Comparison of PID Type Controller Performance in Microgrid Frequency Deviation Enhancement Using MFO Algorithm

Maryam Houshyari
Hossein Shayeghi
Abdollah Younesi

Electrical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
Electrical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran
Electrical Engineering Department, University of Mohaghegh Ardabili, Ardabil, Iran

Abstract

This paper deals with an MFO algorithm based design of load frequency different PID type controller for a microgrid consisting of solar photovoltaic, diesel engine generator, fuel cell with the equa-electrolyzer and ultra-capacitor has been considered for simulation studies. The intermittent nature of solar power may cause serious problem of frequency fluctuation. Therefore, IPD and PDPI controllers designed for the purpose of minimization of frequency deviation and results are compared with PID controller. Control gains of the different controllers are optimized using Moth-flame optimization algorithm. Performance study of the power system is carried out under different perturbation condition. It is found that MFO based optimized PDPI controller is very superior to PID and IPD controllers in terms of settling time, overshoots and some performance indexes.

Keywords: Microgrid, Load frequency control, MFO algorithm, PID controller.

1.Introduction

Any country in the world, electricity is one of the most demanding forms of energy in every one's daily life. In recent years the increasing concerns about the limited fossil fuel resources, their impact on the environment, especially the global warming and the harmful effects of carbon emissions have created a new demand for clean and sustainable energy sources [1]. The gap between power generation and demand is widening day-by-day which has forced electric power utilities to supply power to the customers erratically. Not only this, there are many places in the world which are yet to be electrified due to energy shortage issue. Moreover, growing concern on deteriorating environmental condition has led the electrical power utilities round the world to search renewable energy sources based power generation technologies. Renewable energy sources based power generation technologies are clean, sustainable and environment friendly [2]. Solar power generation is one of the most promising renewable power generation technologies. Fuel cell also has potential to be considered as one of the green power sources of the future. However, renewable energy sources are mostly intermittent, so they can't supply quality power constantly. This problem solved by combining more renewable energy sources together with non-renewable or storage devices [3]. Currently, the microgrid power system is expected to create the smart power system for rural and isolated areas due to some advantages such as high quality and reliability, increasing efficiency, reducing costs, and environmentally friendly etc. The oscillations of load demand lead to mismatch between the power generation and load demand resulting in mismatch in system frequency (f) from the nominal value.

In the past, many researches have been proposed for controlling the oscillations of the frequency in microgrid. Many control strategies have been proposed in the literature. In [4], optimization of controller parameters proposed. Also in Refs. [5-6] variable structure control and in [7] energy storage controllers have been reported

The Proportional-Integral-Derivative (PID) controller has its widespread acceptance in the industrial processes due to its simplicity in understanding and its applicability to a large class of process having different dynamics [9]. Thus, in this paper type PID controllers designed simultaneously, for any renewable / non renewable energy sources. Type PID controllers are IPD and PDPI controllers presented in [10].

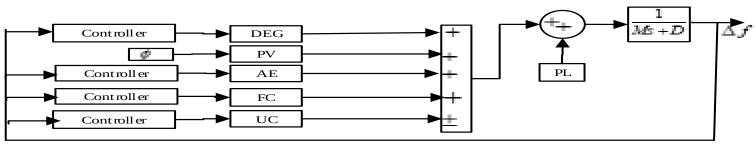
In the recent years, optimization techniques are being used to obtain the optimal solutions efficiently to the problems related to the operation and control of hybrid power system. Thus, the main motivation of the present work triggers from the use of this novel Moth-Flame Optimization (MFO) for optimizing controllers parameters for frequency regulation of the proposed hybrid power system. The main inspiration of this optimizer is the navigation method of moths in nature called transverse orientation. The statistical results on the benchmark functions show that this algorithm is able to provide very promising and competitive results [11].

In this paper, a microgrid consisting of Photovoltaic (PV), Diesel Engine Generator (DEG), Fuel Cell (FC), Aqua Electrolyzer (AE) and Ultra-Capacitor (UC) is proposed. The power system frequency deviates for sudden changes in load or solar PV power. The controllers are installed before the sources to alleviate this frequency deviation. The gain of the type PID controller is optimized using

MFO algorithm to mitigate frequency deviation owing to sudden generation/load change and dynamic performance of PID controller compared with the IPD and PDPI controller.

2.Proposed Microgrid System

The generalized block diagram of the studied microgrid is shown in Fig. 1. The system consists of diesel generator, FC, aqua electrolyzer, solar thermal and Ultra-Capacitor.The mathematical models with first order transfer functions, fuel cell, aqua electrolyzer, PV system, diesel engine generator are shown in this section. Nominal system parameters of the investigated microgrid model are presented in [1].



a.

b. Fig 1. Block diagram of the hybrid power system

A. Diesel Generator

Diesel generator can be used for emergency power supply. With sudden increase in load, it is necessary that a diesel engine prime. Moreover, it has a fast dynamic response and have a good capability of fluctuation rejection. The operation of DEG block may be given by simple transfer functions as stated in Eqs. (1).

$$G_{DEG}(S) = \frac{K_{DEG}}{T_{DEG}s+1} \quad (1)$$

B. Solar PV system

Photovoltaic (PV) system converts the solar radiation coming from the sum into electrical energy. The output power of the system is given by:

$$P_{PV} = \eta S\,\Phi\{1-0.05(T_a+25)\} \quad (2)$$

Where, η is conversion efficiency factor ranging from 9% to 12%, S (=4084 m^2) is the measured area of the PV array, ⍰ is solar radiation and T_a is ambient temperature in degree Celsius. The transfer function of the PV system is given as [12]:

$$G_{PV}(S) = \frac{\Delta P_{PV}}{\Delta\phi} = \frac{1}{1+ST_{PV}} \quad (3)$$

C. Aqua Electrolyzer

AE apart from being used as a device to produce hydrogen for a FC unit, it also serves as the controllable load. With the help of proper controller action, AE absorb the rapidly fluctuating output power from wind turbine generators and solar photovoltaic power system. The transfer function model of aqua electrolyzer can be expressed by [12]:

$$G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}} \tag{4}$$

D. Fuel Cell

Energy of fuel directly into electrical energy without classical combustion. Because of high efficiency and reliability, modularity, fuel flexibility, having no geographical limitations and being environment friendly, FC are seen as very prominent alternative to be used along with intermittent sources like wind turbine generator and solar photovoltaic that can be used in interconnected and islanded micro grid. For low frequency domain analysis it is represented by a first order lag transfer function model given as [19]:

$$G_{FC}(s) = \frac{K_{FC}}{1+sT_{FC}} \tag{5}$$

E. Ultra-Capacitor

Ultracapacitors are electrochemical type capacitors which are used to store electrical energy during surplus generation and deliver high power within a short duration of time duration of time during the peak-load demand. Similarly the transfer function of the ultracapacitor can be represented as a first order lag:

$$G_{UC}(s) = \frac{K_{UC}}{1+sT_{UC}} \tag{6}$$

F. Adopted Control Strategy

In this paper, type PID controllers are equipped for diesel generator, fuel cell, aqua electrolyzer, and ultracapacitor. Input to each controller is the sum of the error in supply demand and product of frequency deviation of power system and the gain. PID controller is one of the most commonly used conventional controllers used by the process industries. It is, easily, realizable and it offers superior performance in eliminating steady state errors and improving overall system dynamic response [13]. The architecture of the considered type PID controller is depicted in Fig. 2.

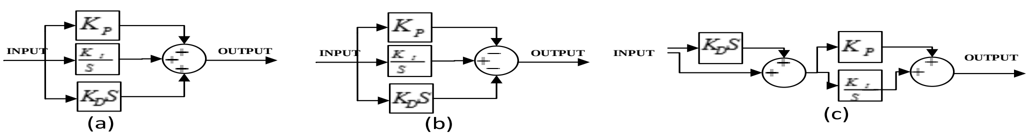


Fig. 2. *Type PID controller; (a) PID Controller, (b) IPD Controller, (c) PDPI Controller.*

3.Moth-Flame Optimization Algorithm

Moth-Flame Optimization (MFO) algorithm is a novel nature-inspired algorithm. The main inspiration of this algorithm is the navigating mechanism of moths in nature called transverse orientation [11]. Moths fly in night by maintaining a fixed angle with respect to the moon, a very effective mechanism for travelling in a straight line for long distances. However, these fancy insects are trapped in a useless/deadly spiral path around artificial lights. In this paper, the MFO algorithm are used to verify the performance of PID controller IPD and PDPI. In this paper, we consider the ITSE performance criteria, of frequency deviation as the objective function. The fitness function is the objective function we want to minimize. By minimizing the fitness function we get the optimal parameters of PID, IPD and PDPI controllers.

4.Simulation Results and Discussions

MFO algorithm has been applied to optimal tune the different gains of the traditional controllers incorporated in the studied microgrid, of Fig. 1 for frequency stabilization. In the present work, the performance of ''PID controller'' is compared with ''IPD and PDPI controller''and the effectiveness of the proposed IPD and PDPIcontroller is examined by simulation studies under two perturbation conditions like (a) 1% step increase in load demand and 2% step in solar PV power, (b) 1% random change in load demand. Results (overshoot and settling time) presented in Table 1.

A. Performance analysis with 1% step increase in load demand and 2% step in solar PV power:

A step disturbance of 0.01 p.u. is applied to the load demand at t= 0.5 s. The profile of Δf for the different system configurations are shown in Fig. 3(a). From this Figures, it may be noted that the proposed ''IPD and PDPI controllers'' system configuration outperforms the other system configuration (i.e. ''PID controller'') in terms of settling time and overshoot. The power output of the diesel generator are shown in Figs. 4(a) for PID, IPD and PDPI controllers. Diesel power plot shows that for ''PDPI controller'', the power input is less, which is better, as the diesel generator is an nonrenewable energy source. Now, a step disturbance of 0.02 p.u. is applied to the solar PV power. The profiles of Δf for the different system configurations are shown in Fig. 3(b). From this Figures, it may be noted that the proposed ''IPD and PDPI controllers'' system configuration is better the other system configuration in terms of settling time and overshoot. The power output of the diesel generator shown in Figs. 4(b). Figs. 4(b) shows similar results, alike while the 1% step increase load demand.Results (settling time and overshoot) presented in Table 1.

Table 1. *Analysis of different controllers sytem with 1% step increase in load demand*

Disturbances at	Controller	OS	Ts(sec)	Disturbances at	Controller	OS	Ts(sec)
Load Demand	PID	0.01	1.8236	Solar PV Power	PID	0.011	7.8982
	IPD	0.0054	1.9274		IPD	5.7718e	10
	PDPI	0.0063	1.9274		PDPI	$8.1944e^{-4}$	6.2491

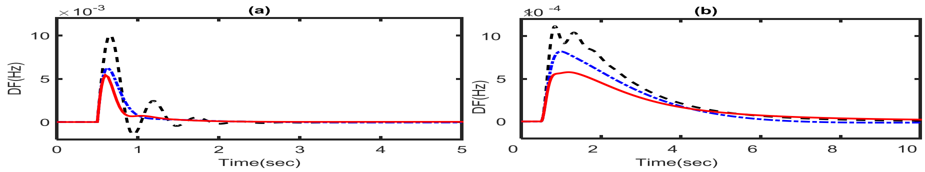


Fig.3. *Frequency deviation-(a) Change in load demand; (b) Change in photovoltaic power, Solid (PDPI Controller), Dashed-dotted (IPD Controller); Dashed (PID Controller)*

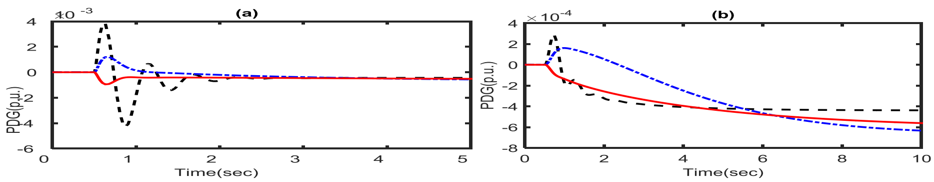


Fig.4. *Diesel power output deviation -(a) Change in load demand; (b) Change in photovoltaic power, Solid (PDPI Controller), Dashed-dotted (IPD Controller); Dashed (PID Controller)*

B. Performance analysis with random change in load demand

The effect of load variation is undertaken into account as random load change as an input disturbance in the proposed microgrid to examine the performance of different system configurations. Due to this random load variation, the nature of Δf is shown in Fig. 5. Even due to the randomness of the variation in load demand, the proposed ''IPD and PDPI controllers'' system configuration is giving better performance than the other system configuration.

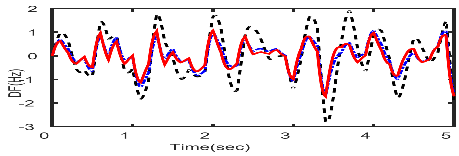


Fig. 5. *Frequency deviation with 1% random in load demand. , Solid (PDPI Controller), Dashed-dotted (IPD Controller); Dashed (PID Controller)*

C. Performance analysis based on performance indices

The values of IAE and ISTE, as defined in Eqs. (7)-(8), are calculated for the three system configurations at the end of developed program. The values of these performance indices are featured in Table 2 on sample basis corresponding to 1% step increase in load demand. From this Table, it may be noted that the proposed "IPD controller" system configuration is the best configuration for the studied microgrid over "PID controller" model in terms of system stability.

$$IAE = \int_0^\infty |\Delta f| dt \quad (7)$$

$$ITSE = \int_0^\infty t.|\Delta f|^2.dt \quad (8)$$

Table 2. Values of different with 1% step increase in load demand.

Performance Index	Controller		
	PID($\times 10^{-6}$)	IPD($\times 10^{-6}$)	PDPI($\times 10^{-6}$)
IAE	3200	1600	2200
ITSE	13.27	3.0666	5.3891

5.Conclusion

The microgrid requires a control system for the purpose of minimization of frequency deviation. In this paper, in order to reduce frequency deviation under varying condition of load and solar PV power, IPD and PDPI controllers has been designed for the proposed system using MFO algorithm. It has been that the proposed controllers outperform the PID controller. IPD and PDPI system configuration works very well under normal condition and it can tolerate satisfactorily the load variation as well as intermittent solar PV power condition. Under small random load system configuration also behaves well.

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