Hybrid Performance of Fuel Cell and Wind Turbine in Islanding Operation Mode

Mohammad H. Moradi[1], Eidy Hadadi[2*]
[1.] Assistant professor within Bu Ali SinaUniversity, Hamedan, Iran
Mh_moradi@yahoo.co.uk
[2.] Master student within Bu Ali SinaUniversity, Hamedan, Iran
power89hadadi@yahoo.com

Abstract: Microgrid connection to network causes various conditions which microgrid can deliver power by fix voltage under any disturbance. But microgrid operation in islanding mode, there's needs to the voltage and frequency controller. In this paper, the microgrid that includes fuel cell and wind turbine is studied in islanding operation mode and to control voltage and frequency, a hybrid controller is introduced. Frequency control is done by inverter. Voltage control is done by designing an AC buse and PI controller. The designed controller causes that wind turbine deliver 1pu and fuel cell that has more power generation cost. Simulation results showed that efficient performance of the controller in its task being robust against load change, set point change and wind speed change.
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1) Introduction

Environmental concerns and increase of energy consumption has offered new opportunities for public use of renewable energy sources. The transmissions and distribution networks have become weak and old and require much investment to be renovated and expanded. These facts together with the need for high quality power have attracted comments to new methods of electrical energy production [1, 2]. Microgrid is one of the suitable options for electricity supply. Micrograds are LV networks which include Distributed Energy Resources (DER) such as micro turbines, solar cells and power storages such as power batteries controllable loads and a powerful control system. Microgrid advantages can be cited as follows:

1- The need for additional suppliers felt due to the rapid growth of load and fossil fuels reduction.
2- Establish of new power generating sources will reduce environmental pollution and global warming.
3- Distributed Generation (DG) sources make it easy to combined heat and power (CHP) which increases its efficiency by reducing losses.
4- These resources are suitable for consumers with low capacity.
5- DG Resource, can back up and thus improves power quality and network reliability due to both possible performances, Islanding and Grid Connected [3-5].

Control of some variables is necessary to improve the microgrid performance in connection to grid and islanding operation mode. These variables are: 1) voltage 2) frequency 3) power.

Microgrid studied in this paper includes solid oxide fuel cell (SOFC), wind turbine, batteries, power electronics converter, and the load and voltage and power controller. Hybrid operation of fuel cell and wind turbine is discussed in references [1-3]. Connection between microgrid and load or network could be done through an AC bus or DC. When microgrid is connected to grid, voltage and frequency control is done. So, when microgrid is in islanding operation mode, designing of voltage and frequency controller is necessary [8].

Frequency stability in microgrid is very sensitive. So power control is a main problem. When microgrid is in islanding operation mode and peak load, a disturbance, such as new load, leads to disturbance in frequency. It makes two problems: first, a small unbalance in power causes large unbalance in frequency and second, this problem occurs very fast. First problem is solvable by using of power storage. Second problem is solved by using the inverter. So, the best choice is using of both power storage and inverter. In many references, different methods are used to fix voltage and frequency. In [11]-[16], some methods are introduced to hybrid operation of DG sources. In [13], hybrid system is introduced which includes fuel cell and photovoltaic and an electrolyzer to produce hydrogen and a battery as power storage. In [14], hybrid system is introduced which includes fuel cell and electrolyzer and diesel generator. Hybrid system including PV, WT and FC is introduced in [15], which tracks maximum power point (MPPT). But a complex fuzzy logic controller is used in it. In [16], a PI is used to regulate voltage of DC/DC converter. In [17], frequency of system is controlled by load control; and by using of a reactive power compensator, voltage of system is fixed in islanding operation mode.

In this paper, voltage, power and frequency controller are introduced to have advantage of other controller mentioned above. In this paper, a control method introduced to control power and fix voltage in reference value. This method reduces cost of control and also fixes frequency in 50Hz. This controller by designing AC buse removes the need of converting AC output to DC output. Performance of this controller is verified by: 1) load change 2) active and reactive set point change 3) wind speed change. Simulation results showed efficient performance of the controller in its task to control power and voltage in islanding operation mode. This article has five sections: Section 2 deals with the introduction of studied microgrid network. The results of performed simulations are presented in Section 3. In Section 4, the general discussion is about the preparation process of this paper. In Section 7, finally, conclusions represented.

2) System Description

Microgrids are small-scale, LV CHP supply networks designed to supply electrical and heat loads for a small community, such as a housing estate or a suburban locality, or an academic or public community such as a university or school, a commercial area, an industrial site, a trading estate or a municipal region [2, 3]. The schema of a sample Microgrid represented in Figure 1. In this paper, power generators are fuel cell and wind turbine. Fuel cell has DC output and connects to AC buse through a voltage source inverter (VSI). Voltage regulator, by measuring load voltage and d&q component voltage, generates pulses for inverter and makes an AC buse that is necessary for islanding operation mode. On the other hand, wind turbine has an AC output. In this study, AC voltage is converted to DC by using of a voltage rectifier, and then it is connected to AC buse through a voltage source inverter. Power controller receives measured active and reactive power and generates pulse for inverter. In result, it has control on power generated by wind turbine. Capacitance is used on the inner of both inverters. This capacitance is used to improve power quality and reject disturbance. The inductor has is used to connect inverter to main grid. Each of these Microgrid subsystems described separately below:

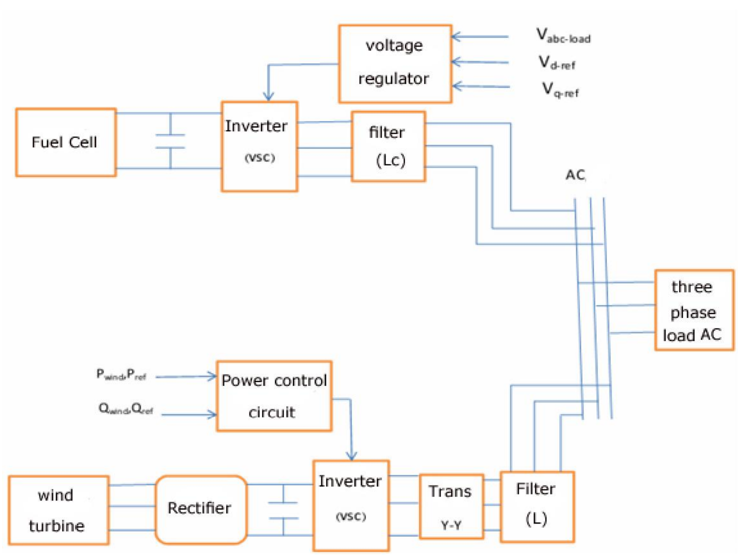

Figure 1.Overview of the described Microgrid

2-1) Fuel Cell

Fuel cell is a technology to generate electricity without producing pollution which has taken the place of conventional methods of energy production. Fuel cell generates electrical energy with an electrochemical reaction directly [1]. Based on reactions that occur at the anode and cathode cell, fuel cell during generate electricity, produces water and thus prevents pollution [1]. According to reference [1], the chemical reactions that occur at the anode and the cathode are as follows:

Anode reaction:

$$H_2 \Rightarrow 2H^+ + 2e^- \quad (1)$$

The cathode reaction:

$$\frac{1}{2}O_2 + 2H^+ + 2e^- \Rightarrow H_2O \quad (2)$$

Figure 2 showing the general Schematic of reaction in the fuel cell.

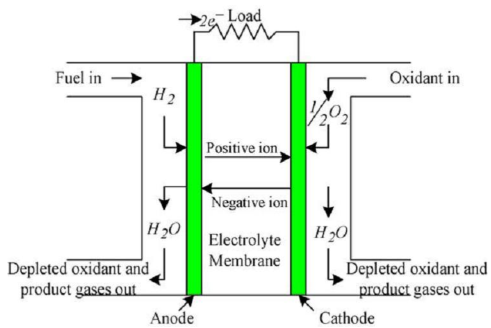

Figure 2)The overall schematic of fuel cell reaction

When the fuel cell is connected to the load and current is drawn from it, Terminal voltage and the efficiency will decrease. Among all reasons, voltage would loss polarization due to internal connections.

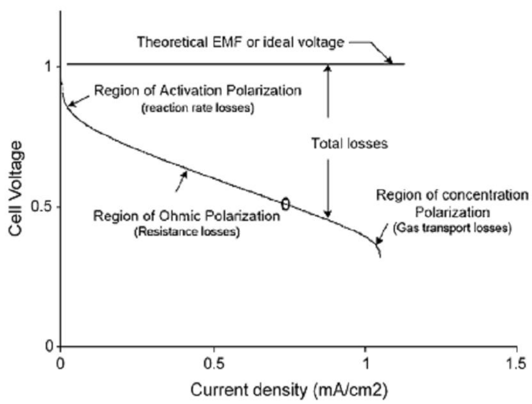

Figure 3) fuel cell current-voltage characteristic

Figure 3: shows the fuel cell voltage as a function of the current [1].

2-2) Wind Turbines

The basic diagram of the wind energy conversion system to be analyzed on this paper is illustrated in Fig. 1. The system is composed by a wind rotor which transforms the kinetic energy from the wind with U wind speed in mechanical torque in the shaft. The shaft drives directly the PMSG, which generates power with variable-frequency and alternate current.

2-2-1) Wind Rotor

The fundamental dynamics of VSWT can be expressed by this simple mathematical model:

$$(1) J\frac{d\omega_m}{dt} = T_a - T_f - T_c$$

Where J is the moment of inertia (rotor inertia plus generator inertia), ω_m is the mechanical angular speed, T_a is the aerodynamic torque; T_f is the friction torque (rotor fiction plus generator friction); and Te is the electrical load torque from wind turbine. Aerodynamic torque T_a is determined by:

$$(2) T_a = \frac{1}{2} C_T(\lambda, \beta) \rho A \frac{D}{2} u_{wind}^2$$

Where C_T is the rotor torque coefficient; ρ is the air density; A is the rotor swept area; D is the rotor diameter; and u_{wind} is the wind speed. Torque coefficient is a non-linear function of the tip-speed ratio λ and blades pitch angle β. This relation can be found by computational simulations or experimentally. Tip-speed ratio is expressed by:

$$(3) \lambda = \frac{\omega_m . D/2}{u_{wind}}$$

For a fixed-pitch blade rotor, C_T is a function of λ only The CT (λ) curve to be used on this work is illustrated on Fig. 3. Friction torque is determined by:

$$(4) T_f = B\omega_m$$

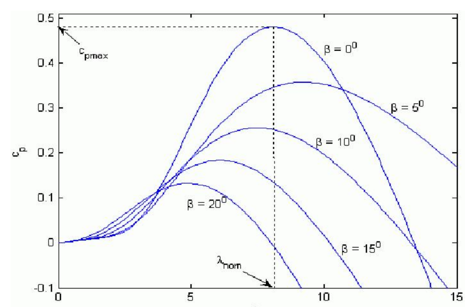

Figure 4) $C_T(\lambda)$ used in this paper

2-2-2) PMSG

Dynamic modeling of PMSG can be described in d-q reference system [7]:

$$(5) v_q = -(R + pL_q) i_q - \omega_e L_d i_d + \omega_e \lambda_m$$

$$(6) v_d = -(R + pL_d) i_d + \omega_e L_q i_q$$

The expression for the electromagnetic torque can be described as:

$$(7) T_e = \left(\frac{3}{2}\right)\left(\frac{P}{2}\right)\left[\left(L_d - L_q\right) i_q i_d - \lambda_m i_q\right]$$

Where P is the number of poles, the relation between electrical angular speed ω_e
And mechanical angular speed ω_m is expressed by:

$$(8)\omega_e = \frac{P}{2}\omega_m$$

2-3) Power Control Circuit

Figure 4 clearly describes the power controller used in article. Power Controller input is active and reactive power, and its output is the "d" and "q" components of reference current for hysteresis control. The hysteretic controller output is also inverter gate pulse and ultimately leading to deliver active and reactive power to the network equal to the reference values [10].

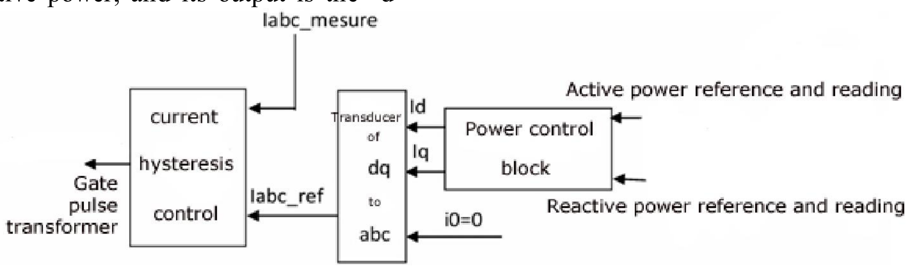

Figure 5) the overall diagram of a Power Control for Wind Turbine

2-3-1) Current Hysteresis Control

The diagram of current hysteresis control that simulated in simulink, illustrate in figure 5.

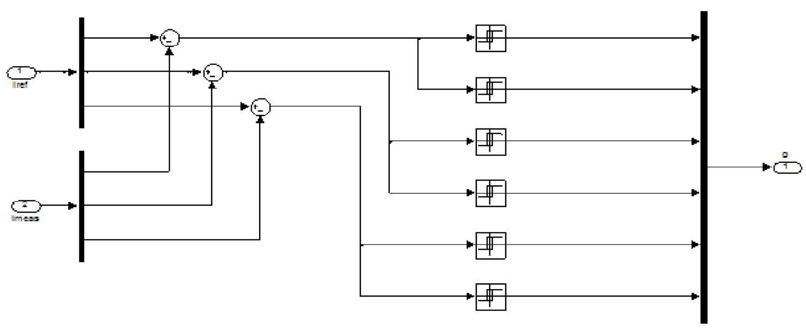

Figure 6) the diagram of current hysteresis control that simulated in simulink

In hysteresis controllers, the feedback from output current is compared with references value and switches state is changed. It led to current error be in allowed domain. The diagram of current hysteresis control for $i_{a,ref}$, $i_{b,ref}$, $i_{c,ref}$, illustrate in figure

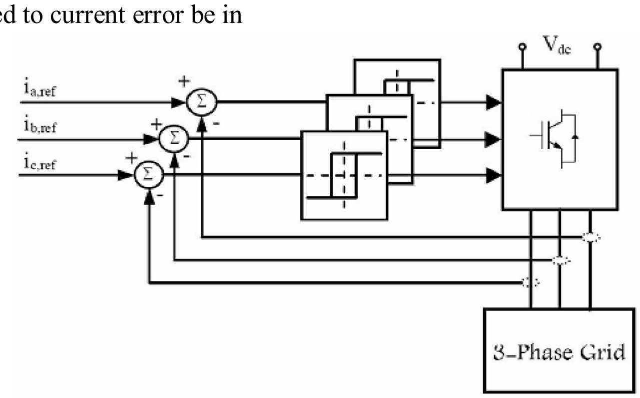

Figure 7) 3phase current hysteresis control

2-4) Voltage Regulation Circuit

In islanding operation mode, the voltage regulator design is necessary for delivery power under fix voltage. The overall diagram of the voltage regulator studied in this paper is illustrated in figure 10. In the Figure 7, it can be seen that voltage regulator receives load voltage and converts it to d&q components and then crosses these value and reference value from PI controller, and so, it fixes load voltage in reverence value

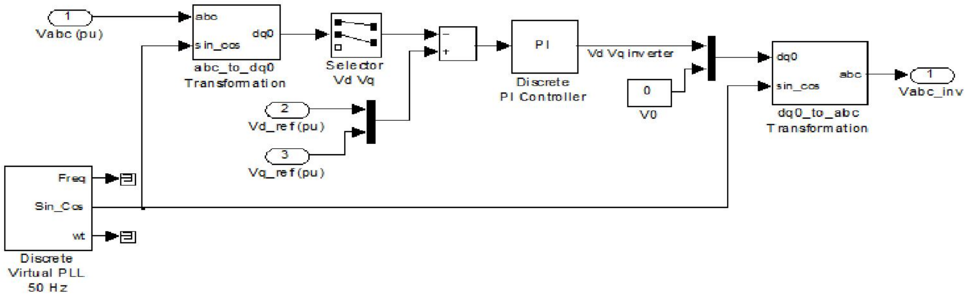

Figure 8) Voltage regulator diagram in simulink

3) Simulation and Results

In this section in order to verify the voltage and power controller performance, studied system (Figure 1) was simulated using MATLAB software (Figure 8). For this microgrid, three different operation modes are used:

1) Step change in connected to grid load
2) Step change in active and reactive power value
3) Change in wind speed

For these operation modes, these values measured and verified. These values are: load current and voltage, active and reactive power of fuel cell and wind turbine. In this paper, base power is 25kw.

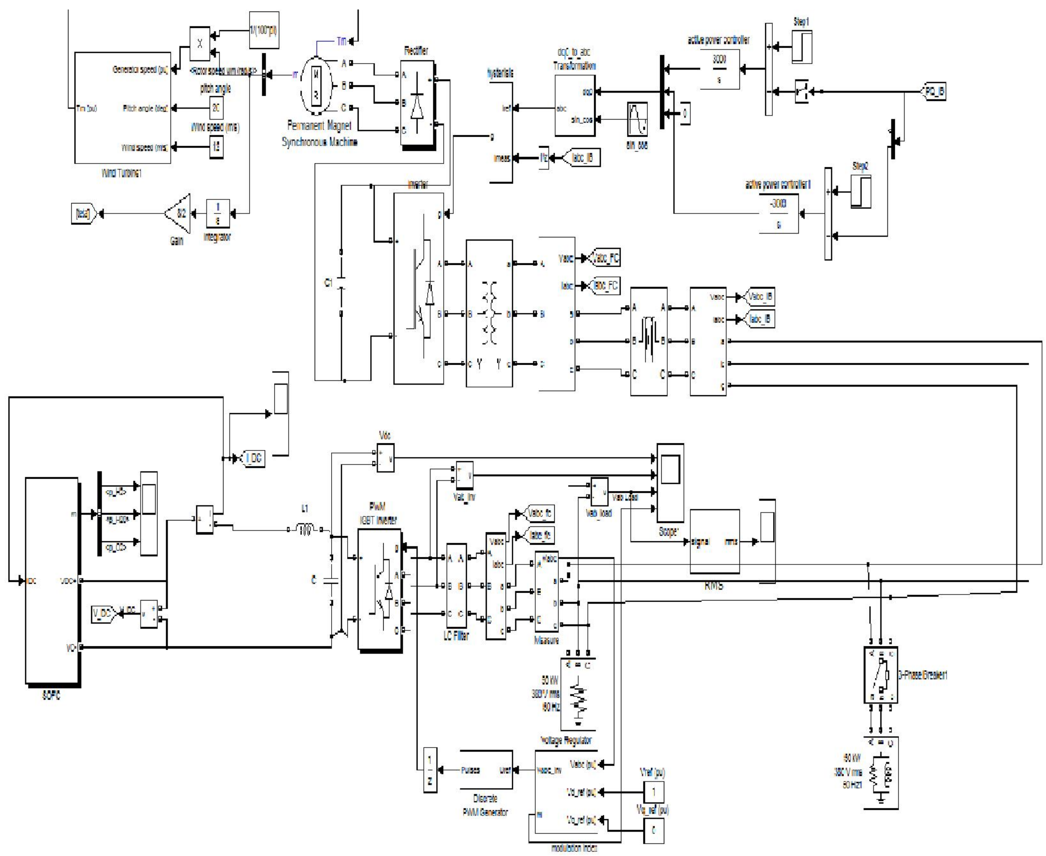

Figure 9) studied microgrid simulated in simulink

3-1) Step change in connected to grid load

The load that is connected to the microgrid studied is a 50kw resistive load whit 50Hz frequency. In this section, in order to verify the voltage and power controller, a RL load, in 1 second, and a RC load, in 1.5 second are added to microgrid (resistive load is 5w, capacitance load is 1kvar and L load is 1 kvar). Simulation results are shown in Figures 9 - 14. These Figures show that all wave forms get its steady state value in 0.3 sec, and this is because of dynamic of fuel cell used in this paper.

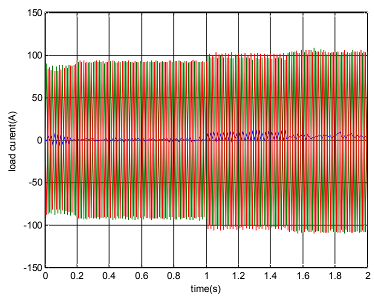

Figure 10) load current under load change

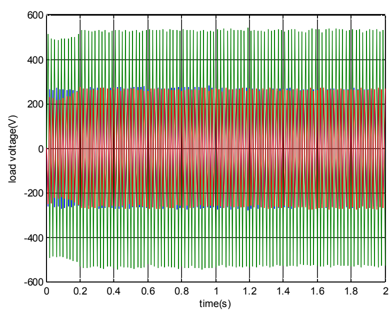

Figure 11) load voltage under load change

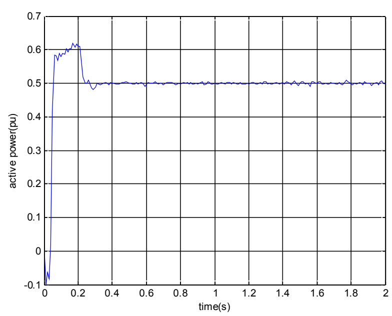

Figure 12) active power generatedby winde turbine under load change

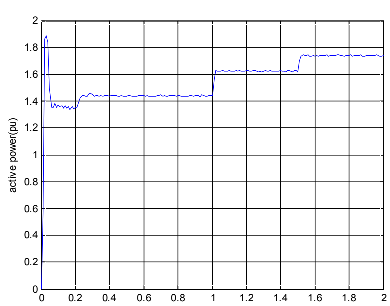

Figure 13) active power generated by fuel cell under load change

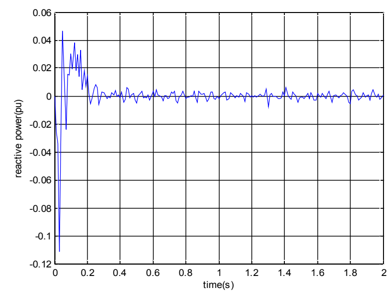

Figure 14) reactive power generated by winde turbine under load change

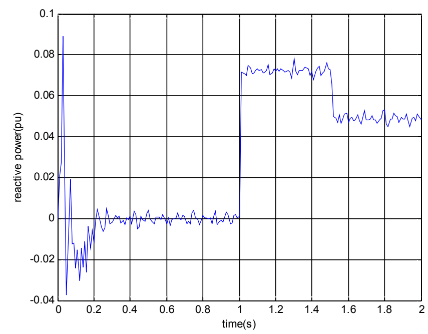

Figure 15) reactive power generated by fuel cell under load change

For this load change, wind turbine active power set in 0.5 pu and its reactive power set in zero. Figures 9 and 10 show that under load change, load current is changed and load voltage is fixed by voltage controller. Figures11-14 shows the active power of fuel cell and wind turbine under this change. It is visible from these Figures that power controller, under this change, can track set point.

3-2) Step change in active and reactive power value

In this section, active and reactive power set points are changed in order to verify the tow controller performance. For active power set point goes from 0.4 pu to 0.7 pu in 1 sec and for reactive power set point goes from 0 to 0.2 pu in 1.5 sec. Results are shown in Figures 15 - 19. Figure 15 shows that the voltage controller is robust against this change in set point, and it, under fix voltage, delivers power. Figures 16 and 17 show that power controller is able to track set point changes.

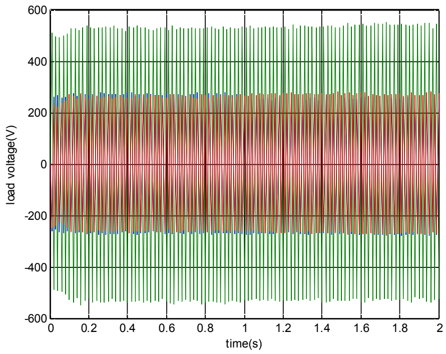

Figure 16) load voltage under change in set point

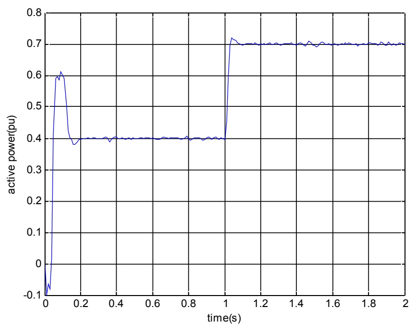

Figure 17) active power generated by wind turbine under change in set point

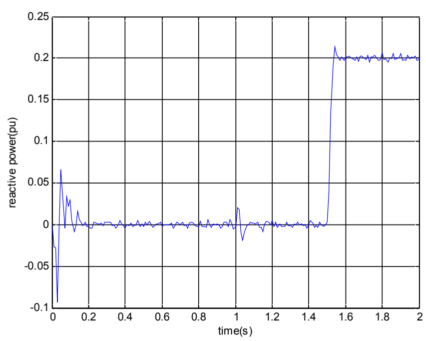

Figure 18) reactive power generated by wind turbine under change in set point

3-3) Change in wind speed

For two before state, wind speed for wind turbine is fixed in 20m/sec. In this section, figure18 proposed as wind speed inner to wind turbine. Results are shown in figures 19-21.

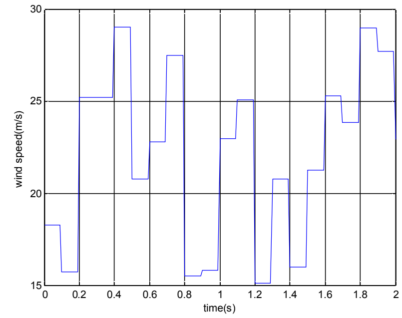

Figure 19) wind speed (m/sec)

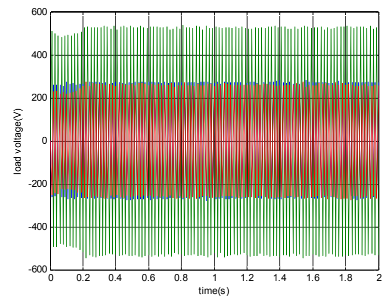

Figure 20) load voltage under changes in wind speed

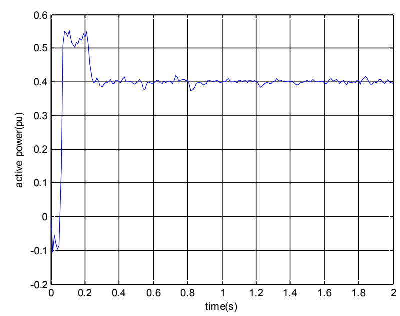

Figure 21) active power generated by wind turbine under changes in wind speed

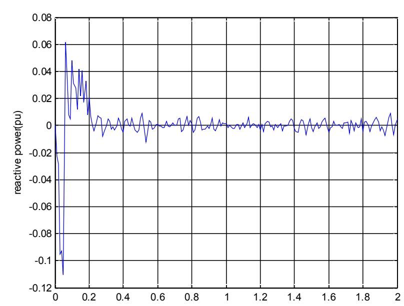

Figure 22) reactive power generated by wind turbine under changes in wind speed

Figure 19 shows that voltage controller delivers power to load by variable wind speed and under fix voltage. Figure 20 and 21 show that power controller, under these conditions, follows the set point.

Discussion

In this paper, a new strategy to operation of mircrogrid including fuel cell and wind turbine is introduced. Simulation results show that:

Load step change: voltage and power introduced in this paper are robust against load step change; and microgrid, under fix voltage, delivers power to load.

Following set point: by step change in amounts of active and reactive power, power controller follows these changes and voltage controller fixes voltage.

Variable wind speed: by variable wind speed for wind turbine, power controller follows set point and load voltage is fixed.

Simplicity is the other advantage of these two controllers, and it is because of using of PI controller in its configurations. Frequency is fixed by inverter. Cost reduction of controller is the other advantage of controller.

4) Conclusion

Islanding mode operation of microgrid needs voltage and frequency controller. In this paper, a new method is introduced to fix load voltage; and frequency is fixed by inverter. Power controller in wind turbine side causes that we are able to control the active and reactive power, which is generated by wind turbine. Simulation results show that these two controllers are resistive against load step change, load change and variable wind speed.

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