ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 13, Issue 7, July 2026

Load Frequency Control of Standalone Microgrid By MFO-WC Based PID Controller

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I. Abstract— The standalone microgrids are sensitive to frequency deviations due to fluctuation in renewable generation and changes in load demand. Worthwhile and effective frequency control requires swift actions, minimal overshoot, and sustained stability under variation and disturbances. In this paper Proportional-Integral-Derivative (PID) controller is tuned by using the advanced hybrid Moth-Flame Optimization (MFO) and Water Cycle Algorithm (WCA) to enhance the frequency response of autonomous microgrid. In The hybrid MFO-WC algorithm, the MFO provide strong global exploration capability while the WCA gives the fast local convergence of best solution. Which improve the efficiency of parameter tuning and prevent from premature stagnation in local minima. The objective function is stated using the Integral of Time Absolute Error (ITAE) to minimize oscillation, overshoot, and settling time. The Simulation model of standalone microgrid is studied in MATLAB software with PID tunning. The results illustrate that the hybrid MFO-WC-tuned PID controller significantly improves dynamic frequency performance compared to conventional PID tuning and standalone optimization techniques.

Keywords— Microgrid, PID controller, hybrid MFO-WC, MATLAB.

I. INTRODUCTION

The continuous increment in the energy demand and fall off the convention sources is the main reason of the expanding the usages of renewable energy resources (RESs). The concept of microgrid is vital to interlaced the RESs into electric grid to maximize the utilization of renewable and distributed energy sources to refine the power system stability. Solar, Wind energy, energy storage and local loads are the parts of the microgrid (MG). The mostly renewable energy sources output depends on the climate condition such as solar, wind etc. The fluctuation in frequencies comes about due to a lack of equilibrium between the load demand and power generation. A good Load Frequency Control (LFC) mechanism is needed to ensure that the microgrid will operate reliably and stably. LFC strives to reduce the frequency variation and provide balance in the system keeping the grid frequency within acceptable range, and additionally enables steady operation of the power system of constant frequency.

There are various studies related to LFC of traditional grid along with microgrid have been published by number of researchers.in [1] the PID controller used for LFC of autonomous microgrid tuned by Grasshopper optimization algorithm (GOA).in [2] D.C das et al. also proposed PID controller tuned by Particle swarm optimization algorithm (PSO) for frequency control of separate microgrid. in [3] Discussed about the frequency deviation caused by imbalance between supply and demand control of microgrid with different types of power sources with help of tie-line. In [4] the FLC of microgrid done by Fuzzy logic Proportion-Integral (PI) controller based on MFO-WC for steady state model of microgrid using MATLAB software. In [5] frequency control of microgrid is done by Genetic Algorithm (GA) based controller. In [6] the dynamic behavior of an autonomous hybrid system is done with the help of wind turbine, solar array, battery and proposed a controller strategy using the microturbine.

In this research the model of an autonomous AC microgrid consist DEG, Solar array, Fuel Cell, WTG, Hydro generator unit and Aqua Electrolyzer which is used to examine the frequency regulation and management during the self-operating mode. The ultimate aim of this research is that to find the suited gain of the PID controller by using hybrid MFO-WC optimization method for FLC of considerate MG to improve the frequency regulation for balancing the supply and load demand to make system stable.

To our limited information, the use of hybrid MFO-WC is not use till now to tune the PID controller for the frequency regulation of MGs. In this paper the dynamic model of the MG is analyzed with the help MATLAB Simulink software.

This paper is organized as follows: Section II present the clear description of an isolated microgrid and its components. The PID controller and fitness function are discussed in section III. The brief information about hybrid MFO-WC algorithm is given in section IV. The result and discussion are considered in Section V. Paper outcome is concluded in the last section VI.

II. MICORGRID MODEL

In this paper we analysed an autonomous MG showing in Fig.1 which is associated with Solar PV system, Diesel generator, Hydro generator unit, Wind turbine generator, Fuel cell and aqua electrolyzer with customer loads. Firstly

ISSN (Online) 2395-2717

International Journal of Engineering Research in Electrical and Electronic Engineering (IJEREEE)

Volume 13, Issue 7, July 2026

all the components of MG are modelled and the complete microgrid model is shown Fig 2.

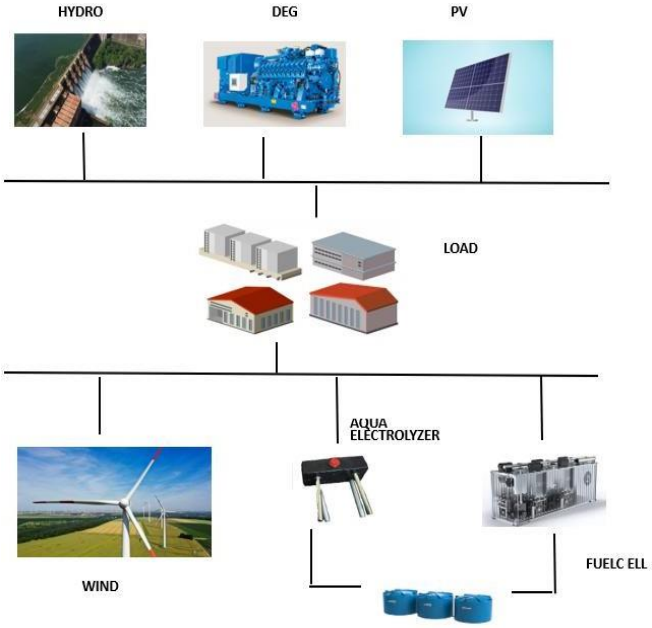


Fig. 1. Configuration of consider MG

A. Wind Turbine Model

The wind turbine generator (WTG) is modelled in its dynamic behavior as a transfer function as given below:

$$G_{\text{wtg}}(s) = \frac{\Delta P_{\text{wtg}}}{\Delta P_{\text{wt}}} = \frac{K_{\text{wtg}}}{1+sT_{\text{wtg}}} \quad (1)$$

Where ΔP_{wtg} is variation in wind turbine generation, change in wind power available is given as ΔP_{wt}. K_{wtg} is gain and T_{wtg} is the time constant of wind turbine generation.

B. Hydro Generating Unit

The hydro generating unit characterized by transfer function is given below:

$$G_{\text{Hu}}(S) = \frac{K_h}{1+sT_{hg}} \times \frac{1+sT_r}{1+sT_{ha}} \times \frac{1-sT_{ht}}{1+0.5sT_{ht}} \quad (2)$$

Where hydro governor gain constant represented as K_h , T_{hg} denotes hydro governor time constant in sec. T_{ha} is time constant of hydraulic amplifier in sec. T_{ht} is time constant of hydro turbine in sec and the reset time for hydraulic amplifier in sec indicated by T_r.

C. PV System Model

The mathematical transfer function of the Solar PV system follows the following expression:

$$G_{pv}(S) = \frac{\Delta P_{pv}}{\Delta P_{\emptyset}} = \frac{K_{pv}}{1+sT_{pv}} \quad (3)$$

Where ΔP_{pv} is variation in solar radiation, $\Delta P\emptyset$ is change in solar power, K_{pv} is gain of PV model and T_{pv} is time constant.

D. Deisel Generator

The DG model has a mathematical transfer function that is described by the following expression:

$$G_{dg}(s) = \frac{1}{1+sT_{dg}} \times \frac{1}{1+sT_{dt}} \quad (4)$$

E. Aqua Electrolyzer and Fuel Cell Unit

The aqua electrolyzer used to generate the hydrogen gas which is used by fuel cell for electricity production. It uses to compensate the power in grid connected renewable energy resources as well in standalone MG. The impact of aqua electrolyzer and fuel cell on MG frequency is discuss in [7].

$$G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}} \quad (5)$$

$$G_{FC}(s) = \frac{K_{FC}}{1+sT_{FC}} \quad (6)$$

Where T_{AE} and T_{FC} are the time constant, K_{AE} and K_{FC} indicates the gain constant of FC and AE, respectively.

F. Microgrid System Model

To examine LFC of microgrid, the considered mathematical model of the MG is shown in Fig. 2. P_{pv} represent the output power of solar PV array system and wind turbine generator output given by P_{wtg} . ΔP_L is the total power consumed by load. The frequency deviation is represented as Δf in Hz.

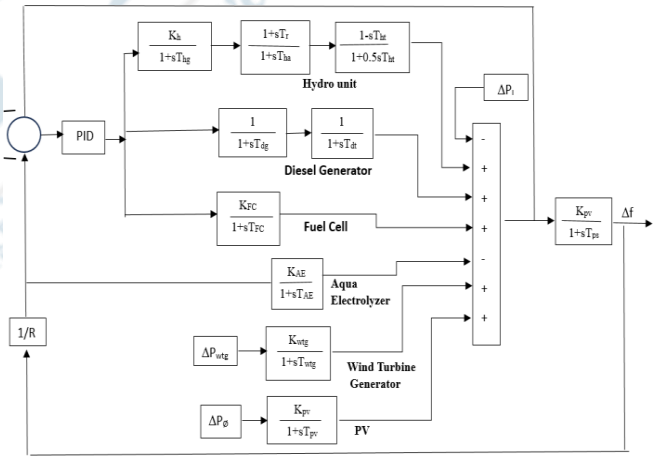


Fig. 2 Block representation of MG system

Equation (7) can be considered as the sum total of the power output of all distributed generation units in the AC microgrid.

$$P_G = P_{wtg} + P_{pv} + P_{FC} + P_{dg} + P_{hu} - P_{AE} \quad (7)$$

Because the output power of RES (PV and WTG) is unknown, these RES are not include in secondary frequency control loop. For the frequency control of system, only HU, FC and DEG are taken for the operation to meet the change the frequency deviation into system due to their flexibility. So the expression for the change in power is given as Eq.(8):

$$\Delta P_G = \Delta P_{wtg} + \Delta P_{pv} + \Delta P_{FC} + \Delta P_{dg} + \Delta P_{hu} - \Delta P_{AE} \quad (8)$$

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The power deviation is define as the difference between the power generation PG and power demand PL. In the power system the swing equation define the generation–load imbalance, the swing equation for one synchronous generator is define as Eq. (9)

$$\Delta f = \frac{f_{sys}}{2H}[\Delta P_G - \Delta P_e] \quad (9)$$

Where

$$\Delta P_e = \Delta P_L + D\Delta f \quad (10)$$

Where f_{sys} is the steady state frequency, D is the load damping factor, H indicates machine inertia and R coefficient represent the droop slope. The transfer function characteristic of power system model is given as:

$$G_{sys}(s) = \frac{\Delta f}{(\Delta P_G - \Delta P_L)} = \frac{1}{D+\left(\frac{2H}{f_{sys}}\right)s} = \frac{K_{ps}}{1+sT_{ps}} \quad (11)$$

Where K_{ps} is 1/D and T_{ps} is 2H/(Df_{sys}).

III. PID CONTROLLER AND FITNESS FUNCTION

The PID controller which is used in the MG model and Fitness function explained in this section.

A. PID Controller

Proportional-Integral-Derivative (PID) controller has been a popular controller in the microgrid frequency control, as it is simple and also has great dynamic performance. It acts on the frequency deviation signal with proportional, integral and derivative terms compensating the system with fast corrective action, steady-state frequency error and transient improvement of damping respectively.

Under the proposed microgrid frequency control model, a PID controller is taken up as a second frequency controller to control the system frequency during load and renewable power disturbances. The controller acts on the frequency deviation signal, the droop characteristic (1/R) follower-fed, and produces a corrective control action in proportional to the deviation signal, plus on an integral form of the decisive control action, and a derivative form of the decisive control action. The result of the PID is sent in parallel to hydro unit, diesel generator and fuel cell to coordinate the power change to the corresponding dynamic characteristics that can reduce power imbalance and reinstate the system frequency. The parameters of PID controller are optimized by using hybrid MFO-WC algorithm to minimize the objective function.

The equation of PID controller for frequency error is shown in Eq. (12):

$$e(t) = K_p\Delta f + K_i \int \Delta f \, dt + K_d \frac{d(\Delta f)}{dt} \quad (12)$$

B. Fitness Function

The objective function used to optimize the controllers in a microgrid is of great importance in the dynamic performance of the microgrid. The controller gains are consequently calculated by minimizing a time-domain performance index to achieve an effective frequency control response. To evaluate the evidence of this work, the Integral of Time-weighted Absolute Error (ITAE), is taken as the fitness function since it puts more emphasis on the frequency deviations which last longer. This property offers assistance in damped sustained oscillations as well as enhancing the transient behavior through minimizing frequency overshoot and the settling time. Thus, fitness function based on ITAE is used to obtain better frequency regulation of the developed microgrid control scheme. The expression for fitness function is shown in Eq. (12) and (14):

$$\text{ITAE} = \int_0^{t_{sim}} |\Delta f| \cdot t \cdot dt \quad (13)$$

$$\text{Fitness} = \text{Minimize}\{\text{ITAE}\} \quad (14)$$

IV. HYBRID MOTHFLAME WATER CYCLE OPTIMIZATION ALGORITHM (MFO-WC)

Water Cycle Algorithm (WCA) refers to a nature inspired algorithm of optimization that simulates the flow of water over the natural water cycle. The algorithm has a high level of exploration ability in the first search, but it has a low level of exploitation ability, which could be a limitation to the accuracy of convergence. The Moth-Flame Optimization (MFO) algorithm is based on the navigation principles of moths that stay on the same angular direction relative to the luminous bodies in nature including the moon. Moths exhibit a spiral path when subjected to artificial light, which allows them to successfully explore the search space. Although this is an asset, MFO can in some instances prematurely converge to local optimal solutions. To address the weaknesses of the two methods, the advantages of WCA and MFO are integrated and create a hybrid optimization algorithm of MFO-WC [8]. This is a blend of the world discovery and the local search that brings about better convergence reliability and solution precision of complex optimization problems.

V. RESULT AND DISCUSSION

The simulation result for MG frequency control is discussed in this section with different types of variable disturbance parameter like ΔPØ, ΔP_{wt} and ΔPL. The PID controller tuned by MFO-WC optimization algorithm and provided the efficient result after optimization.

The PID controller parameter is obtain by MFO-WC algorithm to enhance the performance of PID controller. The performance analysis of Simulink model MG Fig. 2 is done by using the MATLAB/Simulation R2025a software on Intel Core i5 CPU optimization algorithm is run by taking 30 number of populations and 30 iterations. he table1 represent the parameters taken for the simulation model, table 2 represent the PID parameter value before and after optimization for different cases.

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Table 1. MG PARAMTERS

Parameters	Value	Parameters	Values
2H	0.1885	Thg(s)	48.8
Tt(s)	0.6	Tha(s)	0.515
R	2.6	Kh(s)	1
D(pu/Hz)	0.016	Tht(s)	1
TFC(s)	0.28	Tr(s)	6
KFC	1	TAE(s)	0.2
KAE	1	Tpv(s)	0.04
Tdg	0.06	Kpv	0.0076
Twtg	1.5	Kwtg	1

A. Scenario 1: Variation in Wind Power ΔP_{wt}

This case represents the consideration of random variable wind power which shown in Fig. 3 and the output the model after the optimization of PID controller is shown in Fig 4. That show the stabilization of the frequency after the optimization

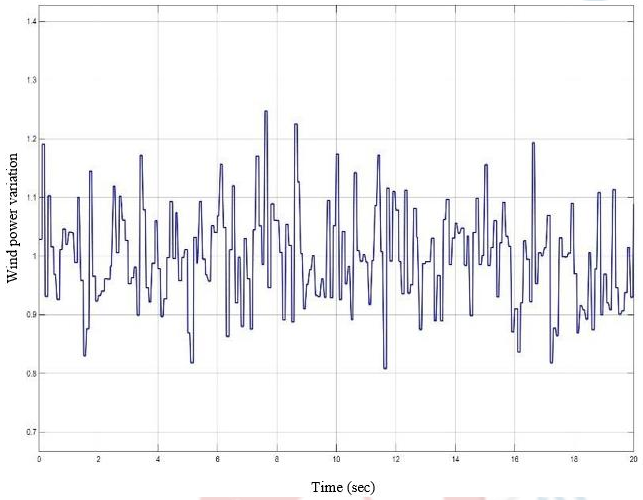


Fig 3 Wind Power Variation

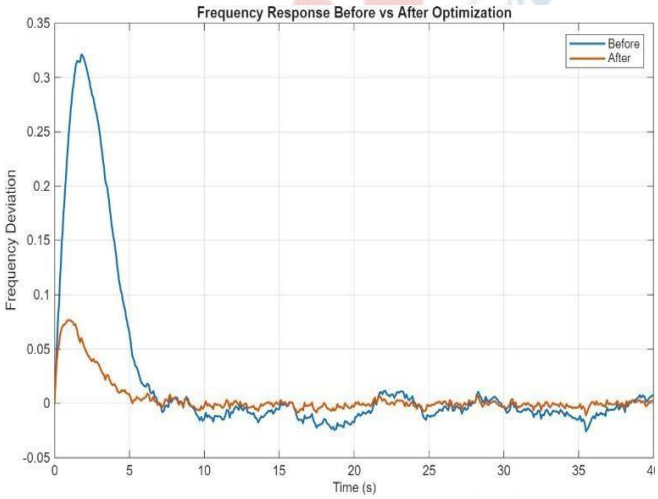


Fig 4. MG Frequency response for Scenario 1

B. Scenario 2; Variation in Load ΔPL

In this case the only variation in load power is applied to the system. The random change in load power is shown in fig. 5 and the frequency response shown in fig. 6:

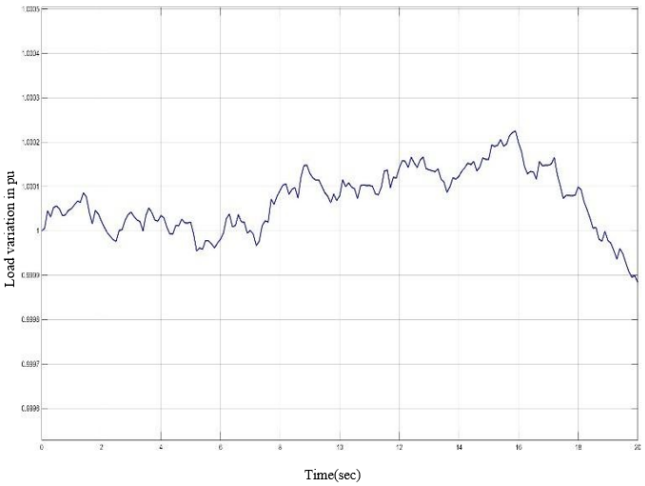


Fig 5. Load Variation

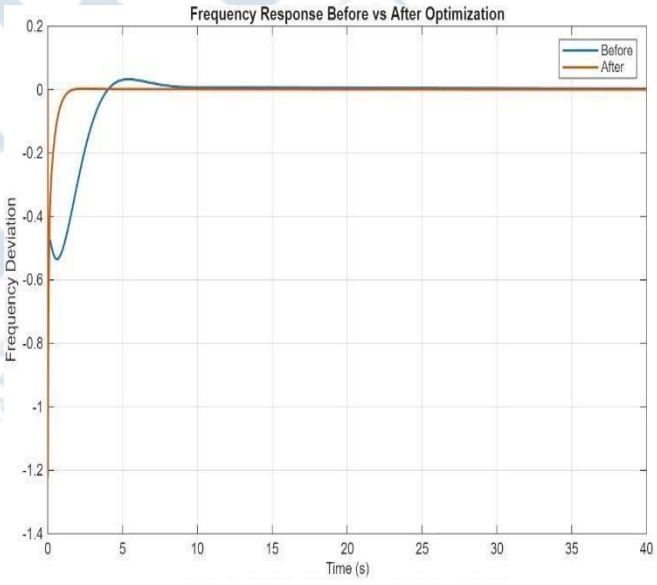


Fig 6. MG Frequency response for Scenario 2

C. Scenario 3; Variation in Solar Radiation

The change in solar radiation is shown in the fig. 7 at different time instant and MG frequency response shown in fig. 8:

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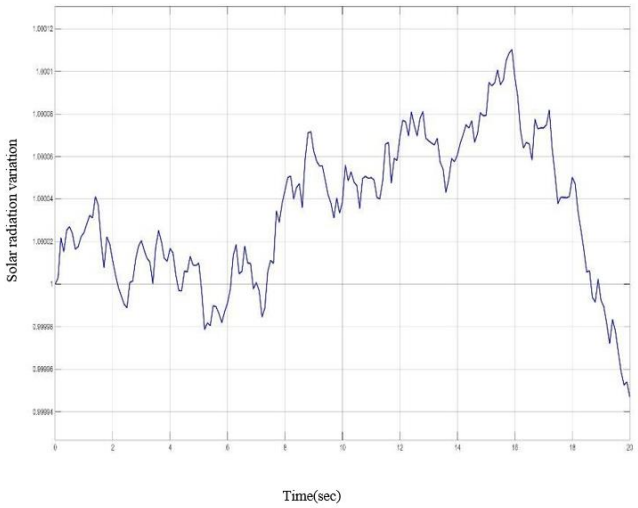


Fig. 7. Solar Radiation Variation

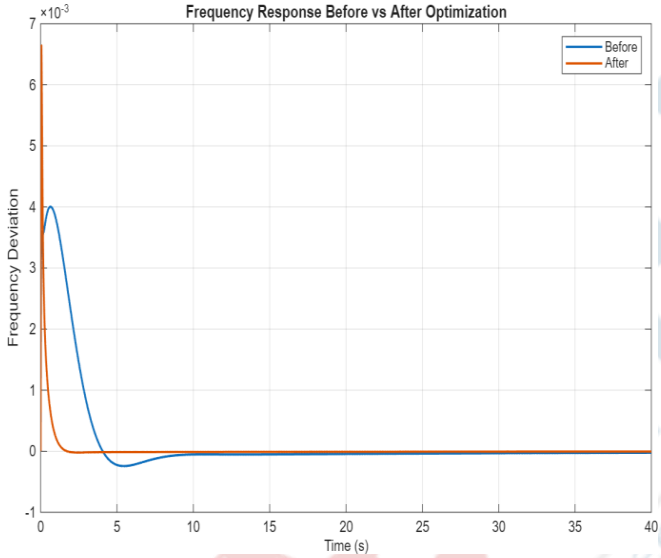


Fig 8. MG Frequency response for Scenario 3

The PID controller parameter after optimization in shown in Table 2 and IATE value and settling time given in Table 3:

Table 2. PID Controller Parameter

Parameter	Scenario 1	Scenario 2	Scenario 3
Kp	4.999428	3.076142	2.936924
Ki	4.999827	5.000000	5.000000
Kd	0.999408	0.505009	0.390307

Table 3. ITAE Values and Settling time

	ITAE	Settling time (s)	Peak overshoot / undershoot (Hz)
Scenario 1	2.080	3.700	0.077
Scenario 2	0.852	1.100	1.220
Scenario 3	0.006	0.055	0.007

VI. CONCLUSION

The present research has effectively utilized a hybrid optimization method, regarded as a combination of Moth-Flame Optimization and Water Cycle Algorithm (MFO-WC) to gain optimal values of PID controller parameters to improve the dynamic stability of an autonomous microgrid. The offered strategy was tested based on several operating disturbances, such as load change, wind power change, and renewable intermittency. The MFO-WC-tuned PID controller was effective and strong. The results of the simulation clearly indicate that MFO-WC algorithm always attains low values of the fitness functions and a huge reduction in frequency deviation in all the scenarios tested. The high quality of transient response, short settling, and better damping properties verify the strength and efficiency of the suggested hybrid algorithm over that of other optimization algorithms. The results point to the fact that the PID tuning strategy based on MFO-WC is a quality and effective approach to frequency regulation in isolated microgrids. Further work may be expanded to grid connected microgrids.

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