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Internal Model Based Load Frequency Controller Design for Hybrid Microgrid System

A.Jeya Veronica[a], Dr. N.Senthil Kumar[b]

[a]*Research Scholar,School of Electrical Engineering,VIT University,Chennai Campus,Chennai-600127, India.*
[b]*Associate ProfessorSchool of Electrical Engineering,,VIT University,Chennai Campus,Chennai-600127, India.*

Abstract

The increase of power demand exponentially over the past decade in developing countries has necessitated the integration of different types of renewable energy sources into the utiligy grids which were earlier running with fossil fuel fired units. Renewable energy sources are integrated with these generating plants since it is economical and pollution free. Power generation through these types of generating plants comprise of a combination of intermittent renewable sources like wind, solar and other generating sources like diesel generators, fuel cells. Also, because of the weak inertial nature of the renewable sources used in microgrid, it is much more important to regulate the system frequency closer to the nominal values. This paper explores the development of an Internal Model based controller approach for better frequency regulation in a hybrid microgrid. Two different cases are examined to validate the robustness of IMC based controller design.

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Keywords: Microgrid; Load Frequency Control; Internal Model Controller.

1. Introduction

The continuous usage of fossil fuels like coal, oil and natural gases in conventional power systems has resulted in increased environmental pollution, poor energy conversion causing depletion of these resources.

*Corresponding author. Tel.:+91 9444242263;
E-mail address: senthilkumar.nataraj@vit.ac.in

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Also, the fossil fuel fired central power generating stations have to transmit power over long distances to the load centers resulting in poor transmission efficiency. Electricity generation is considered to be one of the indicators of economic progress of a country. To meet the increasing demand of electricity it is necessary to have power generating stations which are located closer to load centers. Also, to have better controllability and avoid environmental pollution it is necessary that electricity is generated by the renewable energy sources like wind, solar, biomass, FC, etc. This section presents a brief review of the literature done so far on improving frequency regulation in microgrids.

To facilitate power generation closer to load centres smaller capacity generating stations comprising of a combination of renewable sources and load centers are formed which are termed microgrids. By controlling the generating sources, the generation load balance is obtained which results in improving the frequency regulation in a microgrid [1,2].The DG and BESS outputs are coordinated for better frequency regulation in a microgrid proportional to the random load variations which is estimated by an minimal order observer [3]. A state feedback controller using integral gain is adopted for better frequency regulation in a microgrid comprising of MT, FC and AE [4].

BESS is employed as a primary reserve in which the frequency deviations in a microgrid are minimized [5]. A model predictive control (MPC) approach has been used to regulate the charging and discharging of a BESS for enhancing the frequency control in a microgrid [6]. A squirrel cage induction generator connected to diesel engine and BESS with voltage source converter is employed to improve the frequency regulation in a rural microgrid. Voltage and Frequency control at the PCC of the microgrid is achieved using affine projection- like algorithm which takes care of proper switching of the Voltage Source Converters [7].

A stepwise adaptive load shedding approach for enhancing the frequency stability of an islanded microgrid has been proposed to maintain the frequency deviation within the nominal values [8]. H_∞ and μ-Synthesis methods have been implemented for effective frequency control in a microgrid [9]. Using coefficient diagram method, robust controller is designed to reduce the frequency deviations of the microgrid [10]. A robust control method has been proposed to minimize the effects of intermittent variations in wind generator outputs and system load [11]. Ultracapacitors, Flywheel and BESS systems are coordinated to minimize the frequency deviations of a microgrid [12]. A microgrid consisting of wind, PV, DG, FC, AE, BESS and flywheel are employed to meet the system demand and the controller parameters tuned using Ziegler-Nichols(ZN) method is used for improved frequency regulation [13].

From the above review of literature, it is evident that adoption of better control strategies other than the existing classical methods of control are required to improve frequency regulation in microgrids.This paper is organized as follows.

Section 2 explains the system configuration and modeling details of the islanded microgrid. Section 3 presents the design procedure of IMC for frequency control in the hybrid microgrid. Section 4 and 5 describe the simulation results and the conclusion.

Nomenclature

WTG	Wind Turbine Generator
BESS	Battery Energy Storage System
DG	Diesel Generator
AE	Aqua Electrolyser
FC	Fuel Cell
PV	Photovoltaic
ZN	Ziegler-Nichols
PI	Proportional Integral
IMC	Internal Model Control
MT	Microturbine
MPC	Model Predictive Control

2. Microgrid Configuration and Modeling

The system configuration comprising of the energy sources like (i) WTG (ii) PV (iii) DG (iv) AE (v) FC (vi) BESS is shown in Fig. 1. P_s is total power supplied to the load and is expressed as

$$P_S = P_{WTG} + P_V + P_{DG} + P_{FC} - P_{AE} \pm P_{BESS} \tag{1}$$

where P_{WTG}, P_{PV} ,P_{DG}, $P_{FC,}$ P_{BESS} and P_{AE} are the output powers of the WTG, PV, DG, FC, BESS and AE respectively.

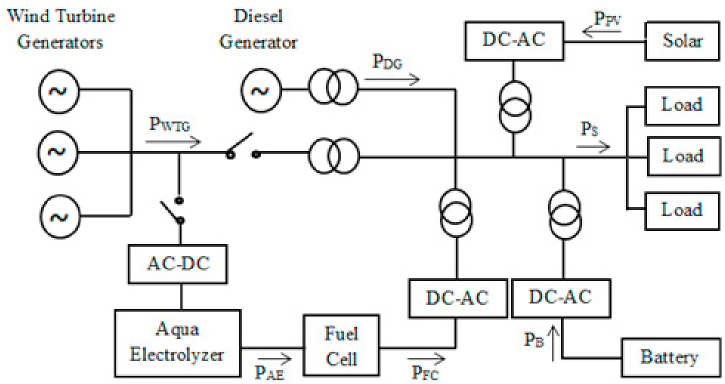

Fig. 1 System Configuration

2.1 DG System

The DG consists of diesel engine and generator. The diesel engine which acts as a prime mover consumes the diesel and produces mechanical energy. The synchronous generator connected to the diesel engine produces the electrical energy. Whenever power fluctuates, the DG compensates the deficit power because of its quick start up. The transfer function of the DG is

$$G_{DG}(s) = \frac{K_{DG}}{1 + T_{DG}\,s} \tag{2}$$

where K_{DG} and T_{DG} are the gain and time constants of the DG respectively.

2.2 Fuel Cell Generator System

The FC essentially consists of an electrolyte and two electrodes. At anode, the hydrogen gas is divided into hydrogen ions and electrons. Through anode, the electrons move to the external circuit and pass to the cathode. The hydrogen ions combine with electrons from cathode and oxygen to form water. The transfer function given is as

$$G_{FC}(s) = \frac{K_{FC}}{1 + T_{FC}\,s} \tag{3}$$

where K_{FC} and T_{FC} are the gain and time constants of the FC respectively.

2.3 Aqua Electrolyzer System

When electricity is passed into the water through two electrodes, it gets divided into hydrogen ions, electrons and oxygen at anode. The hydrogen ions migrate to the cathode and combine with electrons which are provided externally to form hydrogen gas. This hydrogen gas is used as a fuel for fuel cells.

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

where K_{AE} and T_{AE} are the gain and time constants of the AE respectively.

2.4 Battery Energy Storage System

The BESS consists of the cells connected in series and parallel. The BESS are capable of acting as load when the frequency rises or as generator when the frequency drops. The transfer function of BESS is given as

$$G_B(s) = \frac{K_B}{1+T_B s} \tag{5}$$

where K_B and T_B are the gain and time constants of the BESS respectively. To values of K_1, K_2, K_3 and K_4 refer [13].

2.5 Power and Frequency Deviation

To meet the required load demand P_s^*, the total power generation P_s should be controlled by an appropriate controller. The error between the power demand and the generated power is given as

$$\Delta P_e = P_s^* - P_s \tag{6}$$

As load varies, the frequency Δf deviates. Δf is represented as

$$\Delta f = \Delta P_e / K_s \tag{7}$$

where K_s is the system frequency constant. The relation between the frequency variation and power variation is expressed as

$$G_{sys}(s) = \Delta f / \Delta P_e = 1/Ms + D \tag{8}$$

where D and M are the damping and inertia constants of the microgrid. The block diagram of the islanded hybrid microgrid system with transfer function model of various sources is shown in Fig. 2. The Table 1 is framed with the gain and time constants of the various sources.

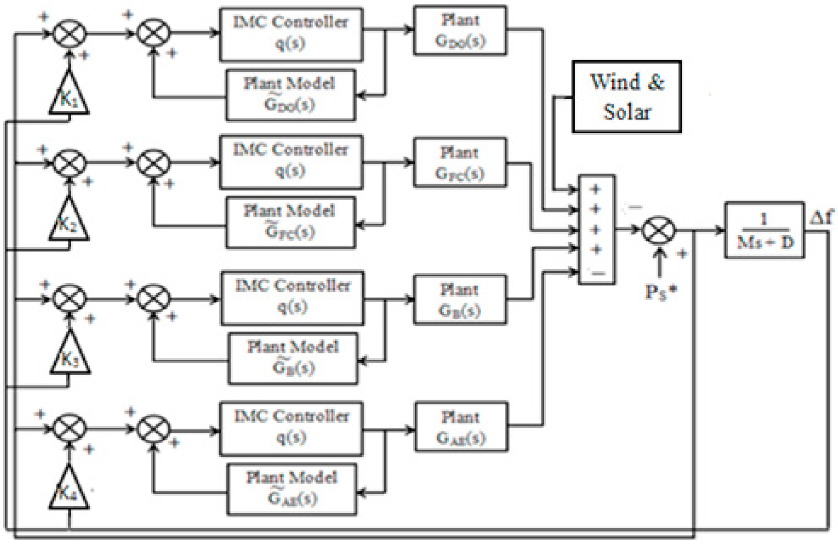

Fig. 2 Transfer function model of microgrid with IMC controller

Table 1. Gain and time constants of various energy sources [1]

Energy Sources	Gain Constant	Time Constant
DEG	1	2
FC	1	4
AE	1	0.2
BESS	1	0.1

3. Design Procedure of IMC

The structure of the IMC is given in Fig. 3(a). g(s) is the actual plant transfer function, $\tilde{g}(s)$ is the plant model transfer function, q(s) is the IMC controller transfer function; r(s), y(s) and d(s) represent the reference input, controlled output and disturbance input respectively [14].

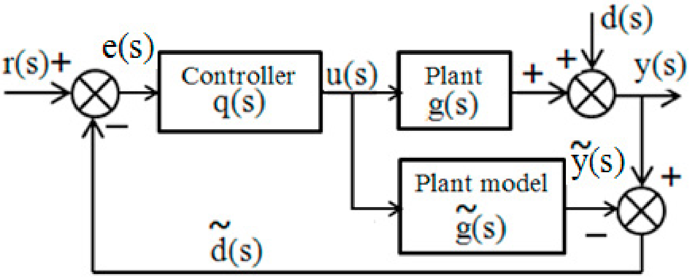

Fig. 3.(a) Structure of IMC

From Fig. 3(a), it can be written as,

$$\tilde{y}(s) = \tilde{g}(s).u(s) \tag{9}$$

$$u(s) = q(s).e(s) \tag{10}$$

By replacing the value of e(s) with r(s), y(s) and $\tilde{y}$ (s) in Eq.10, we get

$$u(s)[1-\tilde{g}(s).q(s)] = q(s)[r(s)-y(s)] \tag{11}$$

A system should exhibit good set point tracking; i.e. r(s) = y(s), when d(s)=0. Then the Eq.11 becomes

$$1-\tilde{g}(s).q(s) = 0 \tag{12}$$

$$q(s) = 1/\tilde{g}(s) \tag{13}$$

Thus, the controller transfer function is equal to the inverse of the plant model.

The IMC controller is designed such that the inverse of $\tilde{g}(s)$ is multiplied by the filter transfer function f(s) [15] and is given in Eq.14. To offset the dominant poles in the plant model, filter containing lead part is designed.

$$q(s) = \tilde{g}(s)^{-1} f(s) \tag{14}$$

$$f(s) = \frac{1}{(\lambda s+1)^x} \tag{15}$$

λ is the tuning parameter and x is the order of $\tilde{g}(s)$. It is represented in Fig. 3.(b) that the $\tilde{g}(s)$ can be fedback with the IMC controller. The feedback controller $g_c(s)$ is given as

$$g_c(s) = q(s)/(1-\tilde{g}(s)q(s)) \tag{16}$$

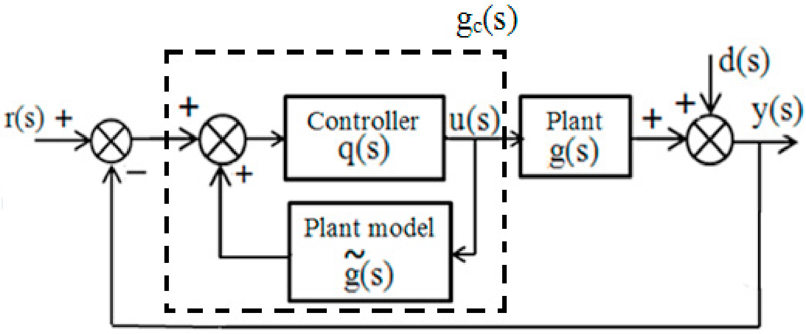

Fig. 3.(b) Feedback Structure

4. Simulation results

In this section, the contribution of WTG,PV, DG, FC, AE and BESS are analysed for load frequency regulation in the microgrid. The IMC structure is designed for DG, FC, AE and BESS independently as briefed in Section 3. Here, two cases have been analysed with variation of load, wind and solar power.

4.1. Case-I

In case-I, at t=30s, WTG output power is decreased from 0.5p.u to 0.3p.u. The output power from PV is kept constant at 0.4p.u and the system load is kept at 0.9p.u. To compensate for the decrease in the WTG output, the DG output increases to 0.155p.u(Fig. 4(a)). The fuel cell output power settles to 0.05p.u(Fig. 4(b)). The AE absorbs electrical power of 0.01p.u for producing hydrogen(Fig. 4(c)) and BESS discharges electrical power closer to 0.005p.u(Fig. 4(d)). In Fig. 4(e), by the coordinated operation of all these energy sources by means of IMC design, the system frequency deviation is -0.031Hz which is very less and reaches the steady state within 0.8s when compared with the PI controller tuned using ZN method.

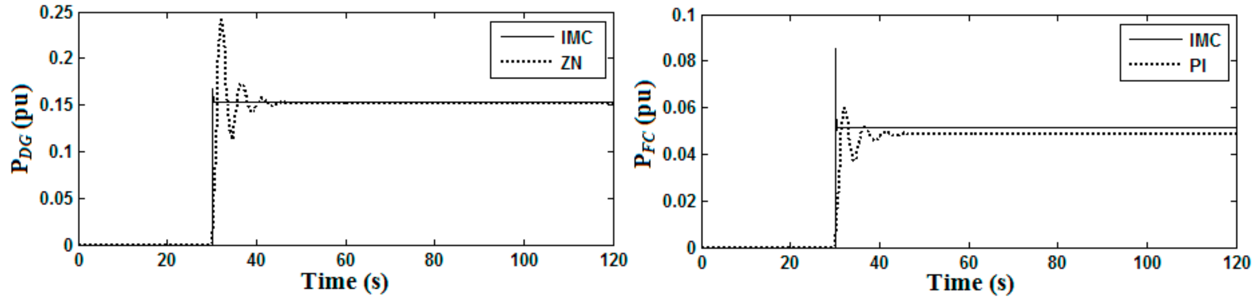

Fig. 4. (a) Power output of DG; (b) Power output of FC

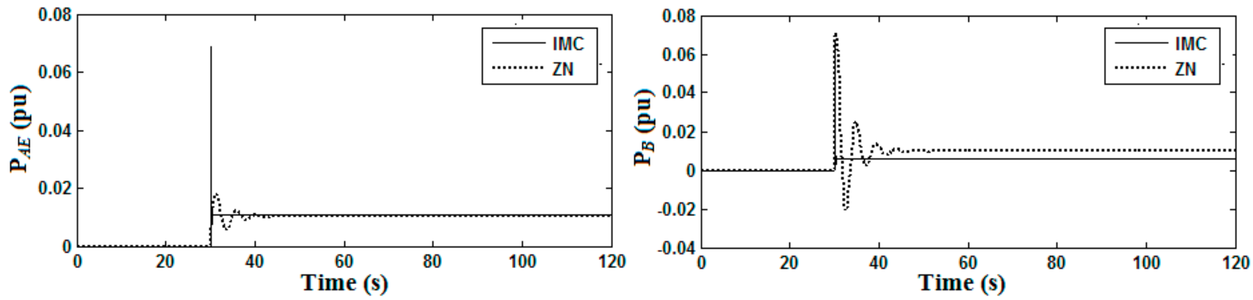

Fig. 4. (c) Power output of AE; (d) Power output of BESS.

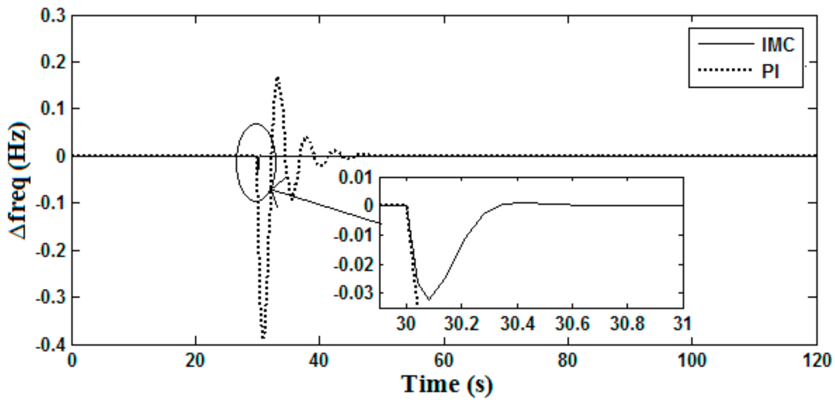

Fig. 4. (e) Frequency deviation of the microgrid system.

4.2. Case-II

In case-II, the load is increased from 0.95p.u to 1p.u at 30s. The wind power output is 0.5p.u.and the solar power output is 0.4p.u. Since, the wind power is increased, the generations from the DG, FC, BESS are reduced compared to case I. The DG generates power output of 0.075p.u(Fig. 5(a)). The FC generates 0.025p.u(Fig. 5(b)).

The AE also absorbs less power of 0.005p.u(Fig. 5(c)) and BESS discharges 0.0025p.u of power(Fig. 5(d)). In Fig. 5(e), the system frequency deviation is very less which is -0.01Hz. The peak overshoot and the settling time are less compared to the ZN method.

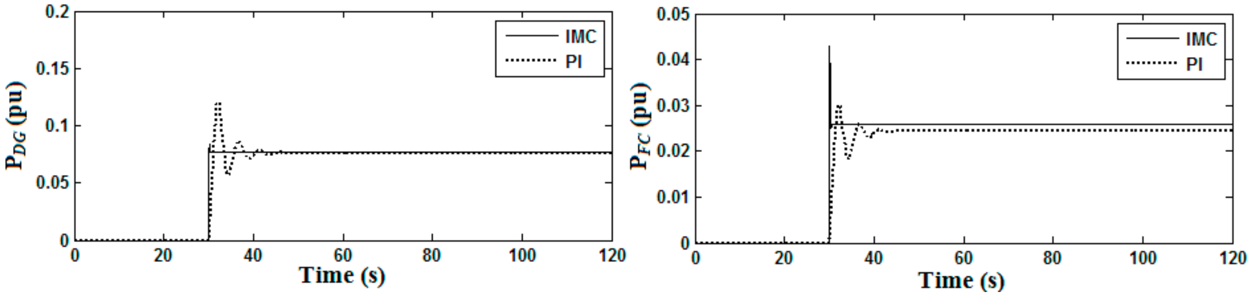

Fig. 5. (a) Power output of DG; (b) Power output of FC

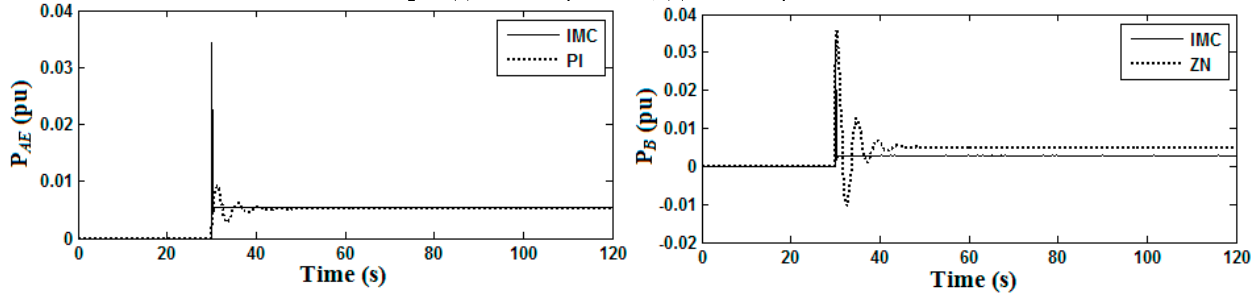

Fig. 5. (c) Power output of AE; (d) Power output of BESS

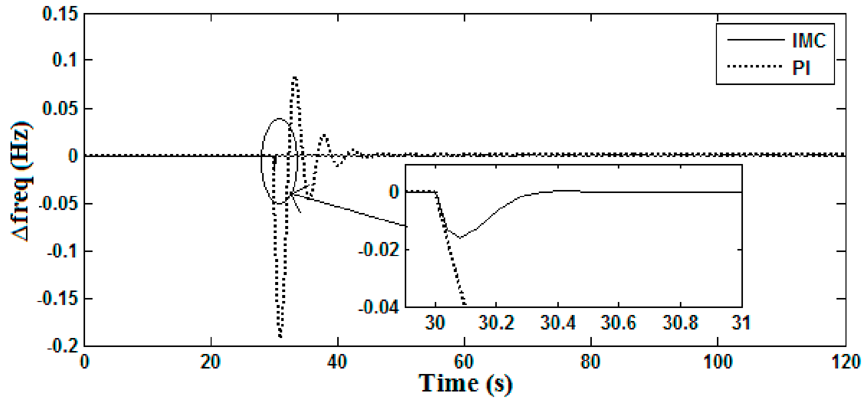

Fig. 5. (e) Frequency deviation of the microgrid

5. Conclusion

This paper has explored the development of an isolated microgrid with the energy sources comprising of PV, WTG, DG, FC, AE and BESS systems. IMC controller structure has been implemented for DG, FC, AE and BESS. Simulation results prove that the proposed internal model controller is superior to that of conventional PI controller tuned using ZN method. The robustness of the controller has been verified by simulating two different cases. It is found that the IMC controller is robust in all the operating conditions.This is due to the fact that the IMC controller emulates the inverse plant model which results in better set point tracking compared to the conventional PI controller.

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