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Secondary Frequency Control of Microgrids In Islanded Operation Mode and Its Optimum Regulation Based on the Particle Swarm Optimization Algorithm

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Abstract

In microgrids, the use of renewable energy sources, such as wind power generation systems (WPGS) and photo voltaic(PV) systems, causes to vary the electrical power. These changes in power systems may lead to imbalance between the load and the power. Since the increase/decrease of the power cannot be compensated by the connection with the grid, instability may be arose in the system by islanded MGs. In this paper, to prevent the changes and to provide stability in the system, a PI controller with a fuzzy system, which concurrently determine the coefficients of the PI controller, is introduced. For optimum regulation of the fuzzy membership functions, the particle swarm optimization Algorithm (PSOA) is applied. The simulation results reveal that the optimal controller makes the frequency changes approach to zero more rapidly than classical controller and the fuzzy.

Keywords: Particle swarm optimization Algorithm (PSOA), Ziegler-Nichols, secondary frequency control, fuzzy controller, PI controller.

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Introduction:

The world's population growth, the increasing needs for energy, the lack of fossil fuels and the environmental issues cause the usual power grid not to provide needs for electrical energy any longer. One of the ways to overcome these difficulties is to use the distributed generation (DG) sources besides fossil fuels. Although the utilization of DG units may increase the reliability and alleviate the environmental concerns, it may, also, lead to nonlinearity and complexity of the power systems. In order to overcome the difficulties, MGs which independently supply the loads are used. MGs including the several DG unit sand energy storage devices are able to supply acceptable power for the Loads (Hawkes and Leach, 2009 and Lassete et al, 2002). One of the most significant reasons for applying the microgrids (MGs) in ''islanded" mode is the balance between generation and consumption. In MGs, using renewable resources yield some changes in the output power and result in system instability. Therefore, to create a balance between generation and consumption and to prevent the frequency changes resulted from the utilization of the renewable energy sources (RES) in MGS, the frequency must remain in the nominal value. Consequently, the secondary frequency plays a starring role in exploiting MGs.

The diverse works on this subject has been done. Using the intelligent control structure based on neural networks for secondary frequency control (SFC) of MG (when it is not connected to the network), minimizes the fluctuations in the system automatically ((Bevrani,and Shokoohi ,2010). It is reported in (Lee and Wang ,2008) that the validity of the proposed mathematical model for MG is confirmed by the simulation results. A novel method of controlling SFC of typical MGs, such as wind turbines generators, PV panels, diesel engine generators, energy storages and flywheels, is introduced by Bevrani et. al. (Bevrani et al, 2012). In the presence of load changes and serious disturbances, frequency regulation is a highly significant subject in the MGs. Also, it is revealed in (Bevrani et al, 2012) that an adaptive controller including a classical controller and a fuzzy system, which determine the controller coefficients, is able to control the frequency of MG system. And also it's shown that the frequency changes approach to zero swiftly through the proposed PSO-fuzzy control technique.

In the present paper, SFC for the MG independently of the network is studied. First, a classical PI controller using Ziegler-Nichols technique, as suggested in (Bevrani et al, 2012), is designed and then in order to improve the controller operation, a fuzzy system which is able to concurrently adjust the controller coefficients is proposed. Since the membership functions of the fuzzy system play a main role in the controller, the PSOA is applied to adjust their parameter sat the same time. The operational effectiveness of the proposed method is revealed by the results.

The paper is organized as follows. In Section II, test MG in ''islanded" mode and the mathematical model of the different units are introduced. In the next section, the PSOA is explained in brief. Applying the proposed control method to MGs is demonstrated in Section IV. In the following section, some simulation scenarios are considered and the simulations are carried out by MATLAB software. Finally, the conclusions are discussed in Section VI.

Test MG

For SFC, the test MG model is illustrated in Fig. 1. (a). The way of building the frequency response model, which is shown in Fig. 1 (b), from MG is completely demonstrated in (Lee and Wang ,2008 and Bevrani et al, 2012) . The test MG parameters are

reported in Table 1. The mathematical models of the different units in the islanded MG are estimated by first-order transfer functions which are suitable for the frequency/voltage control.

Particle Swarm Optimization Algorithm (PSOA)

Inspired by the flocking and schooling patterns of birds and fish, PSOA was invented. A basic variant of the PSOA works by having a population (known as a swarm) of candidate solutions (known as particles). Each particle searches for better positions in the search space by changing its velocity according to rules originally inspired by behavioural models of bird flocking. The algorithm keeps track of three global variables (1)Target value or condition (2) Global best (g_{best}) value indicating which particle's data is currently closest to the Target (3) Stopping value indicating when the algorithm should stop if the Target isn't found . Each particle consists of (1) Data representing a possible solution (2) A Velocity value indicating how much the Data can be changed (3) A personal best (g_{best}) value indicating the closest the particle's Data has ever come to the Target. An assembly of particles in the n-dimensional search-space could be modelled as follows. The position and the velocity of each particle (i) are denoted by $x_i(t)$ and $v_i(t)$, respectively. The velocity in each dimension in the successive iteration is updated by the following position and velocity update equation (Pan and Das and Gupta, 2011):

$$X_i(t+1) = X_i(t) + V_i(t+1) \tag{1}$$

$$V_i(t+1) = \omega V_i(t) + C_1\Phi_1(P_{best,i}(t) - X_i(t)) \quad + C_2\Phi_2(g_{best,i}(t) - X_i(t)) \tag{2}$$

In the next iteration, x_i depends on the velocity (v_i) in the present equation multiplied by factor (ω). Fig. 2 shows the flowchart of PSOA.

Applying the Proposed Control Method to MGs

In this study, for secondary frequency control, firstly, an appropriate PI controller using Ziegler-Nichols technique is tuned and then a smart controller with a fuzzy system, which concurrently determines the coefficients of the classical controller, is utilized.

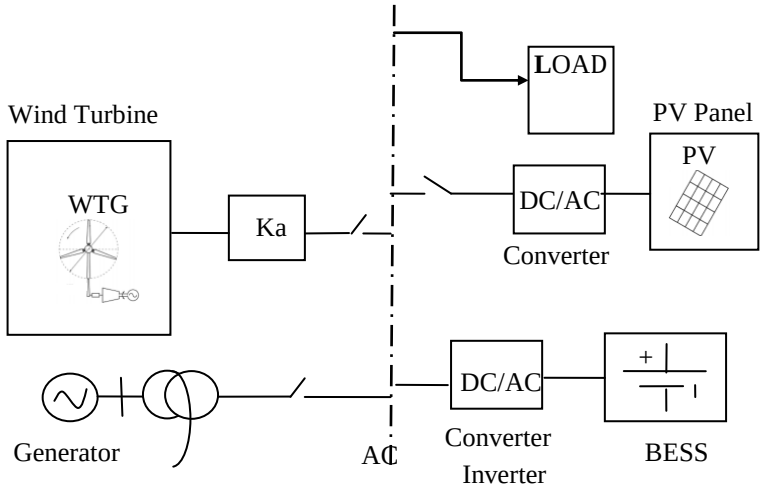
Since the performance of the fuzzy controller hinges on the choice of the type of membership functions (MF), PSOA as an intelligent algorithm is exploited in order to optimize the range of MF changes. By the use of Ziegler-Nichols technique, the proper values of the proportional and integral coefficients of the PI controller, K_p and K_i , are selected to be 4 and 6, respectively.

Designing Fuzzy PI controller

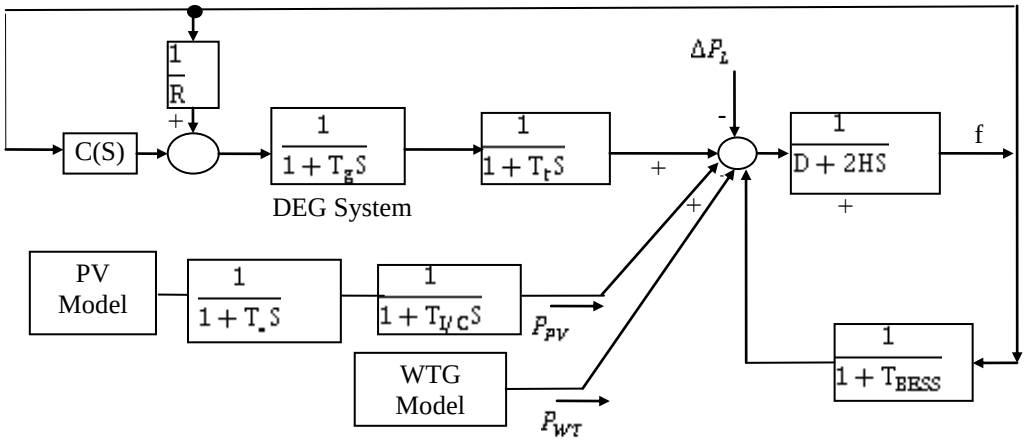
In recent control applications, Fuzzy logic controllers (FLC) as a suitable intelligent method have become

Table 1. Test MG Parameters

Parameter	Vlaue	Parameter	Vlaue
D (Pu/Hz)	0. 015	T_g (s)	0. 08
2H (Pu. s)	0. 1667	T_t (s)	0. 4
T_{BESS} (s)	0. 1	T_{in} (s)	0. 04
R (Hz/pu)	3	$T_{i/c}$ (s)	0. 004



(a)



(b)

Fig. 1. Test MG Model (a) Real Model (b) Frequency Response Model (Bevrani et al, 2012)

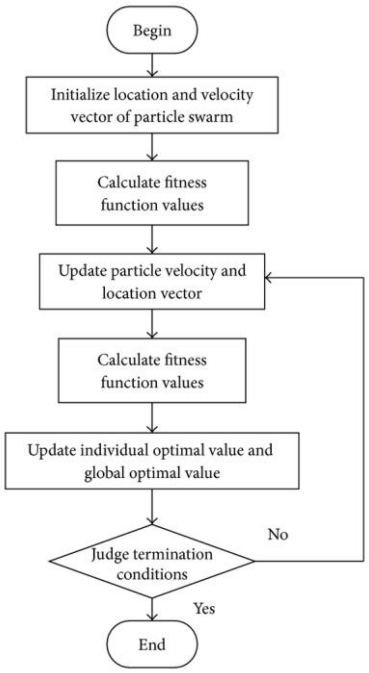


Fig. 2. The Flowchart of PSOA

more common because of its reliability and simplicity. Hence, in the present study, for frequency control of a MG in the islanded mode and determining coefficients of PI controller, fuzzy logic is applied and to optimize fuzzy membership functions according to the on line information, PSOA is exploited to boost the system performance. In Fig. 3 the used control system structure based on fuzzy logic is shown. The fuzzy PI controllers often follow this structure. When it's said "the PI controller coefficients regulation with the transform function $C(s) = K_p + K_i / s$ ", it means to choose K_p (proportional gain) and K_i (integral gain) properly. The idea of using fuzzy logic in the system transient responses applied to optimize the characteristics of these parameters. The fuzzy rules, indeed, are empirical. For example, since the integral term is associated with the percentage of overshoot (%Mp), when the output is more than the regulation point, the overshoot considerably can be reduced by its reduction. In addition, by increasing the integral term, the rising time can be decreased. Besides, the increase in the proportional term will yield decrease in rising time and also increase in the fluctuations. The inputs of the fuzzy system

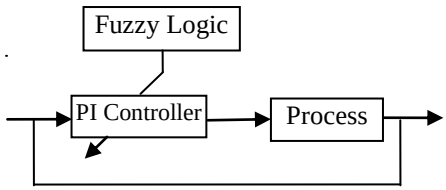


Fig. 3. The Used Control System Structure Based on Fuzzy Logic

adjust the classical controller parameters such as frequency deviation Δf and load perturbation ΔP_L and the outputs determine the classical controller proportional and integral coefficients, K_p and K_i, respectively.

In Table. 2, a set of fuzzy rules consisting of 18 rules is presented. The membership functions corresponding to the input variables are arranged as Negative Large (NL), Negative Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM), Positive Large (PL) and corresponding to the load perturbations as Small (S), Medium (M) and Large (L). Also, corresponding to the output variables, the membership functions are arranged as Negative Large (NL), Negative Medium (NM), Negative Small (NS), Positive Small (PS), Positive Medium (PM) and Positive Large (PL). The antecedent parts of each rule are composed by using AND function. For simplicity, based on the triangular membership functions, they have been organized (Fig. 4). Here, Mamdani fuzzy inference system the center of gravity method for defuzzification are also exploited.

In comparison to the classical controller, the simulation results reveal that the fuzzy one has good performance. Since access to the precise information about the system is not easy, the membership functions, upon which highly performance of the controller depend, cannot be carefully selected. To alleviate this problem, hence, PSOA as an online and a complementary algorithm is used to regulating of membership functions in a wide range of operating condition.

Designing Optimum Fuzzy PI Controller by Applying PSOA

In this study, as previously noted, PSOA as an online algorithm is used to regulating of membership functions in a wide range of operating conditions. The control framework based on PSOA and Fuzzy Logic (FL) for online regulating of the coefficients of the PI controller is presented in Fig. 5 (Bevrani et al, 2012). The purpose of the optimal fuzzy-PI controller (i. e. PSO-fuzzy PI controller) is minimizing of frequency deviations Δf . The model validation: After designing the controller, its validation for secondary frequency control will be examined. As it's shown in Fig. 3 and Fig. 5, the fuzzy PI controller has one input, Δf (frequency deviations) and the PSO-fuzzy PI controller has two inputs, Δf (frequency deviations) and ΔP_L (load disturbance pattern). The performance of the controller must be ensured that the frequency deviation is regulated towards zero after every change in load or supply. In other words, the controller should be included a generation-load balance. So, when the frequency

Table 2. Set of Fuzzy Rules of K_p and K_i

$\Delta f \rightarrow$ / $\Delta P_L \downarrow$	NL	NM	NS	PS	PM	PL
S	NL	NM	NS	PS	PS	PM
M	NL	NL	NM	PS	PM	PM
L	NL	NL	NL	PM	PM	PM

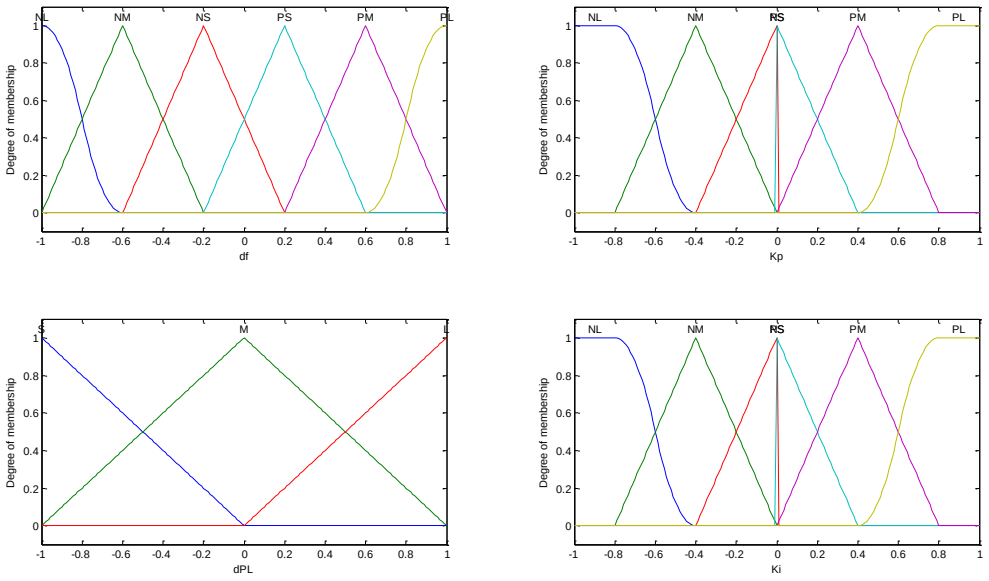


Fig. 4 Membership Functions of Input and Output Variables

deviations are positive large and the demand power of the load is small, it means that the power generated by the renewable and non-renewable energy sources is increased. In this case, by storing it in the battery (the negative sign for battery model in Fig. 1-b) or decreasing Δf , i. e. decreasing the proportional term, and increasing ΔP_L ,i. e. increasing the integral term, the changes in frequency can be prevented. In the present study, the results which obtained through the fuzzy rules show this fact that the balance between load and power which result in the secondary frequency is completely appropriate. The mathematical model which is presented in this study for the MG elements is the same as the model which is used in (Bevrani et al, 2012). Turbine time constant (T_t),

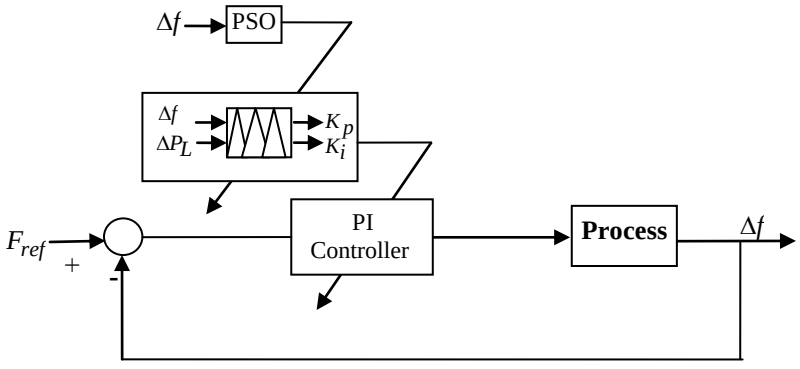


Fig. 5. PSO-Fuzzy-PI Controller Structure

generator time constant (T_g) and photovoltaic constant (T_{PV}) are sufficiently suitable so they can guarantee that the model is closest to the real one.

Simulations

In this section, for the several scenarios, classical PI controller with fuzzy system and fuzzy-PSO-controller are compared with each other. Also, the assessment of their performance is carried out with respect to each other. The analysis of the results obtained through programming with MATLAB software is conducted. Two scenarios are considered.

In the first one, to obtain the frequency response of the system, a unit step with the magnitude 0. 02 in per unit (p. u.), is applied to MG and also the inputs of renewable energy sources are randomly applied to the system. To reveal the advantages of the PSO-Fuzzy-PI controller with respect to classical PI and fuzzy controller, Fig. 6 is used as a performance indicator. As it's shown in Table. 3. , the PSO-Fuzzy-PI controller provides a much better performance, specifically in settling time characteristic point of view.

In the next scenario, in order to compare the behavior and effectiveness of the controllers, used in the system which a step load is applied, the frequency response of the closed loop system is examined with several positive and negative unit loads according to Fig. 7. Optimum performance of the proposed controller associated with many control features is clearly illustrated in Fig. 8 and is shown in Table 4.

Conclusion:

In this study, a new fuzzy controller is tuned for secondary frequency control of a MG. In the proposed method, the classical PI controller is being utilized and in order to determine the coefficients of this controller and also to boost the performance, a fuzzy system is applied. Also, the PSOA as a flexible intelligent algorithms is used to provide an optimal and a desirable performance over the range of membership functions changes. the performance of the proposed controller is qualitatively assessed for the several scenarios by the simulations carried out by MATLAB software. The great and desired performance and also highly effectiveness of the proposed fuzzy PI controller are revealed by the results obtained through this study.

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APPENDIX

Table. 3. Comparing the Performance of the Controllers- the First Scenario

	undershoot	$t_{undershoot}$	overshoot	$t_{overshoot}$	Settling time
Conventional PI controller	-0. 0073	0. 2930	0. 0043	0. 8230	8. 66
Fuzzy PI controller	-0. 0084	0. 3440	0. 0033	1. 0060	5. 42
Pso- Fuzzy PI controller	-0. 0081	0. 3240	0. 0021	0. 8950	5. 4

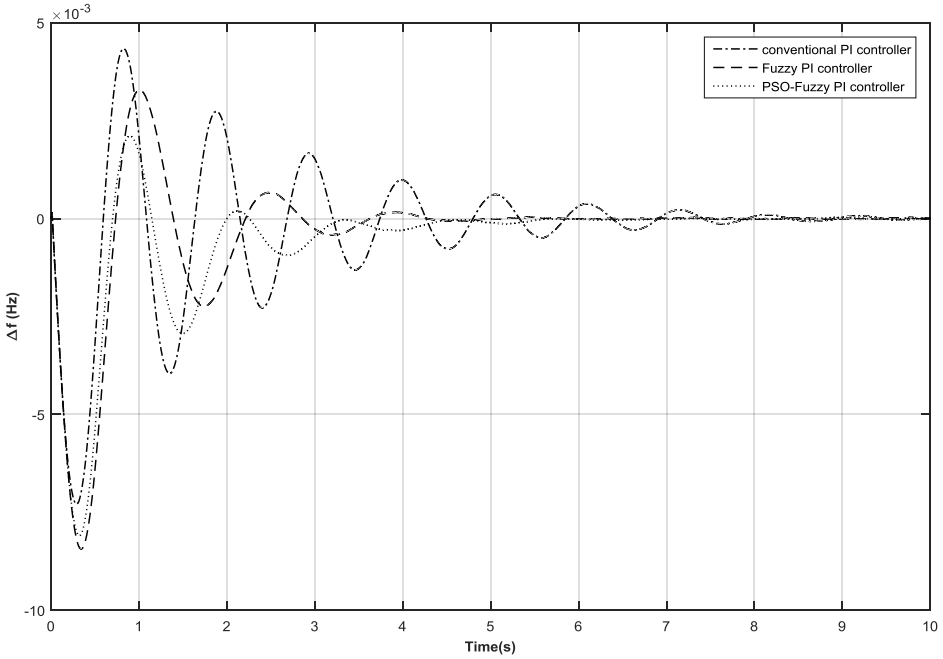


Fig. 6. Frequency Response of the First Scenario

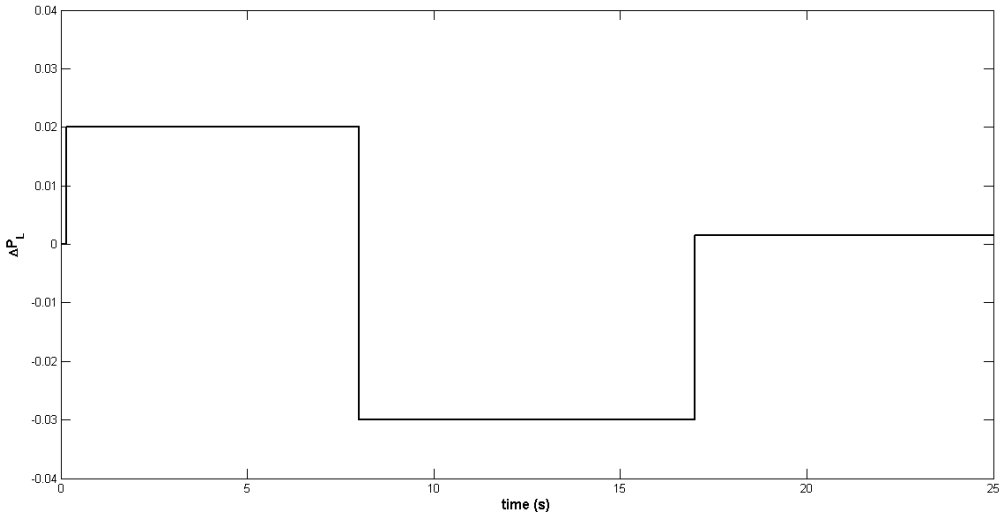


Fig. 7. Step Load of the Second Scenario

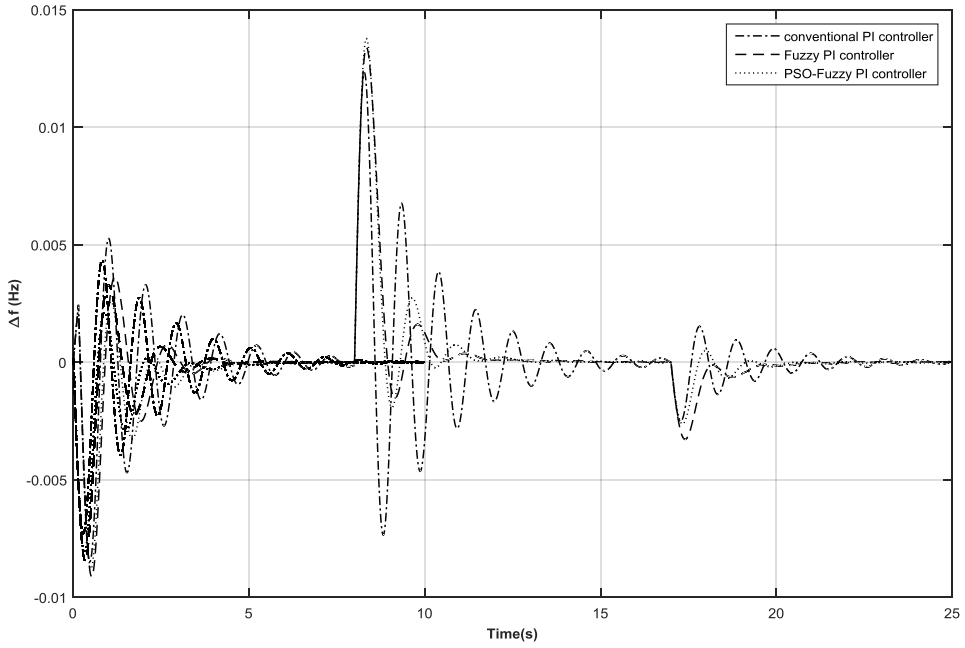


Fig. 8. Frequency Response of the Second Scenario

Table. 4. Comparing the Performance of the Controllers- the Second Scenario

	undershoot	**$t_{undershoot}$**	**overshoot**	**$t_{overshoot}$**	**Settling time**
Conventional PI controller	-0. 0085	0. 4770	0. 0123	8. 2820	24. 7420
Fuzzy PI controller	-0. 0091	0. 5230	0. 0134	8. 3400	20. 6380
Pso- Fuzzy PI controller	-0. 0088	0. 5040	0. 0138	8. 3420	20. 1930