Journal of Electrical Engineering and Automation (ISSN: 2582-3051)
www.irojournals.com/iroeea/

Performance Assessment of a MPID controller in Microgrid Systems for Load Frequency Control

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Abstract

This study provides a novel methodology to design an A.C. off-grid multi-microgrid (MMG) system and suggests an analytical method for load frequency management utilizing a multistage PID (MPID) controller based on the sine cosine algorithm. The unique benefits of an MMG system are similar to those of renewable energy sources (RES), such as solar system models, wind turbine models, etc. There is a conflict between the MMG system's source and the load requirement because of the erratic properties of renewable energy sources. The irregular nature of renewable energy sources has an impact on the frequency of the system. Therefore, it is very difficult these days to check the frequency in a MMG system. This article uses the SCA-based MPID to tune the controller parameter for secondary frequency control, despite all of the complexity. In the power system, LFC (load frequency control) is achieved by regulating active power. The dynamic response of the conventional PI-PID controller has been used to assess the effectiveness of the proposed MPID controller. Using the sine and cosine approaches, the parameters are optimized.

DOI: https://doi.org/10.36548/jeea.2024.1.004
Received: 07.03.2024, received in revised form: 01.04.2024, accepted: 13.04.2024, published: 26.04.2024

Keywords: Microgrid, LFC, Photovoltaic system, Wind Model, MPID.

1. Introduction

There is a significant decrease in fossil fuels at the moment because they are used so extensively in industry, construction, and transportation. Fossil fuel consumption is one of the main causes of the environment's carbon dioxide (CO2) production. Greenhouse gases, such as methane (CH4), carbon dioxide, CFC, and others, are carbon byproducts that pose a serious threat to the ecosystem. The earth's surface emits infrared radiation, which these greenhouse gases absorb and cause the earth's surface temperature to rise daily. This is the cause of climate change and the cause of global warming. Thus, the researchers are attempting to rely more on RES and are dipping the use of fossil fuels. (Such as Solar, Wind, Biomass, Tidal etc.). There are numerous more benefits to renewable energy sources, such as: 1. There is no energy depletion. 2. Neither pollution nor global warming exist. 3. Because these sources are natural, they require less maintenance and have lower operating costs. Because obtaining electrical energy from a grid is not feasible everywhere due to cost considerations, this increased usage of conventional energy sources will only be made practicable by the employment of MGs [1]. The MG functions in two ways. 1. Mode connected to the grid 2. The island mode.

When there is no failure in the main utility grid, additional traditional energy sources are employed to compensate for the variance in load. In typical conditions, the grid-connected mode is active, meaning that MG is connected to the main grid. We refer to this as an islanded microgrid. When renewable energy sources take over as the source of voltage/frequency support, power production fluctuation becomes unavailable, resulting in an imbalance between the load and output of power. Furthermore, the load frequency variation is largest and the voltage and frequency fluctuations pose the biggest danger to grid security when the MGs are coupled to form a multi-micro grid (MMG). To address this issue and ensure a secure and consistent supply, the optimal controller's created technique is helpful. Specifically, MGs need to have backup storage devices that can regulate frequency fluctuations. Therefore, load frequency control, or LFC, is a necessary component for loading equipment correctly. Hybrid renewable energy has become the primary power source in recent years. However, this is also caused by a frequency fluctuation issue. Numerous control systems, including as intelligent control, adaptive control, and Model predictive control (MPC)-based coordinated control, have been proposed to address this issue. With fewer PHEVs needed, the coordinated control that relies on MPC makes wind power generation easier. However, there are two basic features in an MG that make all these control strategies functional. There is a decentralized structure in one of them and a centralized structure in the other. For islanded MGs, a centralized structure is employed, whereas for grid-connected MGs, a decentralized structure is preferred [2, 3].

Figure 1. Illustrative Representation of MG System [16]

There are two ways to operate a microgrid [5]. When operating in off-grid mode, the MG detects a significant frequency control issue that can be resolved with a strong control strategy [6]. It is seen from various study publications that the model involving renewable energy sources has the highest degree of unpredictability [6- 8]. Various renewable energy sources, such as solar and wind power, as well as battery storage systems, are examined for analyzing frequency stability. In a study by [7], the automatic generation control (AGC) of a multi-area power system with diverse energy sources is discussed. Papers [8] delve into the load frequency control of multi-microgrids using energy storage systems. Another paper [12] discusses a modified sine-cosine algorithm-based fuzzy-aided PID controller for automatic generation control in multiarea power systems. The integration of solar energy [10-11], wind energy [12-13], and battery storage systems [14] for load frequency control analysis is elaborated upon. To minimize the control error different controller techniques such as conventional P, PI, PID [15-16] , FO are considered by various researchers.

2. Contribution

In this research clear intention is to provide a frequency control of multi-source multiarea microgrid by using a sine cosine algorithm based multistage PID controller. The detailed contributions are described below by the following points.

- This multi-source multiarea microgrid consists of two microgrids which are interconnected by the tie-lines.
- Both the microgrids are made up of different components such as RES, photovoltaic, wind power production, synchronous generator, and ESS.
- The microgrid frequency control is achieved by applying a Multi stage-PID controller.
- Sine-Cosine algorithm (SCA) is implemented for optimizing the controller parameters.
- The Proposed SCA based MPID controller is estimated with predictable PI, PID controller to know the effectiveness.

3. Design of Micro Grid

In this multi-source multiarea microgrid, different types of components are present which are discussed in this section.

a. Synchronous Generator (SG) System

The purpose of a SG in a microgrid is very much essential. First it observes the demand fluctuation and then manage its fuel utilization by applying a suitable control technique.[9] In this research work the synchronous generator model includes turbine and a governor.

The governor system transfer function is

$$G_g(\text{sys}) = \frac{\Delta P_v(sys)}{\Delta P_g(sys)} = \frac{K_g}{1+sT_g} \quad (1)$$

Where T_g, K_g are the time constant of governor and gain respectively.

ISSN: 2582-3051

Turbine system transfer function is

$$G_t(\text{sys}) = \frac{\Delta P_m(sys)}{\Delta P_v(sys)} = \frac{K_t}{1+sT_t} \quad (2)$$

Where T_t , K_t is the turbine time constant & gain respectively [7, 8].

b. Solar Photovoltaic System

For providing expected output voltage and current solar pv system includes many cells. Solar cells are connected in series and parallel as per required voltage and current. The equation (3) provided below calculates the output power generated by the solar PV system. .[8]

$$P_{pv}=\beta \text{S}\varphi[1\text{-}0.005\{T_a+25\}] \quad (3)$$

where β, S stand for the conversion efficiency and area of the photovoltaic array (m^2) $respectively.$ φ stands for the solar irradiation (kw/m^2) and T_a - ambient temperature (°C).

T.F. of the solar PV model is [10,11].

$$G_{pv}(\text{sys}) = \frac{\Delta P_{pv}}{\Delta \varphi} = \frac{K_{pv}}{1+ST_{pv}} \quad (4)$$

Where $K_{pv}$is the photovoltaic gain & T_{pv} is the time constant.

c. Wind Model

The typical equation for wind system is given away below

$$\delta_w=0.8\sqrt{P_w} \quad (5)$$

Random O/P fluctuation is multiplied by the normal deviation for finding the O/P fluctuation of the wind structure. [12,13].

d. Energy Storage System

ESS has a significant character for flexible working of Multi micro grid system. Gess normally used to stop the power supply disturbance in a MMG system. The T.F. of the Gess and given in the equation (6) .

$$G_{ess}(sys)= \frac{\Delta P_{ess}}{\Delta \omega} = \frac{K_{ess}}{1+sT_{ess}} \quad (6)$$

Where K_{ess} is the ESS gain , T_{ess} is the time constant .

e. Power Deviation and system frequency variation

Combined power production (P_t)of MG structure is.

$$P_t=P_{sg}+P_{pv}+P_w + P_{ess} \quad (7)$$

ΔP_e explains inequality between the combined power production and power insistence character.

$$\Delta P_e=P_t-P_d \quad (8)$$

System frequency can be varied by varying the net power and can be determined by

$$\Delta\omega= \frac{\Delta P_e}{K_s} \quad (9)$$

K_s explains characterstics of system frequency of constant MG.

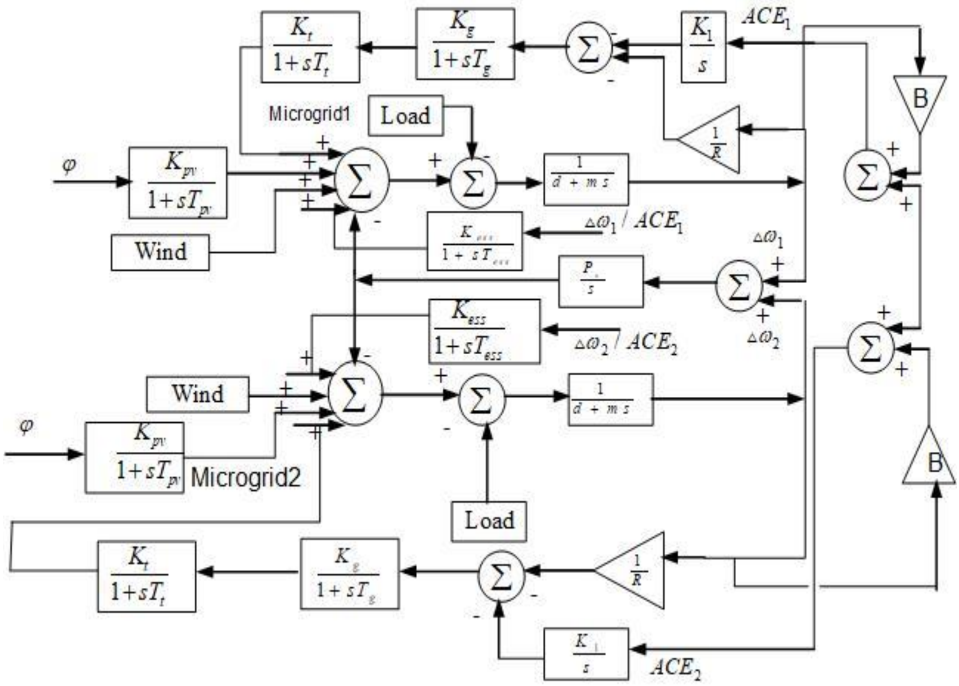

Figure 2. Simulation Model of Proposed MMG System [9]

$$G_S(\text{sys})=\frac{\Delta\omega}{\Delta P_e}=\frac{1}{K_S\,(1+sT_S)}=\frac{1}{d+ms} \tag{10}$$

Where m explains about equivalent inertia constant,d explains about damping constant of MG.

4. Controller Structure

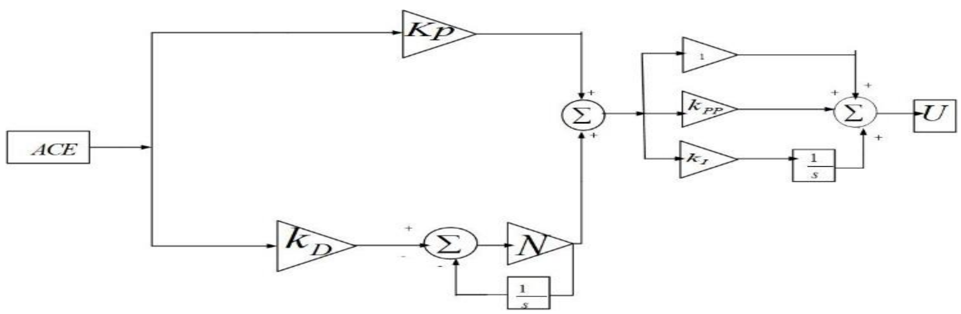

Figure 3. MPID Structure [16]

A PID controller is very popular in the industry. which can be manipulated in 1-proportional, 2-Integral and 3-Derivative. The traditional PID controller sometimes struggles to reach the best performance, but increasing the integral part of the PID controller can help.

By doing so, we can reduce the steady-state error. But during transient period this leads unpleasant operation of the system.

By taking the example for decreasing the steady state error, have to rise the integral gain of the particular controller results unwanted output. During steady-state observation, it's clear that the integral part plays a crucial role in reducing or eliminating steady-state errors. This can be achieved by implementing an MPID controller, composed of a first-stage P controller. The proportional derivative controller (PD) and proportional integral derivative controller (PID controller) of the MPID controller are coupled in series is shown in the fig (3).

For this proposed MMG system the parameters are taken from [14-16].

5. Result and Analysis

A multi microgrid power system is designed using MATLAB/Simulink environment consisting of solar, wind, and storage systems. Primacy of the suggested MPID controller with SCA is offered by associating with traditional PI and PID controller through numerous solutions having 50 iterations and 100 numbers of population. The optimized controller parameters of MPID based SCA has mentioned in Table 1. The Fig 4 (a) to 4(e) shows the output response obtained.

Table 1. SCA Minimum Suitability Augmented Parameters Values

Controller Variables	PI	PID	MPID
KP1	1.8623	2.9873	9.8125
KI1	5.7658	8.4523	3.8124
KD1	-	2.4563	3.4567
KP2	0.9178	8.2802	5.5623
KI2	0.8765	8.4321	1.1756
KD2	-	2.4378	8.5316
N1	-	-	140.5426
N2	-	-	145.1917
KPP1	-	-	2.7970
KPP2	-	-	0.5926

A. Output Response of Δω_1

B. Output Response of 〖Δω〗_2

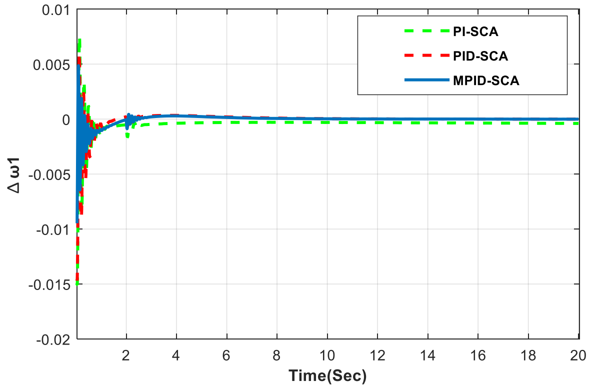

Figure 4. (a)

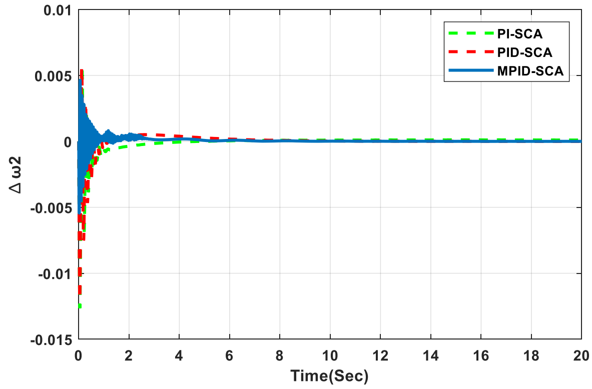

Figure 4. (b)

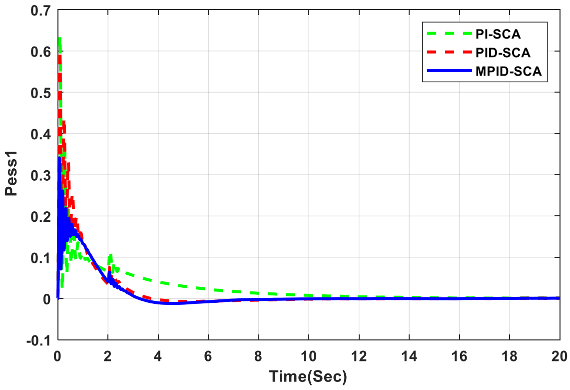

Figure 4. (c)

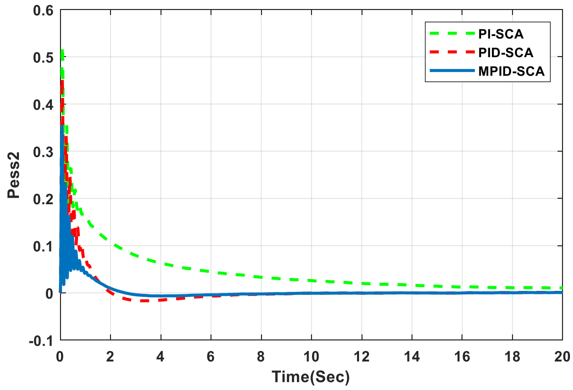

Figure 4. (d)

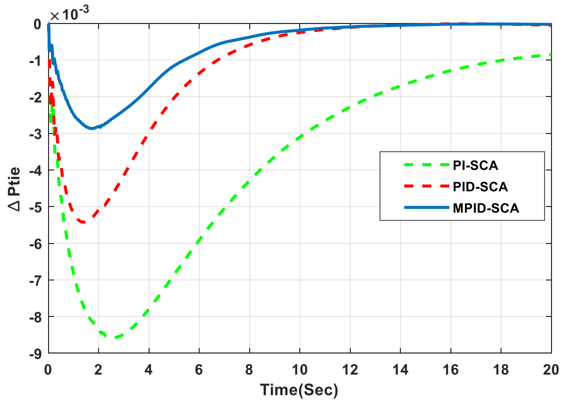

Figure 4. (e)

The frequency control take place in the MG1 ang MG2 which are shown in the Fig.4 (a) and Fig.4 (b). If we will compare the conventional PI,PID controller with MPID, MPID is the primacy controller between two. The settling time of PID and PI controller is 3.7529sec,18.0134 sec respectively. The settling time of MPID is 2.9815sec which is superior in contrast with other two controller. The supremacy of proposed MPID controller over conventional PI and PID are notified in Table 2 with improved dynamic performances in terms of overshoot, undershoot and settling time.

Table 2. Parameters of Different Controllers Responses

Controller Performance	**PI**			**PID**			**MPID**		
	O_{sh} **in pu**	U_{sh} **in pu**	T_s **in sec**	O_{sh} **in pu**	U_{sh} **in pu**	T_s **in sec**	O_{sh} **in pu**	U_{sh} **in pu**	T_s **in sec**
$\Delta\omega_1$	0.0076	-0.0151	18.0134	0.0060	-0.0147	3.7529	0.0049	-0.0105	2.9815
$\Delta\omega_2$	0.0055	-0.0124	6.3380	0.0050	-0.0114	5.4010	0.0044	-0.0059	3.0750
P_{ess1}	0.6356	0	13.0300	0.5964	0	7.5090	0.3410	0	6.6460
P_{ess2}	0.5110	0	19.4400	0.4496	0	7.3390	0.3538	0	6.4490
ΔP_{tie}	0	-0.0085	20.0000	0	-0.0053	13.1000	0	-0.0028	12.4000
ITAE	0.5067			0.2306			0.1666		

- The frequency control take place in the MG2 which is shown in the Fig.4 (b). If we will compare the conventional PI,PID controller with MPID, MPID is the primacy controller between two. The PID settling time and PI controller is 5.4010 sec,6.3380 sec respectively. The settling time of MPID is3.0750 sec which is superior in comparison with other two controller.

- The output response of ESS of MG1 is shown in the Fig.4 (c). If we will compare the conventional PI, PID controller with MPID, MPID is the primacy controller between two. The settling time of PID and PI controller is7.5090 sec, 13.0300 sec respectively. The settling time of MPID is 6.6460 sec which is superior in comparison with other two controller.

- The output response of ESS of MG2 is shown in the Fig. 4(d). If we will compare the conventional PI, PID controller with MPID, MPID is the primacy controller between two. The settling time of PID and PI controller is7.3390 sec, 19.4400sec respectively. The settling time of MPID is 6.4490 sec which is superior in comparison with other two controller.

- The output response of tie-line power of MG1 and MG2 is shown in the fig.4 (e). If we will compare the conventional PI, PID controller with MPID, MPID is the primacy controller between two the settling time of PID and PI controller is13.1000 sec, 20.0000 sec respectively. The settling time of MPID is 12.4000 sec which is superior in comparison with other two controller.

- If we will compare the ITAE, under shoot, over shoot, settling time value of the MPID controller between the two conventional PI,PID controller. The MPID controller is superior.

6. Conclusion

This paper approaches the LFC of the MMG system by presenting the Sine Cosine technique for the PID controller.

- In this paper, we use various conventional controllers such as PI, PID, and MPID controllers to regulate the frequency, energy storage system (ESS), and tie-line power of two interconnected areas

- To enhance the performance of the proposed controller, we apply the SCA algorithm to optimize the parameters of conventional controllers such as PI and PID

- MPID controller gives super dynamic responses in comparison with conventional PI, PID controllers.

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