



A Disturbance Observer Based Fuzzy Feedforward Proportional Integral Load Frequency Control of Microgrids

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ABSTRACT

In this paper, the load frequency control (LFC) problem of microgrids in islanded operation mode is tackled using Fuzzy Feedforward PI (FFPI) controller. To this end, a feedforward loop is considered in the control structure of the microgrid in addition to the classical feedback controller wherein a proportional integrator controller is used. The disturbance signal, which can be load variations or renewable energy resources uncertainties, is estimated using a disturbance observer. The understudy microgrid includes wind turbine and solar cells as renewable sources, a diesel generator and loads. A fuzzy controller is also used for pitch angle control of the wind turbine, which may smooth out the generated power and improve the frequency control of microgrid. To show the capability of the proposed strategy, two different scenarios are considered and the obtained simulation results easily approve the efficiency of the proposed structure for LFC of microgrid in islanded operation mode.

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1. INTRODUCTION

Electrical energy transmission cost in power systems leads to pay much attention to new technologies such as microgrid, which results in some other benefits such as more reliability and power quality improvement. On the other hand, fossil fuel sources are substantially reduced in these years, which causes to much attention to renewable energy sources such as wind energy and solar cells. These renewable sources have unpredictable nature due to change in wind speed or solar irradiance. The variations in produced power or load in a power system leads to frequency deviations, which is an unfavorable phenomenon and must be compensated by the controller as fast as possible.

Microgrids operation mode is defined as the grid-connected and islanded one. In the islanded operation of a microgrid, a local controller is needed to control the frequency deviations due to change in produced power or

load. In this regard, various control strategies and controllers are studied in the literature.

Fuzzy logic sets were the beginning of a new worldview into mathematics and a novel step into real world problems solution in a realistic manner. The fuzzy logic provides the more practical and understandable concept for understudy process with linguistic variables as if-then rules, which further provides more efficient control of the system. A fuzzy controller includes fuzzifier, inference mechanism, knowledge base and defuzzifier [1]. Fuzzy logic finds its path into different applications such as modeling, control [2], and fault diagnosis [3].

Diverse control strategies towards frequency, voltage, current and power control of microgrids have been considered. Conventional feedback structure, computational intelligence based controllers, decentralized and hierarchical control strategies [4, 5], and cascade control structure [6] are used for the

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microgrids. Due to importance of frequency control of the microgrids in islanded operation, various control strategies have been proposed in the literatures. In order to deal with the control challenges of islanded microgrids, an efficient control strategy is required. Toward this end, a Central Management Agent which maintains the stability of the microgrid by controlling an Energy Storage System and a Central Synchronous Generator is presented by Farzinfar et al. [7].

Adaptive controller [8], sliding mode controllers [9], fractional order controllers [10], model predictive controllers (MPC) [11], and multi agent approach [12] are studied for LFC of microgrids. Robust control strategy also noticed for LFC of microgrids in order to make the control system robust to model uncertainties and disturbances [13,14]. Quantitative feedback theory is another robust control method, which consists of a feedback compensator and a pre-filter, and is designed by shaping the frequency responses of the system to satisfy some design constraints [15]. A nonlinear controller for a distribution static compensator of a microgrid based on partial feedback linearization theory and PID controller is proposed by Ara et al. [16], which uses a combination of a fuzzy system and Galaxy-based Search Algorithm to optimize the parameters of the PID controllers. Optimal PI-settings for first-order with delay systems to achieve a specific level of robustness was presented by Grimholt and Skogestad [17] and the results were compared with the simple SIMC-rule. Some surveys on the modeling and control of microgrids, and their control strategies have been published recently [18,19].

On the other hand, computational intelligence based methods have received much attention due to their benefits in modeling and control design of microgrids. Boutabba et al. [20] presented a modeling and implementation of new control schemes for an isolated photovoltaic using a fuzzy logic controller. The proposed fuzzy logic controller provides the appropriate duty cycle to the DC-DC converter for the PV system to achieve Maximum Power Point Tracking in PV. Mahmoud et al. [21] have achieved the LFC of microgrid using neural networks controller. Different metaheuristic methods such as GA, PSO and HSA are used to optimize the controller for LFC of microgrids [22-24]. a fractional order fuzzy PID controller is designed for LFC of a microgrid in isolated mode [25]. LFC of isolated microgrids in a ship power system is considered by Khooban et al. [26], which is based on a new optimal fractional order fuzzy PD+I controller. An adaptive multi-objective fractional-order fuzzy PID controller for frequency control of an islanded microgrid including Electric Vehicles is presented by Khooban et al. [27].

The feedback control strategy for frequency deviation control of microgrid is based upon the effects of disturbance, which leads to frequency deviation. The feedforward controller acts in a different manner and

change the input of the system according to the disturbance signal or its estimation. In fact, prior to have the effects of disturbances on the system outputs, the controller takes the necessary action by properly setting the system input. In this paper, based on a disturbance observer the disturbance signal, which is defined as the power variations due to load or renewable sources, is estimated in the islanded microgrid. The fuzzy logic controller is used in the feedforward controller of the microgrid wherein the disturbance and its variations are used to change the parameters of the controller.

Succinctly, the salient contribution of this paper is stated as follows:

- Presenting a new control structure including Fuzzy Feedforward PI controller for LFC of an islanded microgrid using disturbance observer.

Moreover, a fuzzy logic controller is used to pitch angle control of wind turbine for more smoothing out the power of wind turbine, and consequently possessing a better frequency control of the microgrid.

The rest of the paper is organized as follows. In section 2, the structure of the microgrid and mathematical model for different parts of the microgrid are presented. The proposed LFC strategy for the islanded operation of microgrid is presented in section 3. Section 4 gives the simulation results of the proposed method, which is followed by a conclusion in section 5.

2. PROBLEM FORMULATION and PRELIMINARIES

Due to various sources of energy, different structures of the microgrid may be presented. The considered microgrid in this paper is shown in Figure 1, which includes both renewable energy resources and diesel generator as the deterministic source of energy.

In Figure 1, the generated power of wind turbine, solar cells and diesel generator are represented as P_W , P_S and P_{DG} . The power of the load is also shown as P_L . The considered mathematical models for the above mentioned parts are given as follows.

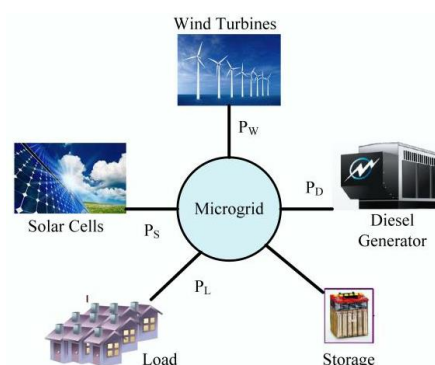


Figure 1. Structure of the microgrid

2. 1. Wind Turbine The mathematical model of a wind turbine is generally involved the mathematical model of wind, generator, aerodynamics and mechanical drive train. Wind model is defined by the wind speed, which is given in Equation (1):

$$v = v_m + v_t(t) \quad (1)$$

v_m is the constant part of wind model with slow variation rate, which shows the mean value of wind speed. v_t is the turbulent part of wind speed with fast variation rate. More details about the turbulent part may be found in literature [28]. The kinetic energy of wind as stated in Equation (2) defines the aerodynamic part of the wind turbine.

$$P = \frac{1}{2} \dot{m} v^2 = \frac{1}{2} \rho \pi R^2 v^3 \quad (2)$$

in which ρ is defined as air density and R is the radius of the rotor. The part of the kinetic energy that converts to mechanical energy is defined by power coefficient (C_p) as (3) as given by Burkart et al. [29].

$$P_r = C_p \cdot P \quad (3)$$

Equation (4) represents C_p , which is dependent on the tip speed ratio (λ) and pitch angle (β).

$$C_p = 0.5176 \left(\frac{116}{\lambda_i} - 0.4\beta - 5 \right) e^{-\frac{21}{\lambda_i}} + 0.0068\lambda \quad (4)$$

where

$$\frac{1}{\lambda_i} = \frac{1}{\lambda + 0.08\beta} - \frac{0.035}{\beta^3 + 1} \quad (5)$$

The maximum value of C_p is given as 0.59 based on Albert Betz's law. This value is 0.49 for the understudy wind turbine ($V47/660kW$), operating in the Manjil site [30,31].

The generator of the understudy wind turbine is an induction one. Although the induction generator has a nonlinear mathematical model, the steady state mathematical model due to the much faster dynamics of the generator in comparison to the mechanical parts is assumed here [32].

$$T_g(\omega_i) = \frac{\rho R_2 L_m^2 V_e^2 \omega_i}{[R_1 R_2 - \omega_a \omega_i (L_1 L_m - L_m^2)]^2 + (\omega_a R_2 L_1 + \omega_i R_1 L_2)^2} \quad (6)$$

The root mean square value of the supply voltage, frequency of supply voltage, rotor frequency, number of pole pairs, mutual inductance, resistance of stator and rotor, stator inductance and rotor inductance are represented by V_e , ω_a , ω_i , p , L_m , R_1 , R_2 , L_1 and L_2 , respectively [32].

The considered one-mass model of the mechanical drive train is given in Equation (7) [33]:

$$J \frac{d\omega_{rot}}{dt} = T_{rot} - nT_g, \omega_{rot} = \frac{\omega_g}{n} \quad (7)$$

where J is the inertia, ω_{rot} is the speed of rotor, ω_g the speed of generator, n is the gearbox ratio, T_{rot} is rotor torque and T_g is generator torque.

2. 2. PV Cells Model Solar cells convert sun irradiance into electrical energy. The considered microgrid includes PV cells as a renewable source of energy, which its power is dependent on the environmental temperature as well. Generally, the mathematical model of PV cells is obtained using the equivalent electrical circuit, which is assumed as a nonlinear current source [34]. Equation (8) is achieved based on KCL law for the equivalent one-diode model of PV cell [34].

$$I = I_{ph} - I_{Rp} - I_d \quad (8)$$

Assuming N_s cells in series and N_p cells in parallel, the relation between I and V for a PV array is given by following equations.

$$I = N_p I_{ph} - N_p I_0 \left[e^{\frac{q[V + I R_s]}{n k T}} - 1 \right] - \frac{[N_p V + I R_s]}{R_{sh}} \quad (9)$$

$$I_{ph} = [I_{scr} + K_i(T - T_r)] \frac{s}{100} \quad (10)$$

where I_{ph} , I_0 and I stand for insulation current, reverse saturation current and cell current, respectively. The series and parallel resistance, thermal voltage, irradiance, the temperature of PV array, reference temperature and the short circuit current are depicted as R_s , R_p , S , T , T_r and I_{scr} , respectively

2. 3. Diesel Generator A controllable and deterministic source of power is required for better control of a microgrid and to compensate the unpredictable conditions of available renewable energies in the microgrid. To this end, a diesel generator is considered here. The mathematical model of the power system is as follows [9]:

$$\Delta \dot{f}(t) = -\frac{1}{T_p} \Delta f(t) + \frac{K_p}{T_p} \Delta P_d(t) - \frac{K_p}{T_p} \Delta P_L(t) \quad (11)$$

$$\Delta \dot{P}_d(t) = -\frac{1}{T_t} \Delta P_d(t) + \frac{1}{T_t} \Delta X_g(t) \quad (12)$$

$$\Delta \dot{X}_g(t) = -\frac{1}{RT_g} \Delta f(t) - \frac{1}{T_g} \Delta X_g(t) - \frac{1}{T_g} \Delta E(t) + \frac{1}{T_g} u(t) \quad (13)$$

$$\Delta \dot{E} = K_e \Delta f(t) \quad (14)$$

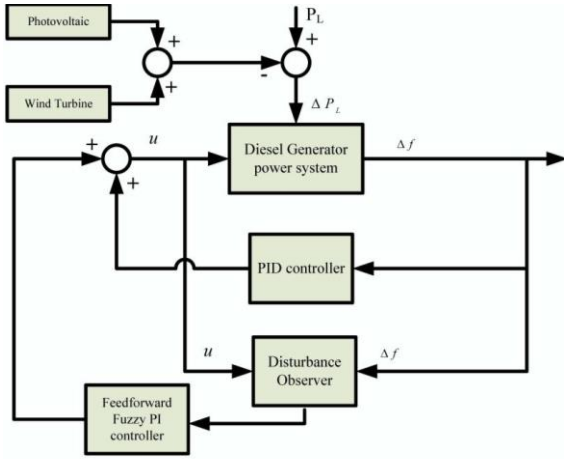
where frequency deviation $\Delta f(t)$, diesel generator power changes $\Delta P_d(t)$, load deviation $\Delta X_g(t)$ and incremental change in governor position ΔE are considered as the states of the system. The definitions and values of other parameters are tabulated in Table 1.

3. CONTROLLER DESIGN

The proposed structure for LFC of the microgrid is depicted in Figure 2.

TABLE 1. Parameters of power system and their values [9]

Parameter	Definition	Value
T_p	Time constant of plant	20
K_p	Plant gain	120
T_t	Time constant of turbine	0.3
T_g	Governor time constant	0.08
R	Speed regulation	2.4
K_e	Integral gain	0.1

**Figure 2.** Structure of the proposed fuzzy feedforward control

This structure includes a FFPI controller and a disturbance observer in addition to the conventional feedback controller. The disturbance observer is used to estimate the disturbance from the input data and frequency deviation at each moment. In the proposed control strategy, the disturbance is defined as the deviation in produced power and load. The disturbance observer, fuzzy feedforward controller and fuzzy pitch angle controller are given in the following subsections.

3. 1. Disturbance Observer Unlike the feedback control strategy that acts based upon the effects of disturbances on the outputs, the feedforward control acts based on the known disturbances prior to affect on the system. In other words, we need the value of disturbance to use the feedforward controller. As the considered disturbance in the microgrid is unknown, a disturbance observer is utilized to estimate the value of the disturbance. The estimated disturbance is given to the fuzzy feedforward controller, which produces an appropriate control signal.

The disturbance observer is a modified version of the given one by wang et al. [9]. As discussed by Wang et al. [9], by augmentation the disturbance as one state of the

system, the augmented state space representation form may be given as follows:

$$\begin{bmatrix} \dot{\hat{x}} \\ \dot{\hat{W}} \end{bmatrix} = \begin{bmatrix} A & I \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{W} \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u + \begin{bmatrix} 0 \\ \dot{W} \end{bmatrix} \quad (15)$$

The observer for the augmented system, which simultaneously estimates the states and disturbances, has the following form:

$$\begin{bmatrix} \dot{\hat{x}} \\ \dot{\hat{W}} \end{bmatrix} = \begin{bmatrix} A & I \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{W} \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u - \begin{bmatrix} L_1 \\ L_2 \end{bmatrix} (\hat{y} - y) \quad (16)$$

$$\hat{y} = C \hat{x} \quad (17)$$

where \hat{x} and \hat{W} are the state and output estimation of the observer, respectively. The two-part gain of the observer is considered as L_1 and L_2 . Equation (17) may be written as Equation (18):

$$\begin{bmatrix} \dot{\hat{x}} \\ \dot{\hat{W}} \end{bmatrix} = \begin{bmatrix} A & I \\ 0 & 0 \end{bmatrix} \begin{bmatrix} \hat{x} \\ \hat{W} \end{bmatrix} + \begin{bmatrix} B \\ 0 \end{bmatrix} u - \begin{bmatrix} L_1 \cdot C \\ L_2 \cdot C \end{bmatrix} \tilde{x} \quad (18)$$

where \tilde{x} is defined as the state estimation error of the observer as Equation (19).

$$\tilde{x} = \hat{x} - x \quad (19)$$

The state estimation error of the observer can be calculated as follows:

$$\begin{bmatrix} \dot{\tilde{x}} \\ \dot{\tilde{W}} \end{bmatrix} = \hat{A} \begin{bmatrix} \tilde{x} \\ \tilde{W} \end{bmatrix} - \begin{bmatrix} 0 \\ \dot{W} \end{bmatrix} \quad (20)$$

where

$$\tilde{W} = \hat{W} - W \quad (21)$$

$$\hat{A} = \begin{bmatrix} A - L_1 C & I \\ -L_2 C & 0 \end{bmatrix} \quad (22)$$

The lemma by Wang et al. [9] is used to calculate the gain of the disturbance observer.

Lemma [9]: For the given L_1 and L_2 as Equations (23) and (24), the state estimation error of the disturbance observer Equation (18) is asymptotically stable.

$$L_1 = A + 2\Lambda \quad (23)$$

$$L_2 = \Lambda^2 I \quad (24)$$

wherein

$$\Lambda = \text{diag}\{\lambda_1, \dots, \lambda_n\}, \lambda_i > 0, i = 1, 2, \dots, n \quad (25)$$

Using the above-mentioned lemma, the values for L_1 and L_2 are obtained as follows for $\Lambda = \{50, 50, 100, 100\}$.

$$L_1 = \begin{bmatrix} 87.5 & 0 & -5.2 & 5.2 \\ 0 & 1.65 & 87.5 & 10 \end{bmatrix}^T$$

$$L_2 = 1e3 \begin{bmatrix} 2.5 & 0 & 0 & 0 \\ 0 & 0 & 5 & 5 \end{bmatrix}^T$$

3. 2. Pitch Angle Fuzzy Controller In order to obtain a smooth power from the wind turbine in its third

operation mode in the microgrid, a fuzzy logic controller is used in this paper. The structure of the fuzzy pitch angle controller is shown in Figure 3.

The input of the controller is the variation in rotational speed and the output is considered as the pitch angle variation. The input and output membership functions are given in Figures 4 and 5, respectively.

Fuzzy rules of the controller are given in Table 2. The Mamdani inference and center of gravity de-fuzzifier method is used in the fuzzy controller.

3.3. Feedforward Fuzzy Controller Feedforward control is used to reduce the effect of disturbances in the system, while the main functions of feedback control are stability and the reference signal tracking. Having a fixed feedforward controller may lead to unfavorable results in some conditions due to the nonlinear dynamics of the system and their limitations. In this paper, a fixed structure feedforward controller is regarded in which the parameters are updated based upon a fuzzy rule. The fuzzy rule structure for updating of the feedforward controller parameters is shown in Figure 6, which leads to better performance of LFC.

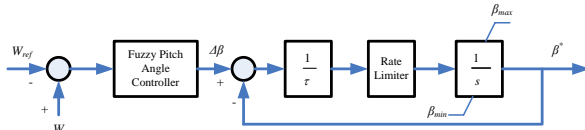


Figure 3. Structure of the fuzzy controller

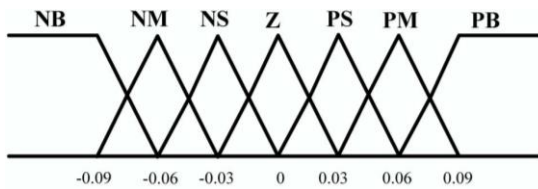


Figure 4. Input membership function for pitch angle control

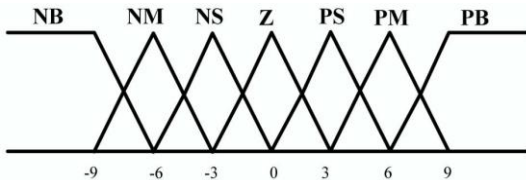


Figure 5. Output membership function for pitch angle control

TABLE 2. Fuzzy rules for pitch angle control.

ΔW	NB	NM	NS	Z	PS	PM	PB
$\Delta \beta$	NB	NM	NS	Z	PS	PM	PB

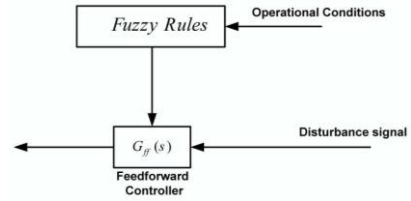


Figure 6. Fuzzy rules for feedforward controller design

A Proportional-Integral (PI) controller is used in the feedforward controller wherein their parameters including K_p and K_I are tuned based on the fuzzy logic. The normalized fuzzy rules for these two parameters are given in Tables 3 and 4.

The membership functions of the input and output of the fuzzy system are depicted in Figures 7 and 8, respectively.

TABLE 3. Fuzzy rules for K_p of the FFPI controller

Disturbance	NB	NM	Z	PM	PB
NB	S	S	S	S	S
NM	M	M	S	S	S
Z	S	S	S	S	S
PM	M	M	M	B	B
PB	B	B	B	B	B

TABLE 4. Fuzzy rules for K_I of the FFPI controller

Disturbance	NB	NS	Z	PS	PB
NB	B	B	M	S	Z
NM	B	B	M	Z	S
Z	M	M	Z	M	M
PM	M	M	M	B	B
PB	Z	S	M	B	B

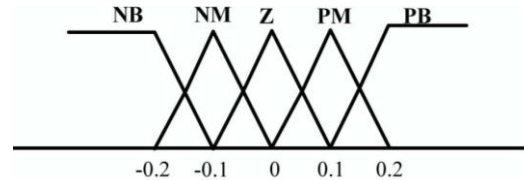


Figure 7. Input membership function of FFPI controller

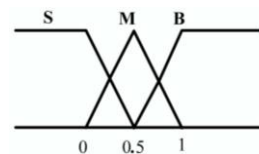


Figure 8. Output membership function of FFPI controller

The Mamdani inference mechanism and center of gravity de-fuzzifier method is used in the feedforward fuzzy controller as well.

4. SIMULATION RESULTS

The efficacy of our proposed feedforward fuzzy controller for LFC purpose is shown through some simulation studies for the considered microgrid. In the following, two scenarios including high integrations of wind power, solar power and load disturbance case and sudden load change case are considered. These two scenarios are studied by Khooban et al. [8].

4.1. Scenario 1: High Integrations of Wind Power, Solar Power and Load Disturbance

In this scenario, the performance of the proposed controller is verified in the presence of high integration of wind, solar and load power. The load model in this scenario is assumed as follows as shown in Figure 9. The wind speed and solar irradiation are also depicted in Figures 10 and 11, respectively.

The power variation of the wind turbine with the fuzzy pitch angle controller is shown in Figure 12.

As it can be seen from the figure, the fuzzy pitch angle controller leads to more smooth power in the wind turbine. Therefore, a better LFC may be achieved by the

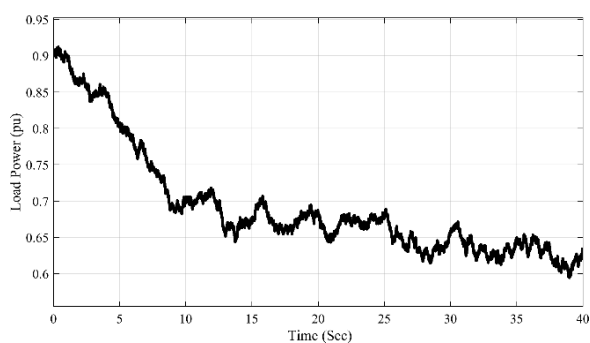


Figure 9. Load model in the microgrid

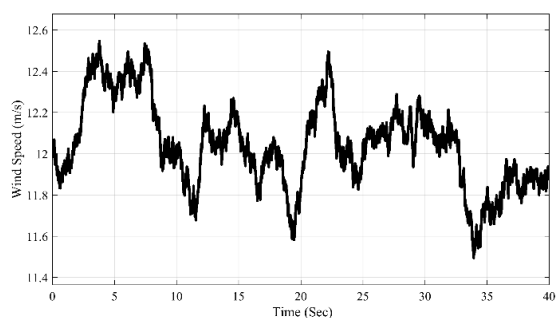


Figure 10. Wind speed

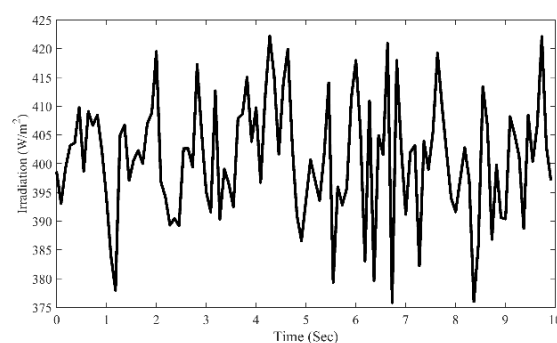


Figure 11. Solar irradiation

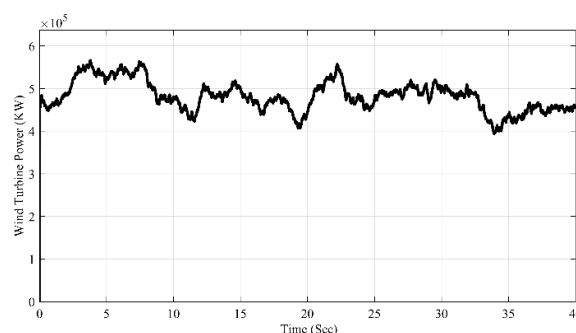


Figure 12. WT power with fuzzy pitch angle controller

main controller of the microgrid. The obtained power from PV array considering given solar radiation is shown in Figure 13.

The estimation of disturbance signal and its real values is shown in Figure 14.

The disturbance observer efficiently estimates the disturbance signal in the microgrid. This estimated signal is given to the fuzzy feedforward controller, which further changes the diesel generator power to alleviate the unfavorable frequency deviation. The frequency deviation of the proposed FFPI control strategy compared to the conventional PID controller is given in Figure 15.

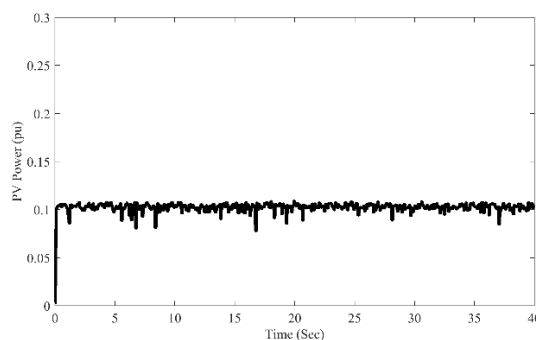


Figure 13. PV array power

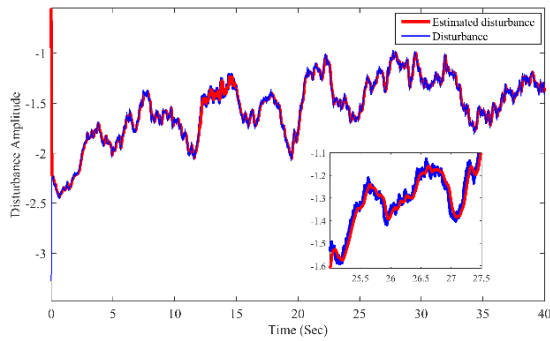


Figure 14. Estimated disturbance signal and its real value

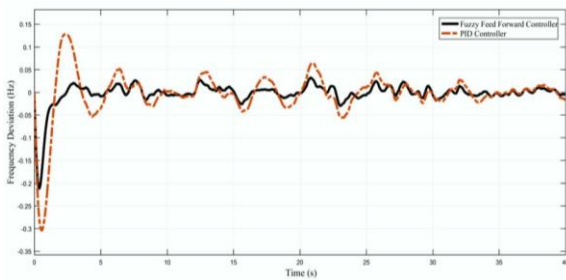


Figure 15. Frequency deviation for the first scenario

The proposed fuzzy feedforward controller and fuzzy pitch angle controller lead to great efficiency in the frequency deviation of the microgrid. For better comparison between the FFPI controller and the conventional PID controller, some criteria of the frequency deviation are given in Table 5, which are nominated as IAFD (Integral Absolute Frequency Deviation), ITAFD (Integral Time Absolute Frequency Deviation) and ITSFD (Integral Time Square Frequency Deviation). The conventional PID control strategy is tuned using modified Harmony Search (HS) algorithm as presented by Shivaie et al. [35]. In the FFPI controller case, we simultaneously have both conventional PID feedback controller and feedforward fuzzy PI controller, while the second case is the PID feedback controller without feedforward controller.

4. 2. Scenario 2: Sudden Load Change In this case, the performance of the controller is studied with

TABLE 5. Frequency deviation criteria of the first scenario for different control strategies of microgrid

Criterion vs. control method	FFPI controller	PID controller
IAFD	0.4851	1.103
ITAFD	6.302	12.72
ITSFD	0.0910	0.4182
Maximum deviation (Absolute value)	0.211	0.309

series step change in the load profile. The wind and solar power fluctuations are not considered in the simulation. In other words, it is assumed that the wind and PV powers are equal to the average wind power and irradiation power in the considered period, respectively. The wind turbine power and PV power are assumed as 0.6 and 0.1 p.u., respectively. The disturbance signal and its estimation are given in Figure 16, which shows the great performance of the disturbance observer.

The frequency deviation of the proposed FFPI control strategy compared to conventional PID controller for the second scenario is given in Figure 17.

As it can be seen from the figure, the proposed method shows much better performance compared with conventional PID controller. The frequency deviation criteria of microgrid for the second scenario are also given in Table 6.

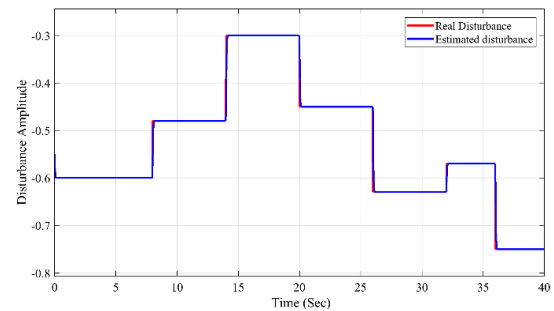


Figure 16. Estimation of disturbance in the second scenario

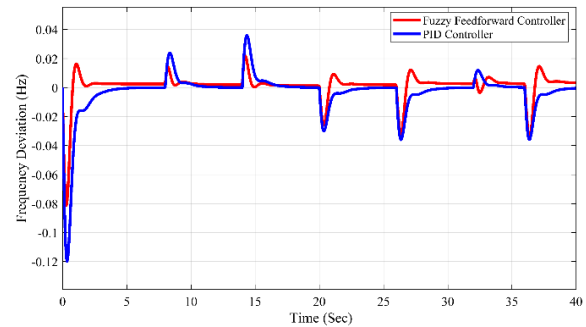


Figure 17. Frequency deviation for the second scenario

TABLE 6. Frequency deviation criteria of the first scenario for different control strategies of microgrid

Criterion vs. control method	FFPI controller	PID controller
IAFD	0.2102	0.2535
ITAFD	3.902	4.077
ITSFD	0.046	0.068
Maximum deviation (Absolute Value)	0.081	0.1198
Settling time (s) (first peak)	2.44	4.99

As it can be seen from the values of the tables, the proposed fuzzy feedforward controller with the fuzzy pitch angle controller has a much better performance compared to the conventional PID controller.

5. CONCLUSION

A novel control strategy including fuzzy logic feedforward controller based on disturbance observer and wind turbine fuzzy logic pitch angle controller for load frequency control of microgrid in its islanded operation mode has been presented. The difference between the renewable sources and load has been assumed as the disturbance in the system. The disturbance has been represented as disturbance term in the microgrid model, which has been estimated by the modified disturbance observer. The understudy microgrid contains load, wind turbine, solar cells and diesel generator. The considered fuzzy pitch angle control in wind turbine leads to more smooth power of wind turbine. Two diverse scenarios including high integration of different power sources and sudden load change have been studied to show the efficacy of both the observer and FFPI controller. The proposed FFPI control strategy has been shown to have a great impact on the performance on the frequency deviation control of the microgrid. Simulation results and numerical values of different criteria of frequency deviations for the proposed controller compared to those of the conventional form easily confirm the outperformance of the method presented in the paper.

The design and performance of the proposed control strategy for converter-based or over modulation cases can be considered as future work

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Persian Abstract

چکیده

در این مقاله به مساله کنترل بار - فرکانس ریزشبه در مود جزیره ای با استفاده از کنترل کننده پیش سوی فازی پرداخته شده است. به این منظور علاوه بر کنترل کننده فیدبک معمول از یک کنترل کننده پیش سو در ساختار کنترلی ریزشبه بهره برده شده است. سیگنال اغتشاش که می تواند تغییرات بار یا عدم قطعیت ناشی از منابع تولید پراکنده باشد توسط یک مشاهده گر اغتشاش تخمین زده می شود. ریزشبه مورد مطالعه شامل توربین بادی، سلول خورشیدی، دیزل ژنراتور و بار است. همچنین یک کنترل کننده فازی برای کنترل زاویه پیچ توربین در نظر گرفته شده است که از تغییرات زیاد توان تولیدی توسط توربین جلوگیری کرده و کنترل فرکانس ریزشبه را بهبود می دهد. نتایج شبیه سازی بخوبی نشان دهنده کارایی روش پیشنهادی برای کنترل بار - فرکانس ریزشبه در مود جزیره ای است.
