Frequency Regulation in an AC Microgrid with Diverse Sources of Power Using Intelligent Control Technique

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***Abstract*—In recent years worldwide, there is considerable focus on the growth of renewable energy sources (RESs) and distributed generation system (DGs) leading to the concept of microgrid (MG), which is becoming increasingly very popular. The RESs, constituting a MG, by nature have intermittent power output. Therefore, due to unpredictable uncertainties in power output of these systems it becomes very difficult for the conventional controllers to give satisfactory performance over a wide range and under different operating conditions. This paper addresses the problem of frequency regulation in an AC microgrid under variable wind speed and multiple random load disturbances and proposes a fuzzy gain scheduled proportional-integral-derivative (FGSPID) controller to withstand these uncertainties and disturbances and provide an improved performance. For comparative analysis, the conventional PID controller is also implemented on the same microgrid system. Simulation results clearly indicate significant improvement in the frequency regulation of the microgrid system with FGSPID controller as compared to conventional PID controller.**

***Index Terms*—frequency regulation, AC-microgrid, renewable energy sources, intelligent control**

I. Introduction

Around the globe, conventional power system is facing the challenges of gradual depleting fossil fuel resources, low energy efficiency and environmental pollution. These challenges have resulted in a new trend of generating power locally at distribution voltage level by using RESs as alternative sources of electric energy. In recent years, there has been considerable progress in technological advancement of RESs and many different renewable resources are developed, but still there are several issues involved in RESs and their control, their integration with existing power system grid, etc. which need to be addressed. The concept of MG has emerged as the cluster of the distributed generation sources comprising mainly of the RESs along with energy storage systems.

The sources of power in the MG are primarily the small generating units in the range of few KWs installed near the local load premises, and integrated into the power grid. These distributed generation sources typically comprise renewable energy sources such as diesel engine generators (DEGs), wind turbine generators (WTGs), photovoltaic (PV) panels, fuel cells (FCs), along with energy storage systems. One of the important control issue associated with the MG is of frequency regulation under different operating conditions, and proper control designs in both connected and disconnected modes. Many researchers have utilized different control concepts for frequency control problem in an AC microgrid [1]-[6].

This paper presents the design and implementation of an intelligent fuzzy gain scheduled PID (FGSPID) controller for frequency regulation in an AC MG operating in isolated mode under different disturbances of load and power generation. To demonstrate the effectiveness of the proposed control scheme, the results are compared with that of the conventional PID controller.

The paper organized is as follows: Section II provides an overview of the AC MG structures and their required control loops. In section III, proposed system configuration and frequency response model of a standalone AC MG is explained. Conventional PID and intelligent FGSPID controller designs are discussed in Section IV. Finally, Section V presents the simulation results showing the performance of the proposed controller and its comparative analysis with the conventional PID controller.

II. AC Microgrid

A typical MG structure is shown in Fig. 1 [7] which consists of electrical loads and micro sources connected through low voltage (LV) distribution network. The loads and the sources are placed close to each other to minimize power losses during transmission. Technically MG can be considered to be an autonomous group of controllable plug-and play micro sources and energy storage devices that are optimally placed and operated for the smooth control of the MG.

The AC MG can be connected to the distribution system by a point of common coupling (PCC) via a static switch (SS). The static switch can facilitate the island mode of the MG as and when required for any purpose. There is microgrid central controller (MGCC) installed at the medium voltage and low voltage (MV/LV) substation for smooth control and management of the MG [8], [9].

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There are micro source controllers (MCs) whose main function is to independently control the power flow and load-end voltage profile of the micro source in response to any disturbance and load changes. The controllable loads are controlled by load controllers (LC). The AC MG has a hierarchical control structure with different layers to respond to the variations and the load disturbances in order to perform frequency and voltage regulation. A general control scheme of an AC MG is shown in Fig. 1.

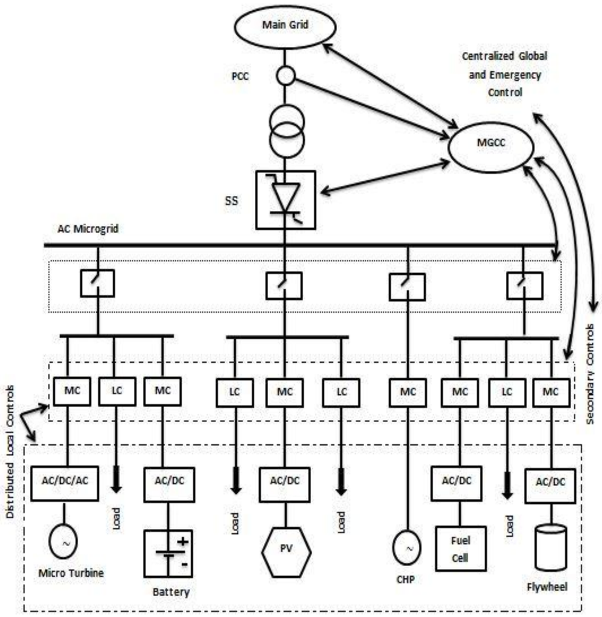

Figure 1. General control scheme for an AC Microgrid [10]

Since MG comprises of several RESs which are uncertain and whose power output is non-linear in nature coupled with unpredictable load variations, therefore, MG control scheme must be able to withstand these variations.

III. Proposed System Configuration and Model of an AC Microgrid

Proposed system configuration of an isolated hybrid AC microgrid system is shown in Fig. 2. The MG system consists of PV panel, FC system, Diesel engine generator (DEG), battery energy storage system (BESS), wind turbine generator (WTG) and flywheel energy storage system (FESS).

As shown in Fig. 2, the DGs are connected to the MG by power electronic interfaces which are required for synchronization in AC sources and to invert voltage in case of DC sources and energy storage systems.

Only the PV, FC, BESS and FESS require suitable power converters for exchanging energy with the AC microgrid system under investigation. BESS is assumed to have sufficient capacity to store surplus energy generated by the energy generating subsystems. The DEG subsystem is controlled using the proposed intelligent control scheme and the conventional PID controller and it participates in frequency regulation by providing suitable power to the system as per need whenever there is some disturbance in the system.

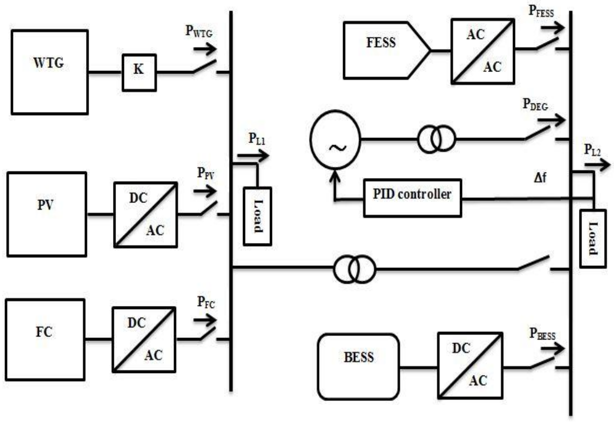

Figure 2. Proposed system configuration of an AC microgrid.

The net power generation (P_s) of the AC microgrid is the aggregate of the output powers of WTG (P_{WTG}), DC-AC converter connected to FC (P_{FC}), PV (P_{PV}), exchanged power of BESS (P_{BESS}), FESS (P_{FESS}) and output power of DEG (P_{DEG}). P_s is determined as in (1):

$$P_s = P_{WTG}+P_{PV}+P_{FC}+P_{DEG} \pm P_{FESS} \pm P_{BESS} \quad (1)$$

The nominal ratings of the DG units, as well as loads are as given in Table I. A certain amount of power produced by the DEG is considered as spinning reserve for frequency control.

TABLE I. Rated Power of DG Units and Loads

Rated power (KW)		Load (KW)	
WTG	125	P_{L1}	220
PV	25		
FC	70		
DEG	150	P_{L2}	200
BESS	40		
FESS	40		

Now for ease of understanding the frequency response model of the AC Microgrid is shown in Fig. 3, where the transfer function representations are given.

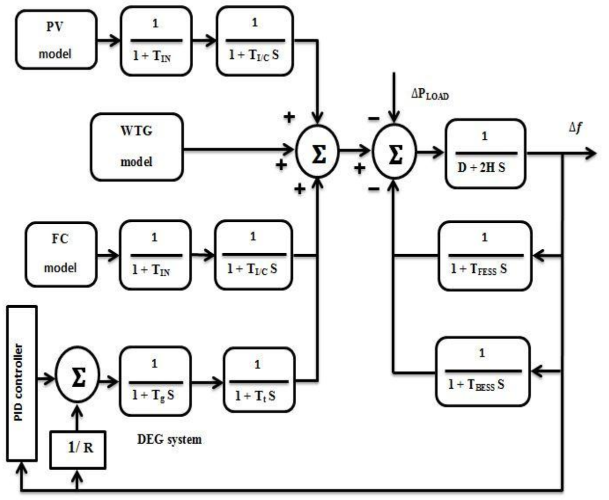

Figure 3. Frequency response model of an AC Microgrid

The system frequency is considered to be 50 Hz and the values of system parameters are given in Table II [10].

TABLE II. SYSTEM PARAMETER VALUES

Parameter	Value
D (pu/Hz)	0.015
H (pu s)	0.1667
T_{FESS} (s)	0.1
T_{BESS} (s)	0.1
R (Hz/pu)	3
T_g (s)	0.08
T_t(s)	0.4
$T_{I/c}$ (s)	0.004
T_{IN} (s)	0.04

IV. CONTROLLER DESIGN AND IMPLEMENTATION

Both, the conventional PID controller and fuzzy based intelligent controller, are designed and implemented as discussed in the following subsections:

A. Conventional Controller

PID is the most popular control structure of the classical control theory and is widely used in industrial control systems [10]. The system performance can be improved by optimal tuning of the controller gain parameters namely; K_p, K_i, and K_d. Mathematically the controller output, u(t) can be expressed in terms of the error signal e(t) as:

$$u(t)=K_p e(t)+K_i\int e(t)dt+K_d\frac{de(t)}{dt} \qquad (2)$$

$$u(t)=K_p\left(e(t)+\frac{1}{T_i}\int e(t)dt+T_d\frac{de(t)}{dt}\right) \qquad (3)$$

where, K_P, K_i, and K_d are the proportional, integral and derivative gains respectively. T_i and T_d are the integral and derivative time constants. The PID controller is implemented for frequency regulation in the AC Microgrid system under different power and load variations. The heuristically tuned parameter values of PID controller gains are shown in Table III.

TABLE III. PID CONTROLLER GAIN PARAMETERS

Gain Parameters	K_P	K_i	K_d
Values	4.5	8.85	17.2

B. Proposed Fuzzy Gain Scheduled PID Controller

Researchers have reported new PID control strategies based on some intelligent algorithms [11], especially using fuzzy logic concepts. The proposed FGSPID controller is a conventional PID controller whose gain parameters are tuned using Fuzzy Inference System as per the frequency deviation (Δf) and rate of change of frequency deviation (d/dt(Δf)).

The frequency error (Δf) and derivative of frequency error (d/dt(Δf)) act as the inputs to the FGSPID controller and K_p, K_i and K_d are the outputs of the controller. Appropriate fuzzy membership functions for the inputs and outputs are as shown in Fig. 4 and Fig. 5 (a to c) respectively, where, NB= Negative Big, NM= Negative Medium, NS= Negative Small, ZE= Zero, PS= Positive Small, PM= Positive Medium, & PB= Positive Big. N= Negative, Z= Zero & P= Positive.

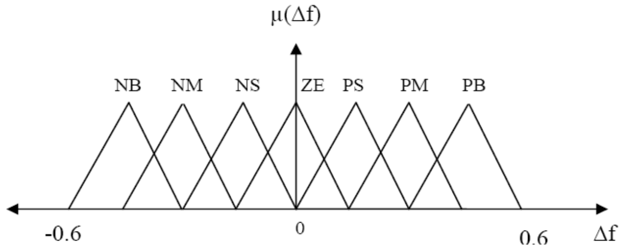

Figure 4. (a) Membership functions of frequency error (Δf)

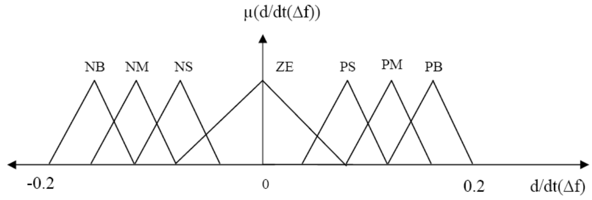

Figure 4. (b) Membership functions of derivative of frequency error (d/dt (Δf))

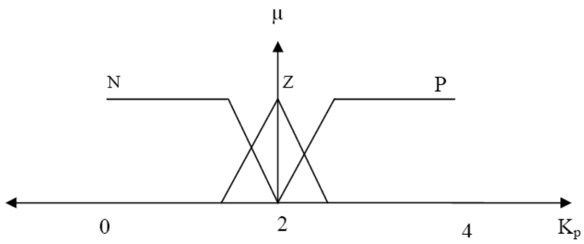

Figure 5. (a) Membership functions of K_P

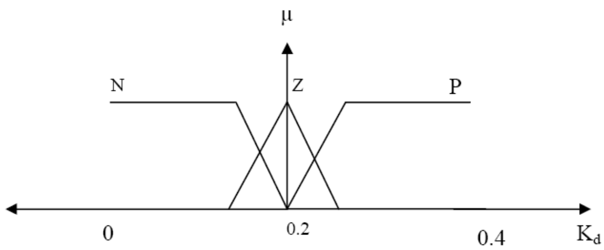

Figure 5. (b) Membership functions of K_d

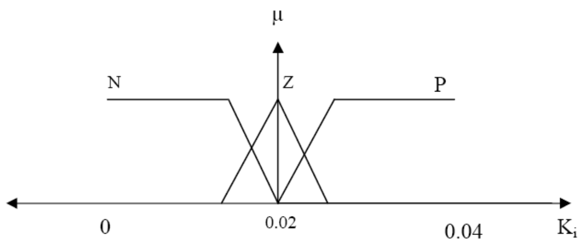

Figure 5. (c) Membership functions of K_i

The fuzzy control rules are designed keeping practical system operation in to consideration and are as shown in Table IV.

TABLE IV. FUZZY RULES FOR FGSPID CONTROLLER

de/dt \ e (K_p, K_d, K_i)	NB	NM	NS	ZE	PS	PM	PB
NB	P`	Z	N	N	N	Z	P
	N	P	P	N	P	P	N
	P	Z	N	N	N	Z	P
NM	P	P	Z	N	Z	P	P
	N	Z	P	P	P	Z	N
	P	Z	Z	N	Z	Z	P
NS	P	P	Z	N	Z	P	P
	N	N	Z	P	Z	N	N
	P	P	Z	N	Z	P	P
ZE	P	P	P	Z	P	P	P
	N	N	N	Z	N	N	N
	P	P	P	Z	P	P	P
PS	P	P	Z	N	Z	P	P
	N	N	Z	P	Z	N	N
	P	P	Z	N	Z	P	P
PM	P	P	Z	N	Z	P	P
	N	Z	P	P	P	Z	N
	P	Z	Z	N	Z	Z	P
PB	P	Z	N	N	P	Z	P
	N	P	P	P	N	P	N
	P	Z	N	N	P	Z	P

V. SIMULATION RESULTS AND DISCUSSION

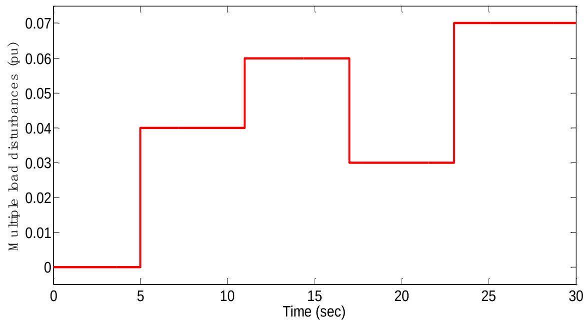

Figure 6. (a) Random step load disturbance

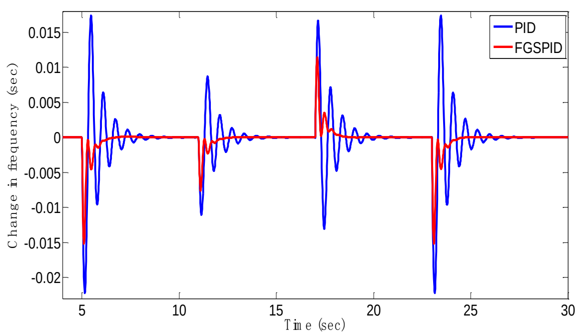

Figure 6. (b) Frequency deviation response

The proposed FGSPID controller and the conventional PID controller are implemented through simulation on the MATLAB/SIMULINK platform for frequency regulation in the AC Microgrid system considered for investigation with frequency control scheme as shown in Fig. 3. The simulations are carried out according to variable wind speed and random step load perturbations. Following two cases have been investigated:

Case (i): Wind speed and other environmental conditions are assumed constant and only the random step load disturbances are applied to AC Microgrid system at 5sec, 11sec, 17sec & 23sec as per the pattern shown in Fig. 6(a). For this case, the frequency deviation response is shown in Fig. 6(b) for both the controllers. It is evident, that the proposed FGSPID controller is able to withstand these variations and controls the system frequency effectively and better than the conventional PID controller following the occurrence of sudden load disturbances. Also the FGSPID controller gives better performance in terms of settling-time, and provides less oscillatory response as compared to conventional PID controller.

Case (ii): Wind speed is assumed to be varying, and as a result the WTG output power also varies. These variations with time, as shown in Fig. 7, are applied to the Microgrid system.

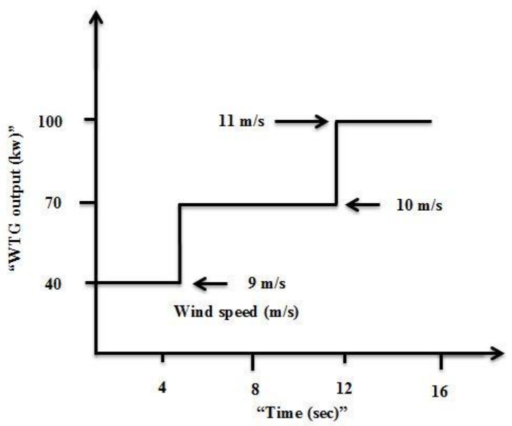

Figure 7. Wind power variations with varying wind speed.

In addition, step load disturbances of 0.04pu and 0.08pu are also applied to the Microgrid system at 26sec & 31sec respectively as shown in Fig. 8 (a).

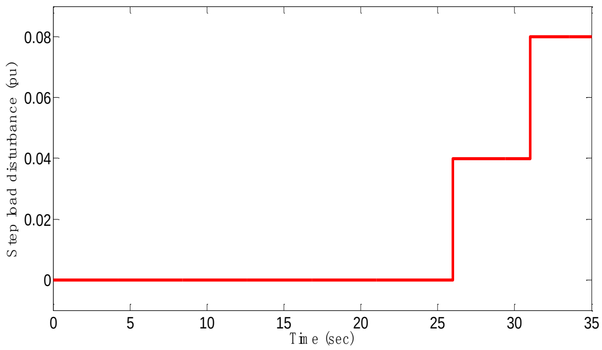

Figure 8. (a) Step load disturbance

For this case, the performance of both the controllers is shown in Fig. 8 (b). In this case also the Fuzzy gain schedule-PID controller method provides much better performance and is capable of withstanding the wind power variations along with the load disturbances.

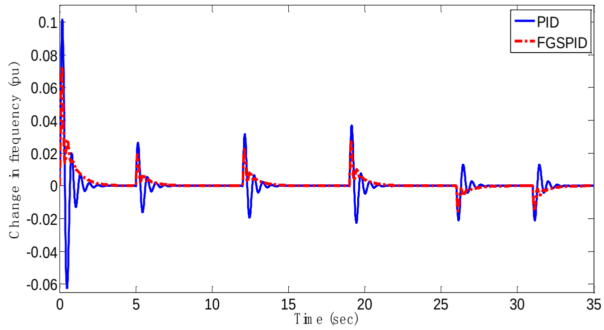

Figure 8. (b) Frequency deviation response

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