2, P_3 ... P_{N_{var}}] \quad (1)$$

The above equation is the variable that will be optimized in this case PID. The cost of each country can be determined by evaluating the position of each country is as shown in Equation (2) as follow: -

$$cost = f(country) = f(P_1, P_2, P_3 ... P_{N_{var}}) \quad (2)$$

The division of the colony should be based on the strength of the imperialists. To divide the colony must be based on the proper imperialist, therefore the imperialist cost must be normalized first using the expression in Equation (3).

$$C_n = c_n - \max_i \{c_i\} \quad (3)$$

where c_n is the cost of the nth imperialist, and C_n is the normalized cost. Following this, the strength of each imperialist is defined as given in Equation (4).

$$p_n = \left| \frac{C_n}{\sum_{i=1}^{N_{imp}} C_i} \right| \quad (4)$$

Number of initial colonies for n empire is as expressed in Equation (5) below: -

$$N.C_{\cdot n} = round\{P_n N_{col}\} \quad (5)$$

$N.C._n$ is the initial number of colonies of the nth empire and N_{col} is the number of early colonies. The colony with the n imperialist will soon form the n empire. The empire will further form the initial empire, as shown in Figure 4.
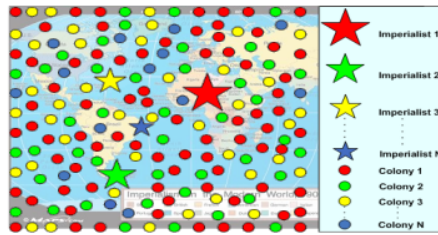
Figure 4. Early Empire (Fassamsi, 2010)

3.2. Movement of the Colony Towards Imperialism

The imperialist will seek to improve his colony by moving all the colonies to him. The movement of this colony is further shown in Figure 5, if this movement continues continuously it will make all the colonies move to imperialist movement.
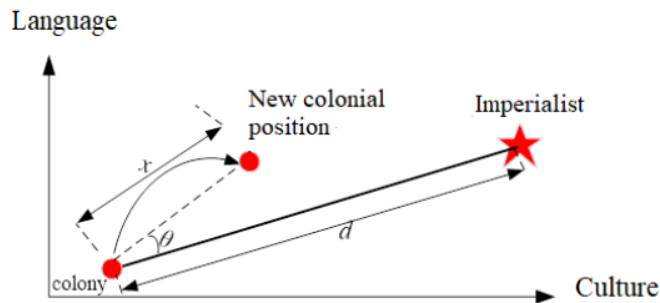

Figure 5. The movement of the Colony towards the Imperialists in random deviations (Fassamsi, 2010)

In Figure 5 above, x is a random variable that is uniformly distributed, which is expressed in Equation (6) below:-

$$x \sim U(0, \beta \times d) \qquad (6)$$

The value of β is a number more than 1, thus making the colony progressively move closer to its imperialist from both sides, and d is the distance of colony and imperialism. The movement of the next colony does not directly lead to imperialism. To model, a random number of irregularities is added to the motion, as given in Equation (7) as follows: -

$$\theta \sim U(-\gamma, \gamma) \qquad (7)$$

where γ is a parameter that governs the deviation from the initial direction. However, the values of β and γ are not arbitrarily chosen, in most implementations, the value β is about 2 and the value of γ is about $\pi / 4$ (rad) to produce a better convergence to global minimum.

3.3 Revolution

Revolution is a fundamental change in organizational structure. In ICA terminology, the revolution will cause a country to suddenly change its socio-political characteristics. That is, despite the imperialist assimilation process, the colony randomly shifts its position to move on the social-political axis.

3.3. Exchange of Positions between Imperialists and Colonies

Furthermore, when the colony moves toward the imperialists, a colony may have a better cost than its imperialists have. When this happens, then the exchange of positions between each imperialist and the colony will occur. Then the algorithm will continue with the new imperialists.

3.4. The Same Empire Merger

In the movement of colonies and imperialism to global minimum, some imperialists may move to the same position. If the distance between the two imperialists is less than the treshold distance, then both will soon form a new empire and a new imperialist in the position where the two imperialists meet.

3.5. The Total Strength of an Empire

S Imperialists have a great influence on the empire's strength, but the strength of the colony also gives little effect. The total cost of an empire is defined as the sum of imperialist cost with the average cost of colonies possessed by imperialists from one empire. The value of ξ denotes the contribution influence of the colony, as given in Equation (8) below: -

$$T.C._n = cost(imperialist_n) + \xi\, mean\{Cost(colonies\,of\,empire_n)\} \tag{8}$$

3.6. The Imperialist Competition

All empires seek to have colonies from other empires and rule them. Competition of power will gradually decrease the strength of the weak empire and increase the strength of the stronger. The competition is modeled by taking only a few or one of the weakest colonies possessed by each of the weakest empires among all empires and rendering competition between even more powerful empires to possess the colonies.

To start the competition, first the probability of possession of each empire is based on its total strength. Normalization of total cost and proprietary probability from empire to n are then sequentially formulated in Equations (9) and (10) as follow:-

$$N.T.C._n = T.C._n - \max\{T.C._i\} \tag{9}$$

$$P_{P_n} = \left| \frac{N.T.C._n}{\sum_{i=1}^{N_{imp}} N.T.C._i} \right| \tag{10}$$

3.7. Empirical Empire Elimination

The weakest Empire will collapse in power competition and the colony of the empire will be distributed to the other empires. An empire will collapse and be eliminated if the empire loses all its colonies.
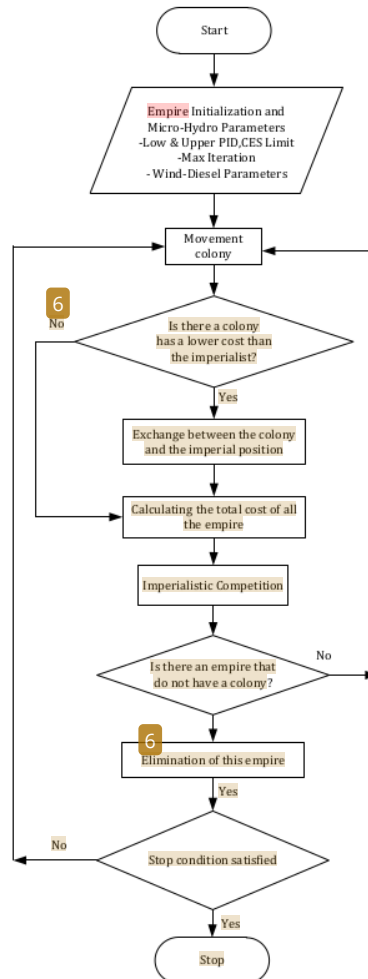

Figure 6. CES-PID tuning flow diagram using ICA (Djalal et al., 2015)

4. ICA IMPLEMENTATION FOR CES-PID OPTIMIZATION

Figure 6 shows the flowchart of ICA method used in this study. The objective function used to test the stability of the system is to minimize Integral Time Absolute Error (ITAE), as expressed in Equation (11) as follow:-

$$ITAE = \int_0^T t \left| \Delta\omega(t) \right| dt \qquad (11)$$

CES-PID parameters are tuned by ICA are Kp_pso, Ki_pso, Kcf_pso, Kp_c, Ki_c, and Kd_c. The CES-PID parameters using ICA method for the tuning process is shown in Figure 6. The ICA parameter data and the ICA convergence graph are shown in Table 1 and Figure 6 below. In addition, the optimization results of ICA method in optimizing CES-PID parameters are tabulated in Table 2.

Table 1. ICA Parameter

Parameters	Values
No. of Countries	50
Initial Imperialists	5
Decades	50
Revolution Rate	0.3
Assimilation Coefficient	2
Assimilation Angle Coefficient	0.5
Zeta	0.02
Damp Ratio	0.99
Uniting Threshold	0.02

Table 2. Results of CES-PID Optimization with ICA

Best Solution =
Columns 1 through 5
3.8464 0.0151 4.0000 99.8004 59.3888
Column 6
9.5142
ImerialistCosts =
0.0169579376715713 0.0162729090760798 0.0166781750304783

ICA optimization results obtained fitness function value of 0.0162729090760798, with 40 iterations. The minimum value of the system performance function at each iteration is plotted on the convergence graph shown in Figure 7. In the Figure it can be seen that the ICA algorithm can quickly converge on the 21 iteration or find the most optimal value at the 21th iteration. Table 3 shows the value of CES-PID parameter optimization results after tuning by ICA.

Table 3. Results of Tuning of CES-PID Parameters

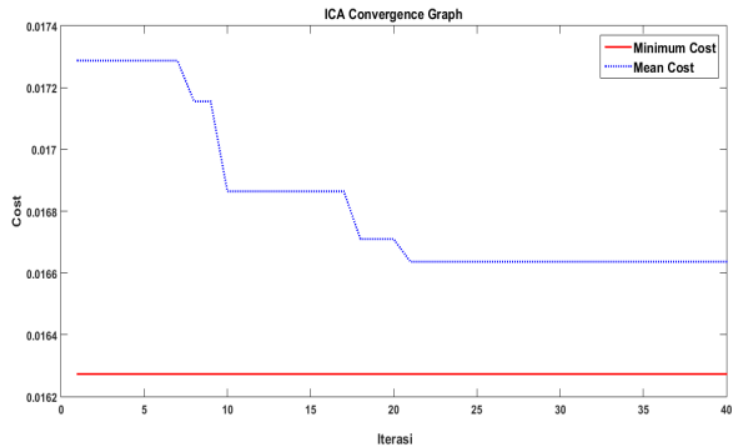| Parameter	Limits		Results
	Lower limit	Upper limit	
Kp_pso	0	10	3.8464
Ki_pso	0	10	0.0151
Kcf_pso	0	10	4.0000
Kp_c	0	100	99.8004
Ki_c	0	100	59.3888
Kd_c	0	10	9.5142

Figure 7. ICA Convergence

Figures 8 to 11 shows the Wind-Diesel power plant design used in this study. Figure 8 shows the Wind-Diesel model design without control. Figure 9 shows the Wind-Diesel model design with PID controller, while in Figure 10 the Wind-Diesel model design with PID-CES controller is illustrated. Figures 11 and 12 give the CES model design and the overall system design, respectively.
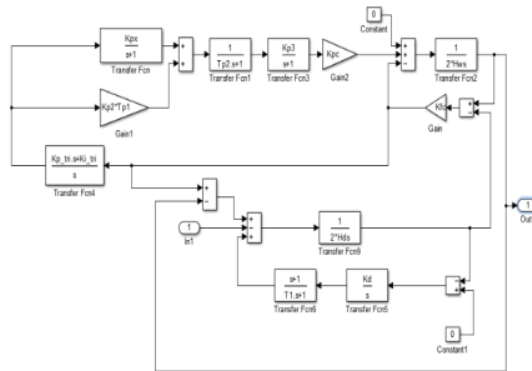

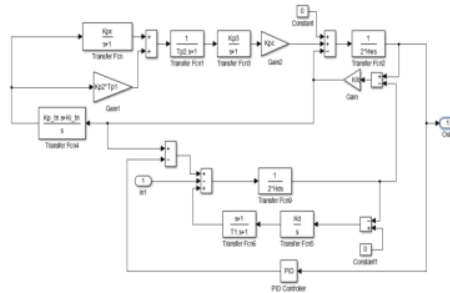Figure 8. Wind-Diesel design without control
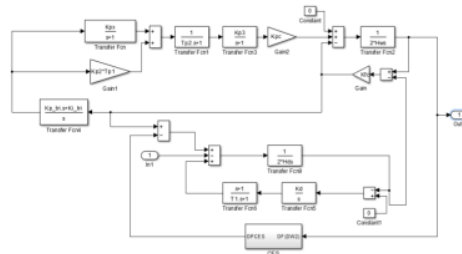

Figure 9. Wind-Diesel Design with PID controller
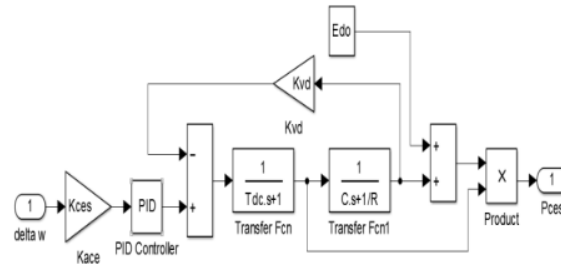
Figure 10. Wind-Diesel Design with PID-CES controller
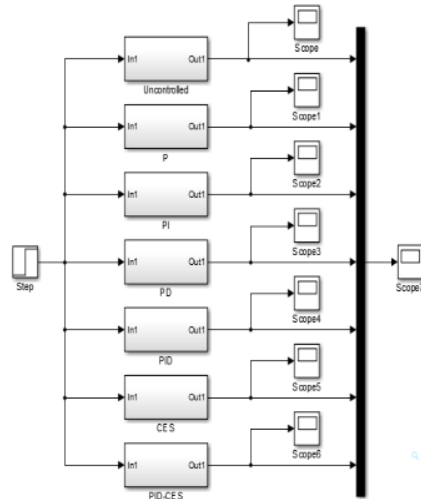

Figure 11. CES Controller Design

Figure 12. Wind-Diesel Controller Design

5. RESULTS OF SIMULATION AND ANALYSIS

A. Frequency Response Wind-Diesel Without Controller

There are several procedures before designing the controller on a wind-diesel generator, and as a first step will be seen the response of wind-diesel system without a controller. The system response is shown in the following graph.
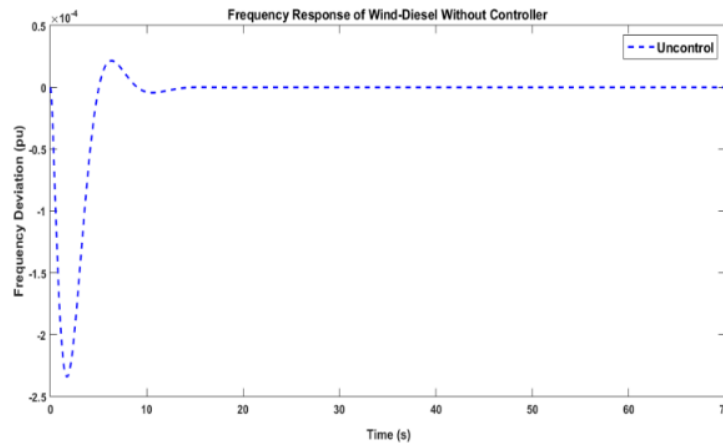

Figure 13. Wind-Diesel frequency graph without controller

From the graph above, we can get a very large Wind-Diesel overshoot value. More results are as shown in Table 4.

Table 4. Overshoot Value

Characteristics	Value
Overshoot (pu)	-0.0002344 & 2.149e-05

From the picture above, the overshoot value generated from the Wind-Diesel generator simulation is the largest overshoot value among all the simulations performed, ie -0.0002344 to 2.15e-05. This is because the frequency control of the system is only done or charged to the governor only. Systems that are not equipped with a frequency controller on the generator will be the most unstable system among other systems given the controller. This result will be used as reference for designing frequency control on wind-diesel.

B. Frequency Response Wind-Diesel Using Proportional Controller

After viewing the system response without the controller, it takes controller to improve the performance of wind-diesel. The following shows the simulation results using the Proportional controller, which is installed as a wind-diesel frequency regulator. The proportional controller parameter is tuned using Imperialist Competitive Algorithm (ICA) algorithm. The simulation results are shown in the following graph.
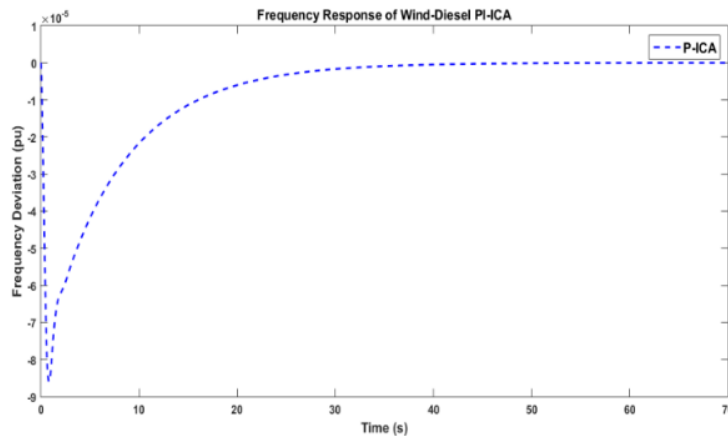
Figure 14. Wind-Diesel frequency response with PI controller

It can be seen from the picture above that when a load or disturbance occurs (in this case load changes), the frequency of the system oscillates before reaching steady state. The overshoot value that occurs can be seen in Table 5.

Table 5. *Overshoot* Value

Characteristics	Value
Overshoot (pu)	-8.595e-05 & 3.443e-09

It can be seen from the value shown in the table above that with the installation of the Proportional controller, the frequency of the system oscillates between -8.595e-05 & 3.443e-09. When compared to the system frequency response that is not equipped with the controller, the overshoot value has become smaller, but not recommended as a controller.

C. Frequency Response Wind-Diesel Using Proportional - Integral Controller

The response obtained by using proportional controller, can still be improved by using a combination of proportional-integral controller (PI). The PI parameter is tuned using the ICA algorithm. The simulation results are shown in Figure 15.
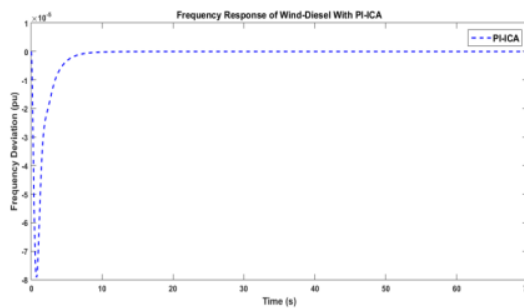

Figure 15. Wind-Diesel frequency response with PI Controller

From Figure 15, the frequency response result for Wind-Diesel system with PI controller. From the data plotted, it can also be seen that the overshoot value, as given in Table 6.

Table 6. O*vershoot* Value

Characteristics	Value
Overshoot (pu)	-7.922e-05 & 6.885e-10

From the graph and table above, it can be concluded for system with PI controller, system performance still not optimal, because there is still overshoot on wind-diesel. Therefore, the performance of the controller can still be optimized again.

D. Wind-Diesel Frequency Response Using Proportional - Derivative Controller

It has been found that the response obtained by using a combination of proportional-integral controller is still not reaching at the optimum level. The following details are the combinations using [19] Proportional - Derivative (PD) controller. The PD parameter is tuned using the ICA algorithm. The simulation results are shown in the Figure 16. Clearly, the frequency response result for Wind-Diesel system with PD controller. From the chart it can also be seen that the overshoot value as in the Table 7.

Table 7. O*vershoot* Value

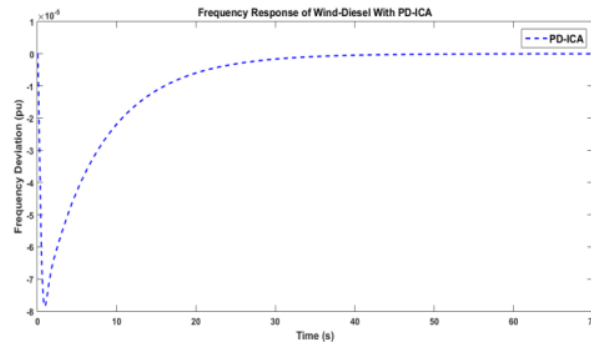| Characteristics	Value
Overshoot (pu)	-7.849e-05 & 2.03e-09

Figure 16. Wind-Diesel frequency response with PD Controller

From the graph and table above, it can be concluded for the system with the PD controller, the performance of the system is still not so optimal, because the response obtained is still overshoot on wind-diesel. Therefore, the performance of the controller can still be further optimized.

E. Wind-Diesel Frequency Response Using Proportional - Integral - Derivative Controller

The responses obtained by using a combination of PI and PD controllers are still not optimal. The performance of the controller will be better if the combination of PID is used simultaneously. Because the PID works simultaneously, the tuning parameters of each parameter must be precise. For that purpose used ICA-based intelligent method to tune the parameters. The following shows the simulation results of the controller combination using the Proportional - Integral -Derivative (PID) controller. The simulation results are shown in Figure 17.
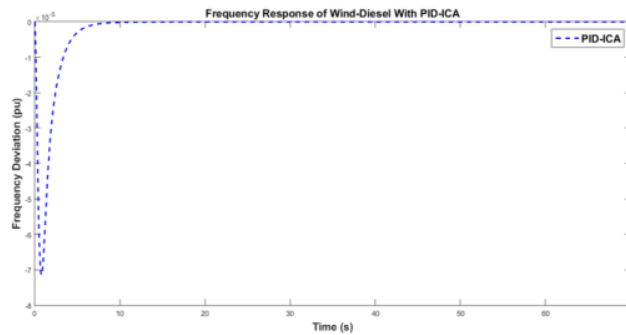

Figure 17. Wind-Diesel frequency response with PID control

As can be seen from Figure 17, the frequency response result for Wind-Diesel system with PID controller. From the chart, the overshoot value is also captured, as shown in the Table 8.

Table 8. *Overshoot* Value

Characteristics	Value
Overshoot (pu)	-7.15e-05 & 0

F. Wind-Diesel Frequency Response Using Capacitive Energy Storage Controller

From the graph and table above, it can be concluded for the system with PID controller, the performance of the controller is good enough to improve the oscillation system, but the performance of the system can still be improved. In this research will be proposed a Capacitive Energy Storage (CES) energy storage to be combined with the PID controller in adjusting the frequency in Wind-Diesel. The overshoot result with PID controller is given in Figure 18.
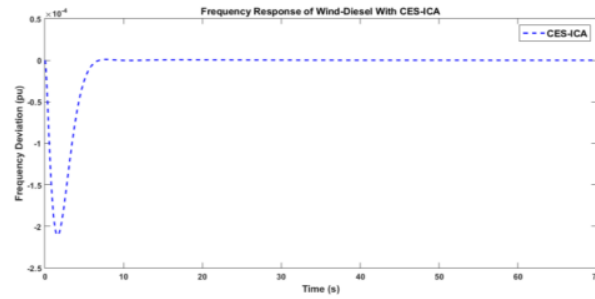
Figure 18. Wind-Diesel frequency response with CES controller

It is apparent that the frequency response result for Wind-Diesel system with PID controller. From Figure 18, the captured overshoot value is as given in Table 9.

Table 9. Overshoot Value

Characteristics	Value
Overshoot (pu)	-0.0002106 & 9.552e-07

G. *Wind-Diesel Frequency Response Using PID- Capacitive Energy Storage (CES) Controller*

The control method proposed in this study is PID-CES-based controller. The PID-CES parameters will be optimized using ICA-based intelligent algorithms. The results in this response are shown in Figure 19.

Figure 19. Wind-Diesel frequency response with PID-CES controller

Clearly, the frequency response result for Wind-Diesel system with PID-CES controller, with the the overshoot value as given in Table 10. From the data shown Figure 19 and Table 10, it can be concluded for systems with PID-CES controllers, can properly improve the overshoot system, in other words the frequency in Wind-Diesel does not oscillate too high. The comparison results for each controller are shown in Figure 20.

Table 10. *Overshoot* Value

Characteristics	Value
Overshoot (pu)	-1.435e-05 & 0

Figure 20. Wind-Diesel frequency response chart with PID & CES controller

6. CONCLUSION

This research proposes an additional controller for load frequency control at a Wind-Diesel power plant using PID-CES. The PID-CES parameters are optimized using smart methods, ICA algorithms, with the details as discussed in the earlier section. In conclusion, the PID-CES controller proposed in this study has a significant influence in the damping of the oscillations. Therefore, it is proposed for application in a Wind-Diesel.

ACKNOWLEDGEMENT

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