Load Frequency Control in Island Microgrid by Model Predictive Control (MPC) Method

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ABSTRACT:

One of the most important issues of the microgrid in the form of separation from network is power, the frequency and voltage control. In this paper, a control-based method of model predictive control is presented for control of load frequency in the microgrid network. The proposed controller is located in the second frequency control loop and, by applying the control signal to the sources, the frequency disturbances are mimicked after the power changes in the microgrid. The simulation results in the MATLAB / Simulink environment show that the proposed controller has a better performance in comparison with the proportional-integral controller based on Zigler-Nicoles based PI (ZN-PI), proportional-integral controller based on fuzzy logic,(Fuzzy-PI), proportional-derivative-integral controller of fractional times base on Canonical Particle Swarm Optimization based Proportional Integral differential (CPSO-PID) and proportional-derivative-integral controller based on optimal particle algorithm, so that 1) frequency fluctuations decreases in terms of the oscillation range and its number effectively; 2) it is more resistant than the certainty of the microgrid parameters; and has better function in the parameters change to the other one.

KEYWORDS: Microgrid, Load frequency control, Model predictive control.

1. INTRODUCTION

By increasing the usage of electric energy in the world, the power industry has faced such challenges as the high cost of building new power plants and development of transmission networks,, over-distribution and distribution, environmental concerns and climate change. In order to overcome these problems, increasing reliability ginving service to customers and reducing the density and losses in transmission and over transmission lines, distributed and renewable energy sources are new and appropriate alternatives that have been introduced over the past two decades [1]. The benefits of renewable energy sources have led to increase in the number of electrical power plants and the increasing expansion of microgrids in most countries of the world [2]. Microgrid are small power networks that are consisted of several renewable energy sources and local looms. Microgrids are normally connected to one of the distribution networks, but in case of emergency, in the event of major turbulences, they separated from the power microgrid and feed some of the loads (important loads). Due to the change of wind speed, sunlight intensity, variations and load fluctuations are one of the important issues in the main stream microgrid, controlling and controlling frequency and power fluctuations. This issue is also noticeable in terms of the time intervals associated with exploitation and management (which the aim was controlling power fluctuations), as well as in corresponding time intervals with Load frequency control (LFC). In the subject (LFC), the aim is to rapidly fluctuate the oscillations and ensure the dynamic performance of the system, so that oscillations are located within a satisfactory range.

Several studies have been provided on controlling the health of Load frequency control in microgrid. In [4,6] has been reviewed on the work done in this area. The research is divided into two general categories in the design of controllers: controllers based on conventional methods and on-the-go controllers. //In [7,8], Proportional Integral based controllers (PI) and Proportional Integral differential (PID[3]) based on the determination of coefficients by the Ziggler-Nichols method [9] and the deficit order [10] for Frequency control is provided in the microgrid. In [11,13], have been used resistant control methods to controller design, so that reference provide the (H_∞) control [11,12], and Robust control using μ-synthesis and D-K iteration [13]. In [14.18], the dropping control method is provided in [14, 16] of control method of (in linear dropping), [17] non-linear dropping and [18] linear dropping control with loads controllable) for controlling the load frequency in the microgrid. In [19], observer-based slider control is used to control the load frequency in the microgrid.

From controllers based on supra-enterprise algorithms, it refered to the Genetic Algorithm (GA) Particle Swarm Optimization (PSO), Social-spider optimizer (SSO), Biogeography-based optimization to control PID, and Extended search harmonic algorithm for controlling the frequency of load in microgrid. References [25, 27] are determined from fuzzy controller, which coefficients using the particle swarm algorithm [25] and secondary type of fuzzy logic [26, 27] have been used to control the load frequency.

Reference [28,29] also used the secondary frequency control on the converter of renewable energy sources for controlling the load frequency. One of the proper controllers for considering various uncertainties in a system is predictive control that has capability to predict future events and adopting appropriate control actions [30]. In [31,32], the Model predictive control MPC, in [33], two-level predictive control, and in [34], multiple predictive control with consideration of charging and discharging of electrical hybrid cables to mimic the volatility of power resources in time intervals corresponding to the operation and management of the Mgrid (applied controlling signals in a few minutes). Also in [35], a method is provided to coordinated control of wind turbine blades and hybrid electric vehicles based on predictive control, in order to mimic the power and frequency fluctuations in the microgrid. A new formulation of the MPC is presented to compensate time delay when the generation rate is constraint in multiarea power systems [36].

In the present paper, a predictive control is provided to control the load frequency in a microgrid. The proposed control method is used in the secondary control loop of the frequency and the control signal is applied to the renewable energy sources in themicrogrid. Intended microgrid include a variety of renewable energy sources with a dynamic model (small signal), this signal is around a work point, and the equations of state-of-the-art are extracted. The proposed controller for controlling the frequency variations of the microgrid is under normal conditions, as well as in the case of uncertainty and change of parameters, than controllers such as the CPSO-, Fuzzy-PI11, ZN-PI, FOPID, CPSO-PID which is provided a better performance. Therefore, the novelty of the paper is to: 1. Provide a new method for reducing the frequency fluctuations in the microgrid (seperate from the main network) based on predictive control; 2. Prove the efficiency and better performance of the proposed controller in the reducing of frequency fluctuation (under normal conditions as well as in exposure to uncertainty of parameters) in compared with other controllers, by simulating and comparing their performance results in the load-frequency control problem.

This paper has been written in the following sections: Section 2: The overall structure of the microgrid and the control strategy; Section 3: Dynamic performance of the icrogrid components; 4: Model-based predictive controller; 5: Simulation and 6, Conclusions and references.

2. MICROGRID GENERAL STRUCTURE AND STRATEGY OF AVAILABLE CONTROL STRATEGY

2.1. Structure of Microgrid

Fig. 1 shows the schematic of the studied microgrid which is located in a separate mode from the main microgrid. A used micro grid includes a Photo voltaic (PV), Diesel Engine Generator (DEG), Wind Turbine Generator (WTG), Frequency control (FC) and two Battery energy storage system (BESS), Flywheel energy storage system (FESS), Aqua electrolyzer [25,37]. The used energy sources in micro grid are connected to the main bus with the power electronic converters, and from this source the injector power is controlled by the main bus.

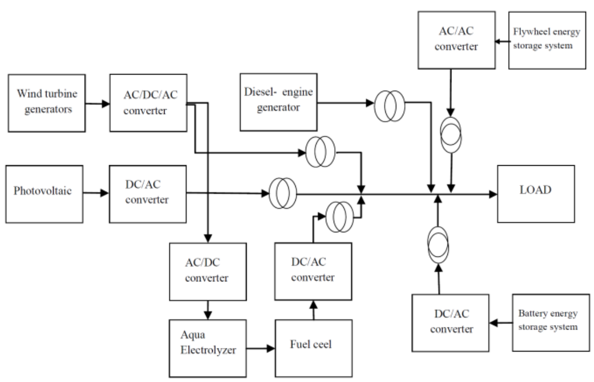


Fig. 1. Microgrid Schematic.

2.2. An Small Signal Model for the Microgrid Components

In order to investigate the frequency-load control issue in the microgrid, it is necessary to use a small signal model of renewable energy sources and storage devices (which are roughly linear).The small signal model of each of the microgrid components is:

2.2.1. Wind Turbine Generator (WTG)

The dynamic model of Wind Turbine Generator for small signal analysis, eq. (1), and its characteristic function is expressed by (2):

$$\Delta P_{WTG} = \frac{K_a K_{WTG} \Delta P_W}{T_{WTG}} - \frac{\Delta P_{WTG}}{T_{WTG}} \quad (1)$$

$$G_{WTG}(s) = \frac{K_a K_{WTG}}{1 + sT_{WTG}} = \frac{\Delta P_{WTG}(s)}{\Delta P_W(s)} \quad (2)$$

In (1) and (2), T_{WTG} و T_{WTG} respectively, efficiency and constant time wind turbine, k_α , is a numerical coefficient representing the wind turbine power percentage which is delivered to microgrid, ΔP_{WTG} : the electric power output variations of the Wind Turbine Generator and ΔP_W: Wind Turbine Generator variations the extracted mechanical wind power (P_W) is obtained from equation (3)

$$P_W = \frac{1}{2} C_P . pA_r V_W^3 \quad (3)$$

In (3), C_p: coefficient of turbine operation,, ρ: Air density (kg/m^3), A_r: Blade level vacuum cleaner (m^2) and V_w: is Wind speed (m / s).

2.2.2. Photo Voltaic (PV)

Dynamic model of solar cell is expressed in small signal analysis, eq. (4), and its characteristic function with relation (5).

$$\Delta P_{PV} = \frac{K_{PV} \Delta \emptyset}{T_{PV}} - \frac{\Delta P_{PV}}{T_{PV}} \quad (4)$$

$$G_{PV}(s) = \frac{K_{PV}}{1 + sT_{PV}} = \frac{\Delta P_{PV}(s)}{\Delta \emptyset(s)} \quad (5)$$

In (4) and (5), T_{PV} and K_{PV} respectively will be obtained efficiency and Photo voltaic, ΔP_{pv}, the variation of the electrical power of the Photo voltaic, $\Delta\varphi$:the variation in the intensity of the solar radiation. The electrical power of the Photo voltaic (P_{pv}) is given by (6).

$$P_{PV} = \eta S \varphi [1 - 0.005 \times (T_a + 25)] \quad (6)$$

In equation (6); Ƞ : Photo voltaic efficiency; S: Photo voltaic area (m^2); Φ : Photo voltaic intensity (kw/m^2); T_a : is the temperature of the environment.

2.2.3. Diesel Engine Generator (DEG)

Diesel Engine Generator plays a major role in the independent hybrid processor, so that when load increasing, is required a part of the power supply to achieve the balance (power) position. The dynamic model of Diesel Engine Generator is expressed in the small signal analysis, eq. (7), and its characteristic function in equation (8).

$$\Delta P_{DEG} = \frac{K_{DEG} \Delta P_C}{T_{DEG}} - \frac{K_{DEG} \Delta F}{R T_{DEG}} - \frac{\Delta P_{DEG}}{T_{DEG}} \quad (7)$$

$$G_{DEG}(s) = \frac{K_{DEG}}{1 + sT_{DEG}} = \frac{\Delta P_{DEG}(s)}{\Delta U_{DEG}(s)} \quad (8)$$

$$\Delta U_{DEG}(s) = \Delta P_C(s) - \frac{\Delta F(s)}{R}$$

In equation (7),(8), K_{DEG} and T_{DEG} respectively is efficiency and constant time and Diesel Engine Generator, R: fall speed coefficient, $\Delta P_{DEG:}$ power variation of Diesel Engine Generator, ΔU_{DEG} : input signal variation of Diesel Engine Generator, ΔP_c : applied signal varition of controller to Diesel Engine Generator and ΔF: Frequency variation.

2.2.4. Aqua Electrolyzer (AE)

The Aqua Electrolyzer provides the necessary hydrogen for the fuel cell. The power of the Aqua Electrolyzer is provided with a part of the wind turbine power ((1-K_a)PWTG. The dynamic model of the Aqua Electrolyzer in a small signal analysis is described in eq. (9) and its characteristic function in eq. (10).

$$\Delta P_{AE} = \frac{K_{AE}(1-k_a)\Delta P_{WTG}}{T_{AE}} - \frac{\Delta P_{AE}}{T_{AE}} \quad (9)$$

$$G_{AE}(s) = \frac{K_{AE}}{1+sT_{AE}} = \frac{\Delta P_{AE}\,(s)}{\Delta P_t(s)} \quad (10)$$

In eq. (9) and (10), K_{AE} and T_{AE} is the efficiency and constant time of the Aqua Electrolyzer, ΔP_{AE} *:* produced hydrogen variation of Aqua Electrolyzer and ΔP_1 : Input power variation of Aqua Electrolyzer.

2.2.5. Fuel Cell (FC)

The fuel cell generates electrical energy by using electrically generated hydrogen. The dynamic fuel cell model in the small signal analysis is described in equation (11) and its characteristic function in eq. (12).

$$\Delta P_{FC} = \frac{K_{FC}\Delta P_{AE}}{T_{FC}} - \frac{\Delta P_{FC}}{T_{FC}} \quad (11)$$

$$G_{FC}(s) = \frac{K_{FC}}{1+sT_{FC}} = \frac{\Delta P_{FC}(s)}{\Delta P_{AE}(s)} \quad (12)$$

In eq. (12) T_{FC} و K_{FC} respectively, are efficiency and constant time of fuel cell's and ΔP_{FC} : The electrical power variation in the output of the fuel cell.

2.2.6. Battery Energy Storage System (BESS) and Flywheel Energy Storage System (FESS)

The battery storage system stores the received electrical energy in the form of chemical energy (mechanical). Batteries and Flywheel energy storage system store energy in the microgrid and provide electrical power shortages. In the analysis of the small signal, the dynamic model of the battery and the Flywheel energy storage system are expressed in terms of eq. (13) and (14) and their characteristic functions with equations (15) and [16].

$$\Delta P_{BESS} = \frac{K_{BESS}\Delta U_{BESS}}{T_{BESS}} - \frac{\Delta P_{BESS}}{T_{BESS}} \quad (13)$$

$$\Delta P_{FESS} = \frac{K_{FESS}\Delta U_{FESS}}{T_{FESS}} - \frac{\Delta P_{FESS}}{T_{FESS}} \quad (14)$$

$$G_{BESS}(s) = \frac{K_{BESS}}{1+sT_{BESS}} = \frac{\Delta P_{BESS}(s)}{\Delta U_{BESS}(s)} \quad (15)$$

$$G_{FESS}(s) = \frac{K_{FESS}}{1+sT_{FESS}} = \frac{\Delta P_{FESS}(s)}{\Delta U_{FESS}(s)} \quad (16)$$

In eq. (13) to (16), K_{BESS} and T_{BESS} respectively, is efficiency and constant time of Battery energy storage system and K_{FESS} and T_{FESS} is efficiency and constant time of Flywheel energy storage system, ΔP_{BESS}: absorbed/produced power variation from battery, ΔP_{FESS} absorbed/produced power variation from Flywheel energy storage system, ΔU_{BESS}: applied signal variation of controller with battery system and ΔU_{FESS}: applied signal variation of controller to Flywheel energy storage system.

2.2.7. Frequency Variation and Microgrid Power

Changes in power output will cause frequency variations. Dynamic dynamic model is used to analyze the small signal with relation (37).

$$G_{SYS}(s) = \frac{1}{K_{SYS}(1+sT_{SYS})} = \frac{1}{M_S + D} = \frac{\Delta F(s)}{\Delta P(s)} \quad (17)$$

In eq. (17), D: constant of system drowning, M: constant of system inertia (pu) , ΔF: System Frequency variation (pu), ΔP: System Power variation which are calculated from equation (18) and (19)

$$\Delta P = \Delta P_S - \Delta P_L \quad (18)$$

$$\Delta P_S = K_t\Delta P_{WTG} + \Delta P_{PV} + \Delta P_{DEG} + \Delta P_{FC} + \Delta P_{FESS} + \Delta P_{BESS} \quad (19)$$

In eq. (18) and (19), ΔP_s : variation of the electrical power of the microgrid supplies and ΔP_L :the variation in the constant load factor, which is considered as a constant power load. Fig. 2 shows the small binary signal model by block of different components.

2.3. Frequency Control

As seen in Fig. 2, In the event of turbulence in the microgrid and the collapse of the power balance the frequency is changed. To return the frequency to a nominal value, it acts on two levels: primary control and secondary control of frequency.

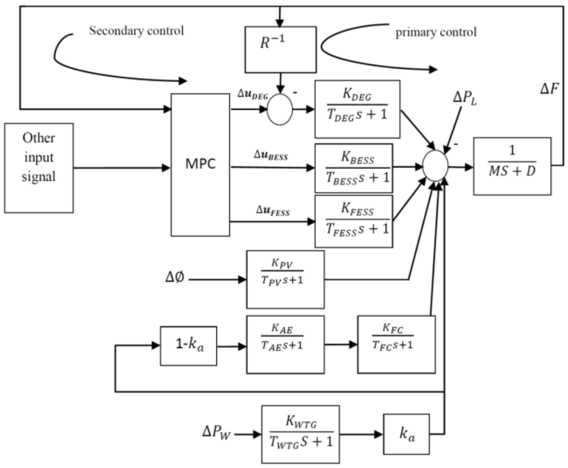


Fig. 2. Dynamic Modeling of Microgrid.

2.3.1. Primary Frequency Control

As seen in Fig. 2, in the studied microgrid, the primary control of the frequency with the diesel generator loop is done according to equation (20), in which R is the dropping coefficient (pu).

$$\Delta f \times \frac{1}{R} = \Delta P_{,} \Delta f = f - f_{0,} \Delta P = P - P_0 \tag{20}$$

2.3.2. Secondary Frequency Control

The primary control loop limits the dropped frequency, but it is unable to return the frequency to a nominal value; therefore, another interlocking loop, called the secondary control frequency, is used [38]. According to Fig. 2, in this paper, the model-based predictor controller is used to restore the frequency to a nominal value in the secondary control loop.

3. MODEL BASED PREDICTIVE CONTROLLER

3.1. General Structure

The model-based predictive controller has been used in a wide range of applications in various fields such as chemical processes, petroleum industry, and electromechanical systems [30]. The general structure of the predictive controller is given in Fig. (3).

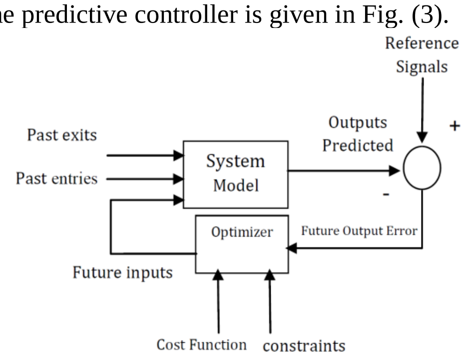


Fig. 3. The overall structure of the predictive controller.

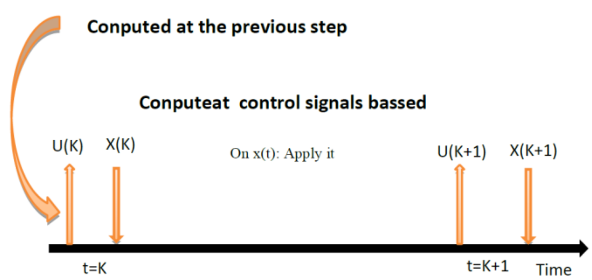
According to Fig. (3), in the mentioned controller, it's future behavior is predicted and controlled by using a model of the system,. In this controller, the control signal is obtained by minimizing the cost function. The values of the controlled signal in the control horizon are determined so that the system output in the future on the specified horizon follows the specified reference path. For this purpose, the cost function must be minimized, which is generally taken as the square of the deviation of the controlled variables from the desired value and the sum of the values of the control signals in consideration. Eq. (21), cost function, and eq.s (22) and (23), respectively, indicate the constraints imposed on the control and output signals.

$$J(N_1, N_2, N_u) = \sum_{J-N_1}^{N_2} \beta(j)[y(k+j)/k) - W(k+j]^2 + \sum_{J-1}^{N_u} \lambda(j)[u(k+j-1)]^2 \tag{21}$$

$$u_{min} \leq u(k) \leq u_{max} \tag{22}$$

$$y_{min} \leq y(k) \leq y_{max} \tag{23}$$

In eq.s (21) to (23), $J(N_1,N_2,N_u)$, J: The cost function which is to be minimized; N_1: Low horizons of forecasting, N_2, High horizons of forecasting, N_u, , Horizons of control : y (k + j k), the predicted value of the output signal at the instant k + j, If the system is at the k moment W(k+j), reference output on the control horizon at the instant k + j, :u (k+j-1) controlling signal calculated for time k+j-1, If the system is at the instant K, β(j): Weighing factor (weighted error coefficients) and γ(J) Weighing factor (weighted control coefficients). Fig. (4) shows the order of calculation of control signals and the way which are calculated.



U:Control signals of MPC

X:input signals to MPC

Fig. 4. The order of the signals in the predictor controller.

3.2. Designing of Predictive Controller

Changes in the production capacity of resources and load in the grid cause a change in frequency. Power Supplies of microgrid power are divided into two categories: A) Controlled sources: including diesel generator, Battery energy storage system and Flywheel energy storage system; B) Uncontrollable sources including fuel cell, Photo voltaic and Wind

(21)

Turbine Generator. In the design of the predictive controller, uncontrollable power sources variaiton are predictable as disturbances and load variations are considered as unpredictable disturbances. Figure 5 show the structure of the proposed predictive controller of microgrid and productive controller equations The as follows.

$$\dot{X} = AX + BU + DW$$
$$Y = CX$$
$$X = [\Delta F \ \ \Delta P_{DEG} \ \ \Delta P_{BESS} \ \ \Delta P_{FESS}]^T$$
$$U = [\ \Delta u_{DEG} \ \ \Delta u_{BESS} \ \ \Delta u_{FESS}]^T$$
$$W = [\Delta P_{PC} + \Delta P_{WTG} + \Delta P_{PV} - \Delta P_L]$$
$$A = \begin{bmatrix} \frac{-D}{M} & \frac{1}{M} & \frac{1}{M} & \frac{1}{M} \\ \frac{-K_{DEG}}{RT_{DEG}} & \frac{-1}{T_{DEG}} & 0 & 0 \\ 0 & 0 & \frac{-1}{T_{FESS}} & 0 \\ 0 & 0 & 0 & \frac{-1}{T_{FESS}} \end{bmatrix} \quad (24)$$
$$B = \begin{bmatrix} 0 & 0 & 0 \\ \frac{K_{DEG}}{T_{DEG}} & 0 & 0 \\ 0 & \frac{K_{BESS}}{T_{BESS}} & 0 \\ 0 & 0 & \frac{K_{FESS}}{T_{FESS}} \end{bmatrix}$$
$$D = \begin{bmatrix} \frac{1}{M} & 0 & 0 & 0 \end{bmatrix}^T$$
$$C = [1 \ \ 0 \ \ 0 \ \ 0]$$

In eq. (24), X: Vector of state variables, A: State space matrix, U: Control output vector, B:, Coefficient vector, W: Disturbance vector (uncontrollable input), D: The matrix of turbulence coefficients.

In the proposed controller, according to Fig. (5), in the first stage, the changes in power and load, as well as the frequency of the microgrid, are evaluated and measured; then in the next step, the system output (frequencies changes) and the application of appropriate signals controller is made according to the law. The equation governing the controller's behavior are described using equations (25) to (32).

$$\min J_{\Delta U} = \sum_{J=N_1}^{N_2} W_J\big(\Delta F(k+j)\big)^2 + \sum_{i=1}^{N_U} V_i \ (\Delta U_{DEG}(k+j) - \Delta U_{DEG}(k+j-1))^2 \quad (25)$$
$$subject \ \ to$$

$$\Delta U_{DEG}(K) = \Delta u_{DEG}(k-1) + \sum_{i=0}^{Nt} \delta_i \Delta F(k-i) \quad (26)$$

$$\Delta U_{min} \leq |\Delta u_{DEG}(k) - \Delta u_{DEG}(k-1)| \leq \Delta U_{max} \quad (27)$$

$$W_i^{min} \leq W_j \leq W_j^{max} \quad (28)$$

$$V_j^{min} \leq V_j \leq V_j^{max} \quad (29)$$

$$\Delta U = \{\Delta u_{DEG}(k), \Delta u_{DEG}(k+1), \ldots, \Delta u_{DEG}(k+N_u)\} \quad (30)$$

$$X(k+1) = AX(k) + BU(k) + DW(k)$$
$$Y(k) = CX(k) \quad (31)$$

$$\Delta u_{BESS} = \Delta u_{FESS} = \Delta F \quad (32)$$

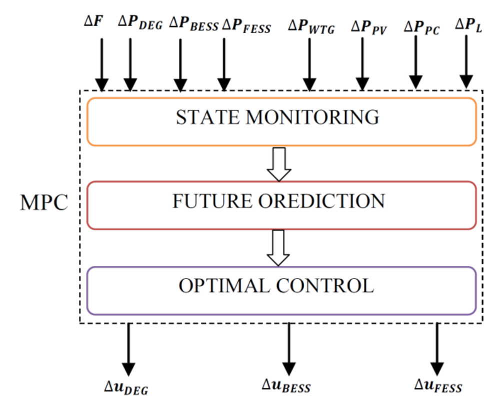


Fig. 5. Structure of proposed predictive controller.

In the above equation, the eq. (25) is the objective function, which is arranged in the form of a square curriculum, and by minimizing it, the set of control signals, eq.n (30) is obtained; eq. (26) describes the way of calculation in the signal ΔuDEG in each time. δ is numerical coefficients which are obtained by solving the problem (J minimized). Eq. (27) shows the minimum and maximum range of applied control signal at each time. Eq.s (28) and (29) respectively indicate the limit of the selected coefficients in the target function. Eq. (31) describes the way of variables calculation and the eq. (32) show the considered control signals for energy storage resources, as well as in the calculations, the following index is also obtained. Presented index in eq. (33) is used to compare the control methods in the simulation section.

$$P_{indx} = \int_0^T |\Delta f|^2 dt \quad (33)$$

Predictive control not only controlling the frequency of the microgrid, also should be controlled and adjusted the voltage level of the icrogrid by power source converters and the diesel generator's stimulation system.

5- Simulation

As stated in the third section, a variety of renewable energy sources are considered in the simulated microgrid. The values of the parameters of renewable energy sources are shown in Table 1.

Table 1. Values of energy supply parameters of the microgrid

Parameter	Value	Parameter	Value
D (pu/HZ)	0.012	$T_{WTG}(s)$	1.5
2H (pu s)	0.1667	$T_{AE}(s)$	0.5
$T_{FESS}(s)$	0.1	K_{WTG}	1
$T_{BESS}(s)$	0.1	R(HZ/pu)	3
$T_{FC}(s)$	4	K_t	0.6
K_{FC}	1/100	K_{DEG}	1/300
K_{AE}	1/500	K_{FESS}	-1/100
K_{BESS}	-1.300	K_{PV}	1
$T_{DEG}(s)$	2	T_{PV}	1.8

The predictive control parameters are also considered as follows.

N_1 0
N_2 5
N_u 2
0 Weight on manipulated variables
0.1 Weight on the speed of manipulated variables
0 to 2 Weight on the output signal
0.0002 Sampling time intervals

The maximum and minimum values of the control signal ($u_{min} < u(k) < u_{max}$) are set as follows.

1pu Maximum amount of control signal
0.1 pu Minimum amount of control signal

The maximum and minimum frequency deviation (perion) is also considered as follows.

1pu Maximum frequency deviation
-1pu Minimum frequency deviation

To evaluate the performance of the proposed control method, simulation has been performed in the MATLAB / SIMULINK environment. The disturbances on the microgrid (such as sudden changes in load and changes in distributed generation sources) are applied to the microgrid in accordance with Figs. (6) to (8). The disturbances of Fig. (6) is related to the change in Photo voltaic power, Fig. (7) relates to Wind Turbine Generator, and Fig. (8) relates to the variation in microgrid load.

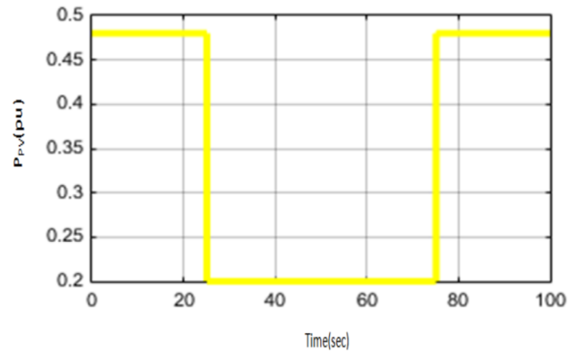


Fig. 6. Change of Photo voltaic Power

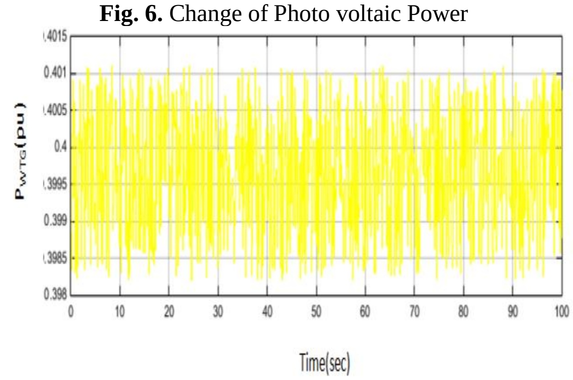


Fig. 7. Change of Wind Turbine Generator

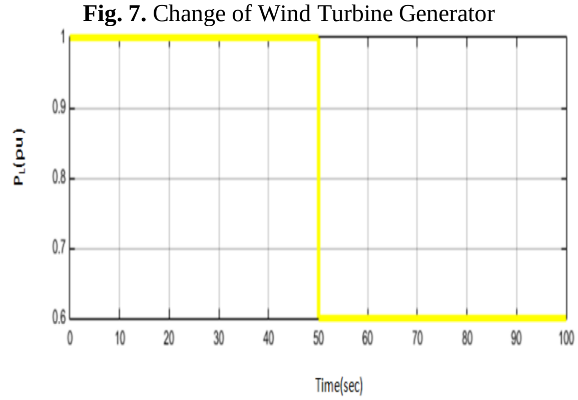


Fig. 8. Change of the Microgrid Load

Scenario 1: In this scenario, the performance of the controllers CPSO-PID , CPSO-FOPID (the coefficients and parameters of controller have been taken from (6) to (8) and the proposed control are evaluated for the disturbances of Figs. (6) to (8) which is applied to microgrid at the same time. The function of the controllers is shown in Fig. 9 for frequency fluctuations. As it can be seen, the performance of the proposed controller is better than other controllers, so that it has less frequency fluctuations are less

Frequency fluctuations, fluctuation amplitudes and fluctuations. The responses.

Scenario 2: As in Scenario 1, but it is assumed to assess the robust performance of controllers, that parameter (2H) can also be changed at intervals of [1 1.5]x0.1667. The response of the controllers to the simultaneous application of the disturbances in Figs. (6) to (8) is shown in Fig. 10.. In this case, the controller has a better performance than other controllers.

Scenario 3: As in Scenario 1, but it is assumed to assess the robust performance of controllers, that parameter (2H) can also be changed at intervals of [0.5 1]x0.1667. The response of the controllers to the simultaneous application of the disturbances in Figs. (11) is shown in Fig. 10. In this case, the controller has a better performance than other controllers.

Scenario 4: In this scenario, the step load turbulence is applied to the microgrid according to Fig. 12. In order to compare the response of different controllers, scenarios (4) and (5) of the presented renewable energy sources parameters has been used. [25]. Figure 13 shows the performance of the Fuzzy-PI and ZN-P controllers and the proposed controller (the coefficient and parameters of the Fuzzy-PI and ZN-P controllers have been taken from [25]). The proposed controller performance is considerably better than the controllers.

Scenario 5: In this scenario, the conditions are similar to scenario 4; however, entered turbulence is a relatively high disturbance in accordance with Fig. 14. The performance of the proposed controller and the Fuzzy-PI and ZN-PI controllers are showed to decrease the frequency variations in Fig. 15. The performance of the proposed controller is much more favorable than other controllers in this scenario.

For a better evaluation of the proposed controller and the Fuzzy-PI and ZN-P controllers, an index is defined according to (33). [25] The results of the evaluation of different controllers in scenarios (4) and (5) are shown in Table 2). It is noticeable that the performance of the proposed controller is better than other controllers.

Table 2. The performance of controllers according to index in scenarios 4 and 5

Scenario	MPC Controller	Fuzzy-PI (25)	ZN-PI (25)
4	+0/0001374	+0/00020	+0/00024
5	+0/00109	+0/00272	+0/00426

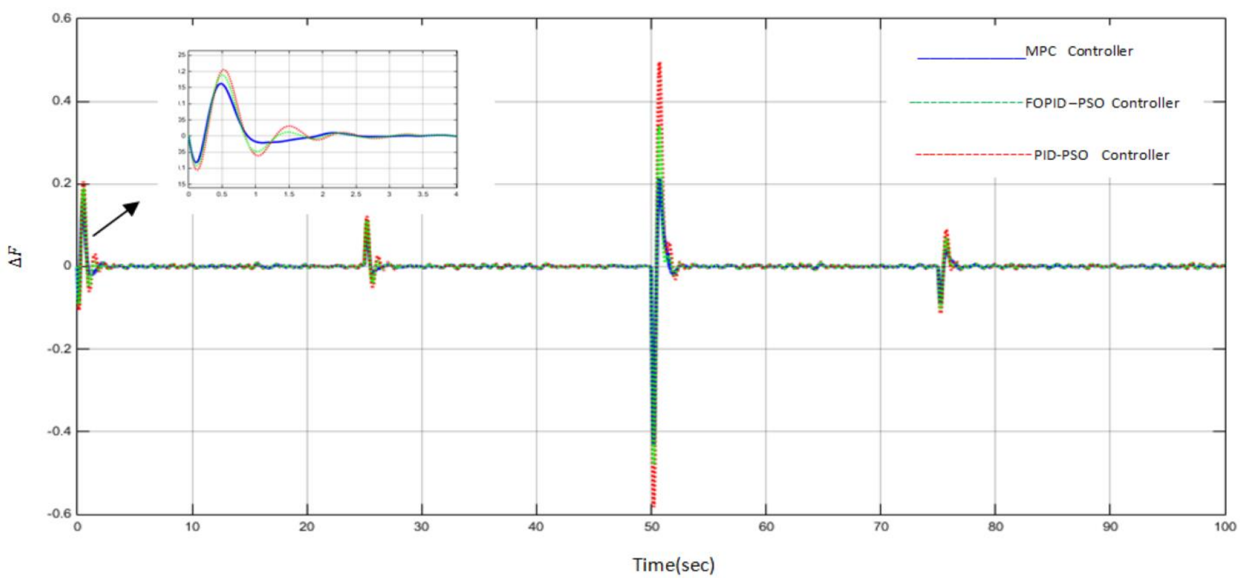


Fig. 9. The performance of controllers to decrease frequency variations in the scenario 1.

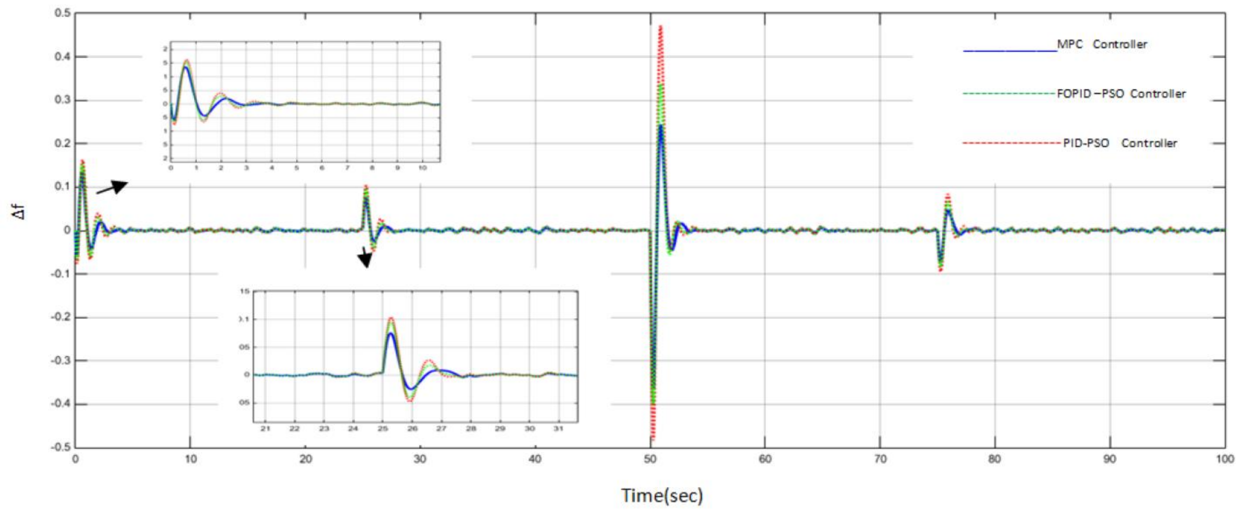


Fig. 10. The performance of controllers to decrease frequency variations in the scenario 2.

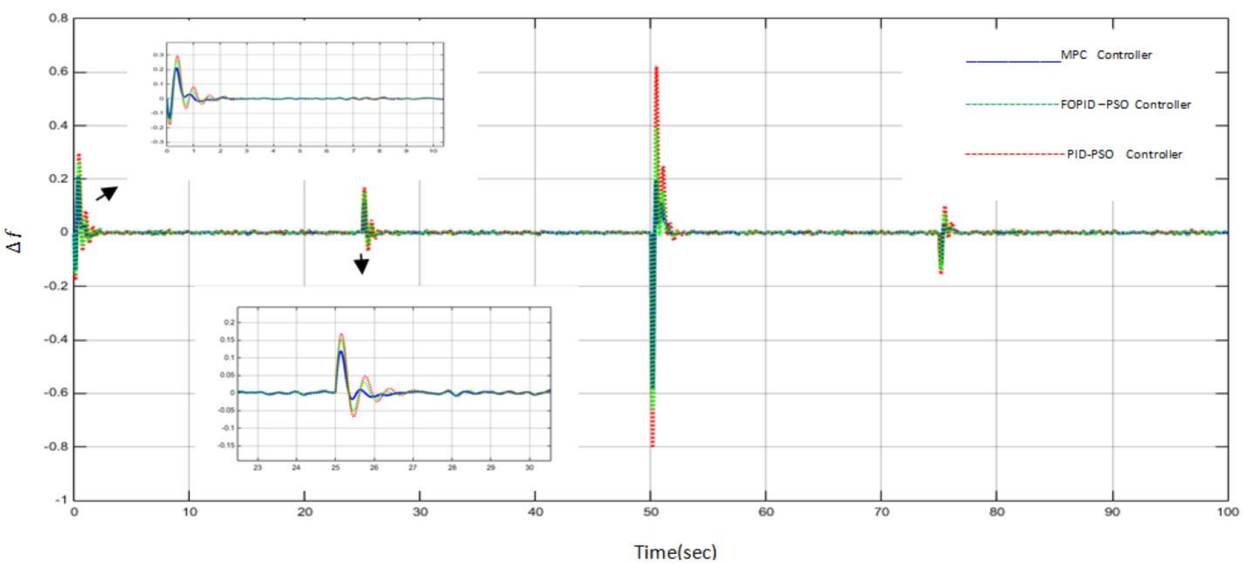


Fig. 11. Performance of controllers to decrease frequency variations in the scenario 3.

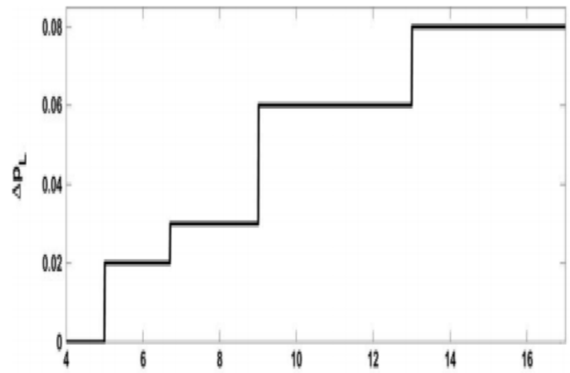


Fig. 12. turbulence of loads as multi step

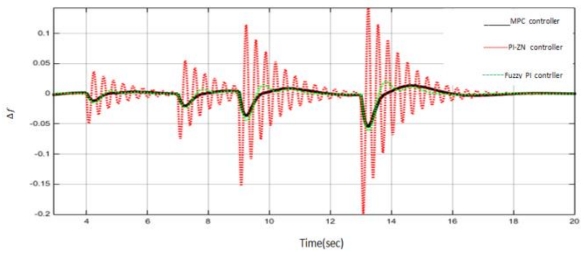


Fig. 13. Performance of different controllers for mimic frequency quenching in the scenario

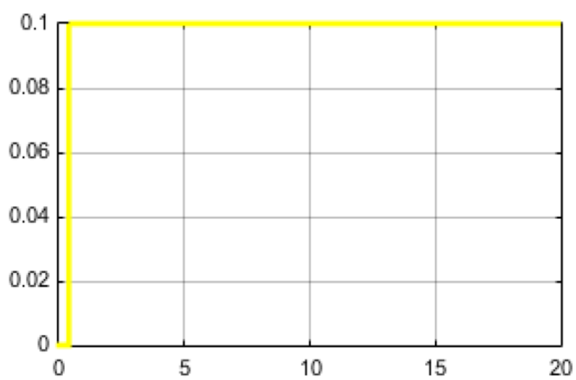


Fig. 14. Tturbulence of loads like fairly intense

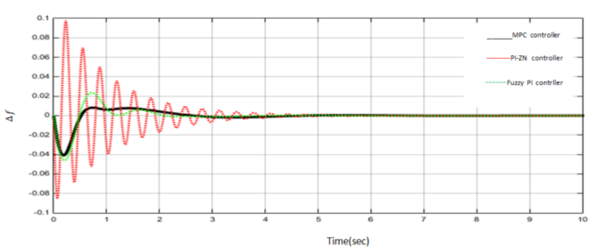


Fig. 15. Performance of different controllers for mimic frequency in the scenario 5

CONCLUSION

One of the most important issues in controlling the separate microgrid from the main grid is control the frequency. In this paper, a robust method based on predictive control of the model is presented to control the load-frequency in the microgrid. The proposed controller applies control signals to renewable energy sources with the secondary control loop. To investigate the proposed control, a simulation of a variety of renewable energy sources has been simulated in the MATLAB / SIMULINK environment. Comparison of the results with controllers such as Fuzzy, ZN-P, CPSO-PID, and CPSO-FOPID, PI, represent a better and more desirable performance of the proposed controller to mimic frequency fluctuations and its performance are against uncertainty and variations microgrid parameters.

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