Active and Reactive Power Control of Grid Connected Micro Grid by PI-NN Hybrid Controller

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Abstract: In this paper, a combined control techniques introduced which consists of an improved neural network and PI to control the active and reactive power of a grid connected micro grid whose energy supplier is a fuel cell. The neural network controller improves system performance in tracking set point and the PI controller decreases the steady state error to zero. It also eliminates confusion and robust the closed loop system against its change parameters. The micro grid and its proposed controller are simulated in Matlab/Simulink. Simulation results show efficient performance of the controller in its task to follow active and reactive power, to reject system disturbance and to robust it against system parameter changes.

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1- Introduction

Environmental concerns and rising energy consumption has offered new opportunities for public use of renewable energy sources. The transmissions and distribution networks have become 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].Micro grid is one of the suitable options for electricity supply. Micro grids are LV networks which include DER[1] sources such as micro turbines, solar cells and power storages such as power batteries controllable loads and a powerful control system. Micro grid 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- Establishing new power generating sources will reduce environmental pollution and global warming.
3- DG[2] sources make it easy to combined heat and power (CHP) which increases its efficiency by reducing losses.
4- The 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].

Micro grid studied in this article includes solid oxide fuel cell (SOFC), batteries, power electronics converter and the load. The purpose of micro grid is to be independent, but for increased security and flexibility, Micro grids must be connected to either an upstream network or a neighboring one. Power Exchange can be either unilateral or bilateral, from upstream network to micro grid and vice versa [6]. Connection to the upstream network can be in two forms. This relationship can be an AC synchronous communication which has the simplicity advantage. So only the breakers and possibly a transformer are required. The problem in this case is pre-connection to the network and its Synchronization if Micro grid is disconnected from the network [6]. The second type of connection can be DC. One advantage of this relationship can be Micro grid isolation from upstream network. In this case micro grid is designed like a DC network. In DC micro grid, resources, generate DC power and injected into the network. In consumer's side, DC to AC inverter gives AC power to consumer. In this case, micro grid task is to balance Active and reactive power in its collection and network connection is only for power entrance or existences that the micro grid independently provides power quality (frequency, voltage, reactive power and harmonics) is related to their field. Micro grid type of AC or DC is chosen based on environmental conditions, potential types of its generators and micro grid network size [6]. Controller which used to connect micro grid including the fuel cell to the network, use the PI control method [14-16]. This type of control, despite of its simplicity of implementation, its low speed in following the set point change, is one of the disadvantages of this

1-Distributed Energy Resources
2- Distributed Generation

method of control. To overcome this fault, a neural network can be used to control active power and reactive. Neural network follows the Set Point well, but compared with the PID has low ability to remove input disturbance and does not robust against parameter changes.

In this paper, a PI-NN controller is introduced in which the neural networks are responsible for the improved performance and speeding up system response. PI controller makes omits the disturbance and robust the controller.

This article is of seven sections: Section 2 deals with the introduction of studied micro grid network. The idea of grid connected Micro grid is discussed in Section 3. Section 4 deals with the issue of power control using neural networks. The results of performed simulations are presented in Section 5.In Section 6, the general discussion is about the preparation process of this paper. Finally, in Section 7, conclusions are discussed.

2- Micro grid

Micro grids are small-scale, LV CHP supply network s designed to supply electrical and heat loads for a small community, such as a housing estate or a suburb an 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 Micro grids given in Figure 1. Micro grid used in this article includes fuel cell as power source, capacitor, inverter DC-AC, the inductor is connected to the network and infinity Network. Each of these Micro grid subsystems is described separately below:

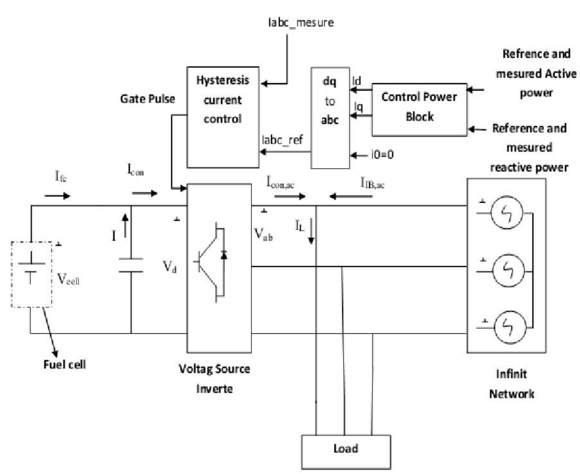

Figure 1.Overview of the described Micro grid

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:

$$H_2 \Rightarrow 2H^+ + 2e^-$$

The cathode reaction:

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

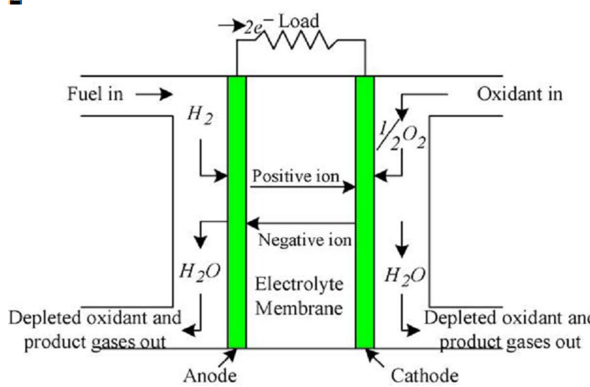

Figure 2)The overall schematic of fuel cell reaction

When the fuel cell is connected to the load and current is drawn from it, Terminal voltage and the efficiency will decrease. Among its reasons are voltage losses of polarization and losses due to internal connections.

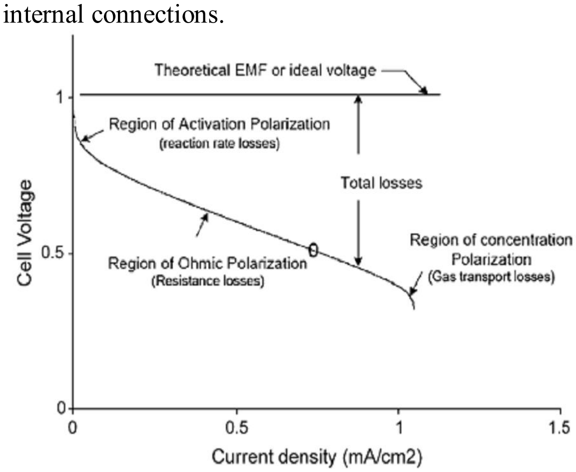

Figure 3) fuel cell current-voltage characteristic

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

2-1-1) modeling of solid oxide fuel cell (SOFC)

Fuel cells are of different types based on type of electrolyte used in them: Solid oxide fuel cell, molten carbonates fuel cell, alkaline fuel cells and polymer electrolyte fuel cell. A list of fuel cell types with their specifications is shown in the attached table (1) [10].Among the types of fuel cells, SOFC is a fuel cell with solid electrolyte that does a chemical reaction at high temperature and despite the high working temperatures and Slow startup allows several gas types to enter simultaneously in and generates electric energy with high efficiency. This type of fuel cell has many advantages over conventional power plants and for the island mode operations indicating better performance. Energy conversion efficiency in solid oxide fuel cell to reach over 65 percent and when are employed in CHP (Combined Heat and Power) applications, this efficiency is above 70 percent. Fuel cell modeling is performed to predict and control its operation [15, 16]. Tend to use the SOFC increases need to model this dispersed kind of source. Modeling accomplished for the fuel cell is in two groups: semi-empirical models achieved based on experiments and tests and the theoretical models obtained based on physical laws. Fuel cell modeling in this paper has been done based on physical laws governing the fuel cell and the reference [1] and is shown in Figure 4.

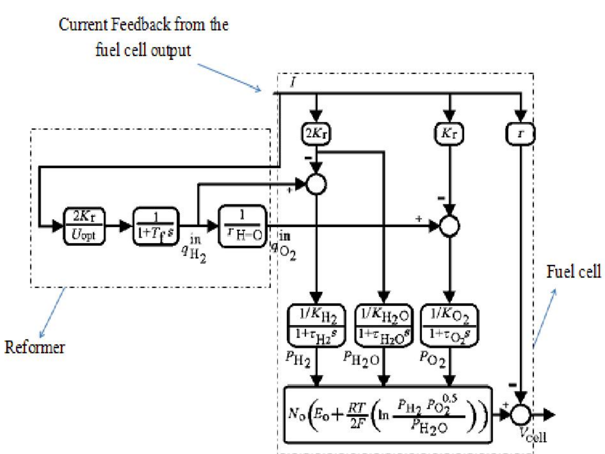

Figure 4) simulated model of solid oxide fuel cell in Simulink

Parameters used to simulate fuel cellar shown in Table 2. Offered Model for fuel cellis included also reformer model. In the reformer model, a feedback of the current cell is considered to control input hydrogen, Based on output power. The amount of oxygen flow is obtained using hydrogen-Oxygen ratio) rH_O) [10].Parameters required for simulation are shown in Table 2.

2-2) energy storage resources

Among the energy storage units, batteries, magnetic energy storage, superconductors, super capacitors, hydro pumped can be noted. Most of these units are used during peak times, the island micro-grid for the lack of power, voltage Regulations ... [17]. Some advantages of these resources in Micro grid, especially in the islanding mode, can be named as follows:

1- The improvement power quality and reliability, 2– Reduction of size of dispersed generation, 3-Energy Savings, 4– reduction of new equipment construction in transmission and distribution network, 5- Energy sustainability.

The use of storage energy with DG resources allow to them that have a stable output power. Thus DG canfeeda load with a larger peak power than itself [18].

The Power quality improves because the DG resources can not follow rapid changes alone and energy storage units provide them with this ability. Therefore use of storage resources makes the DG to follow changes better. Energy storage that is used in this paper is a capacitor that is parallel with the fuel cell to generate power. These capacitors are used to improve power quality and disturbance rejection input to the fuel cell.

2-3) the inductor is connected to the network

In order to connect micro grid to the network, in Figure 1, a voltage source inverter is used. A series inductance is used to connect VSI to the network. The series inductance gives the possibility to control Inverter output. The inductance values are come in the simulation.

3) Micro grid connection to the main network

One of the most important issues in determining the structure and planning Micro grid is Discussion about being connected to the network or being separated from the network. For example, in some areas for some reasons connection to the network is difficult and costly which is better in these areas Micro grid works as autonomous and separate from the network. The purpose Micro grid is having a feature independent. But for increased security and flexibility, Micro grids must be connected to the upstream network or even possible to be connected to a neighboring Micro grid. Power Exchange can be either unilateral or bilateral, from upstream network to micro grid and vice versa [6]. Associated with the upstream network can be either. This relationship can be an AC synchronous communication that advantage is simple. So only requirement is the key breakers and possibly a transformer. the problem in this case is pre-connection to the network and Synchronization with its, if Micro grids disconnected from the network [6]. If we consider a set of DG within a Micro grid in the circumstances that micro grid is connected to its upstream network, in this mode, all inverter connected to this DG, due to voltage and frequency reference, are operated in the PQ control mode.

3-1) Control of fuel cell in connected to the network operation

Fuel cell control can be performed under any of the following conditions:

1) **Following the peak power**: this case reduces the investment cost, but due to more voltage drop and cell low thermodynamic efficiency, the cell cost will increase.
2) **Performance In maximum efficiency**: The maximum thermodynamic efficiency in the high voltage and low power is achieved .Although fuel cell performance in this state reduces the current cost, But by low power generates, can increase the investment cost.
3) **Using In optimal operation point:** This point is approximately 80 to 90 percent of rated load.

In this section the proposed method that is used to control of active and reactive power of grid connected micro grid, are described. This micro grid that it's power generator is fuel cell, for connect to the network is required to DC-AC converter. Power control of micro grid get out by control offering angle of DC-AC inverter gate. In this Method, the goal is to follow change of the reference active and reactive power that will enter as input to the controller. The controller output is the current component d, q, that finally by crossing Reference conversion dq to abc, abc components of current Be built. These reference currents, together with readed three-phase currents, enter into the hysteretic controller and produce the desired pulse for converters regarding to the load changes. General block to generate the reference currents for the hysteretic controller is shaped in Figure 5 [13].

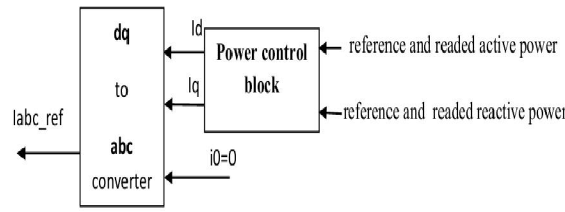

Figure 5) Schematic overview of how to generate the reference currents for the hysteretic controller

4) The proposed controller

Usually, the PI controller is used to control the active and reactive power of Micro grid connected to the network [14-16].Despite of the implementations implicitly of this controller type, low speed in following the change set point, is one of the disadvantages of this control method. To overcome this fault, neural network can be used to control active and reactive power. Neural network does not follow the Set Point well, but compared with the PID, its ability to remove the input disturbance is less, and does not robust against parameter changes.

In this paper, a controller structure is introduced based on neural networks and then a hybrid controller will be presented which is made from aP1 and a NN.

4-1) neural network topology

In order to control the active and reactive power, controller with neural network is trained which has two layers .In its hidden layer, 5 neurons and logsig activation function are used. In its output layer, a linear activation function (purelin) is used, too. Neural network input is active and reactive power, and its output is the d and q components of reference current for hysteretic 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 [11]. Figure 6 clearly describes the neural network blocks used in article.

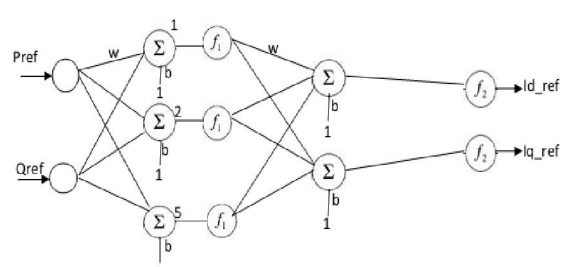

Figure 6) model of neural network used for control of active and reactive power

4-2) the neural network training

As mentioned in the previous section, the proposed neural network input, is active and reactive power and its output is component d, q of current. For the purpose of training data collection**,** we have specify different numbers to the current sd, q components when that active power changes in ranges from zero to 1 and reactive power change in ranges from -1 to 1 and Each time two pairs of training data (id,p)and (iq,q), are obtained. Finally, for training the neural network, 100 training data is used. Collecting method of these data is shown in Figure 7.

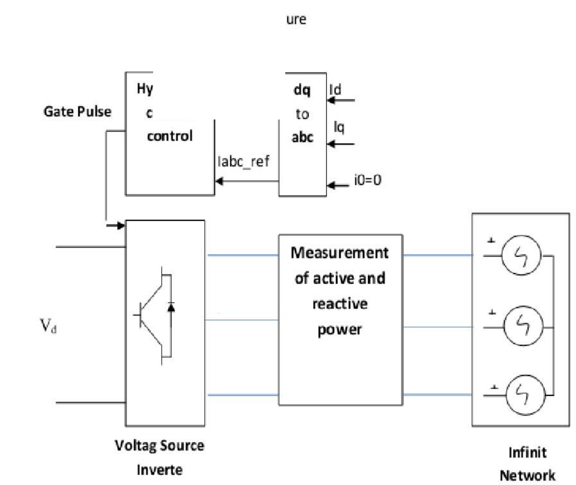

Figure 7) Methods of training data production for neural network controller

Testing and validation curve for training data of the neural network are in Figure 8.

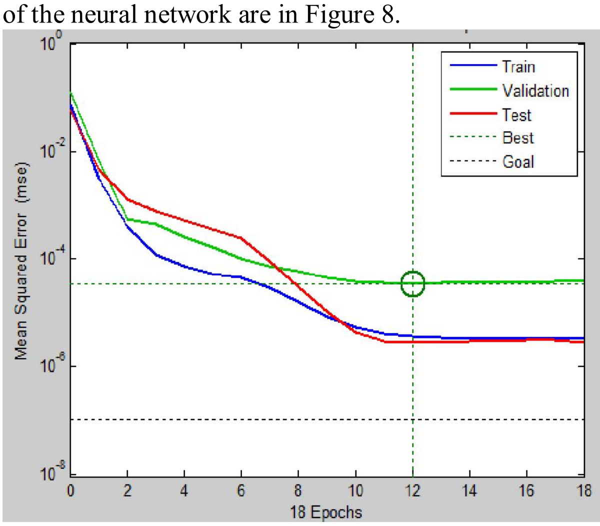

Figure 8) testing and validation curve for training the neural network

4-3) Introduction of PI-NN controller

Due to the inverse neural network structure, Lack of robustness against system parameter changes, is the disadvantage of the neural network controller in Section 4.Therefore, this section will introduce a new topology in which both flaws of PI controller and neural network are solved. In a transient state in this method, neural controller performs power control. If the testing system parameters contradict with the system that neural network is trained for, the system output will have a steady-state error value. In the PI-NN controller, By entering PI blocks in parallel with a neural network this defect is resolved and steady-state error becomes zero. Consequently, efficiency of this system at tracking set point, disturbance rejection and robustness to change system parameters, is given. Figure 9 shows this idea generally.

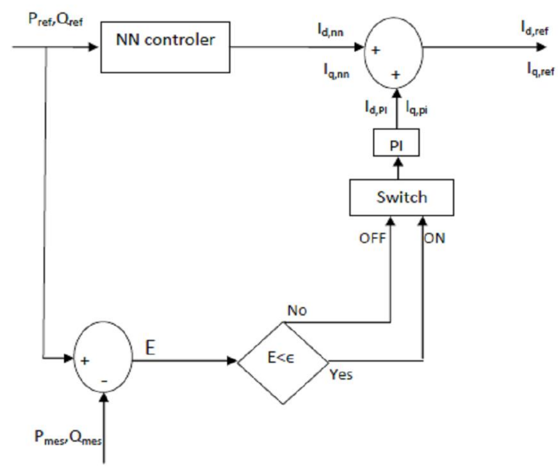

Figure 9) the overall diagram of a PI-NN controller

5) Simulations

In this section in order to verify the method presented, Fuel cell system connected to the network (Figure 1) was simulated using MATLAB software. Then these controller performances, (i.e PI, NN and PI-NN) - presented in Section 4-are compared according to the following aspects on the above **system**:

Follow the set point,

Disturbance rejection,

Robustness against System parameter changes

Sensitivity Analysis

Parameters used in the simulation are: phase to phase voltage of network 360 V, Capacity of input capacitance is 1 mf and the inductor is connected to the network, 1mH. The base amount of active and reactive power is 50KVR.

5-1) following the set point

In this section Set point changes for active and reactive power is applied to system in Figure 1,The results for the PI controller with PI-NN and NN and the reference are given in Figure 10 and 11.

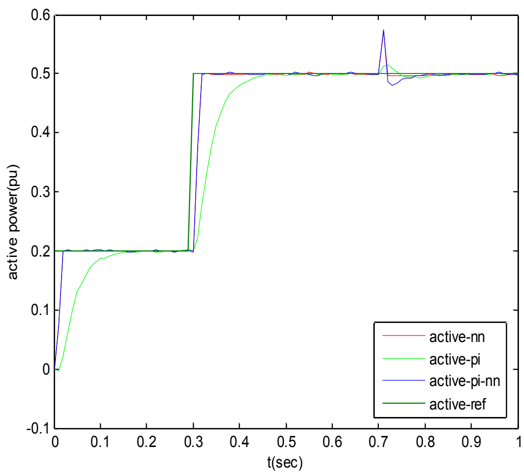

Figure 10) reference active power compared with the output controller PI, the neural network and PI-NN controller

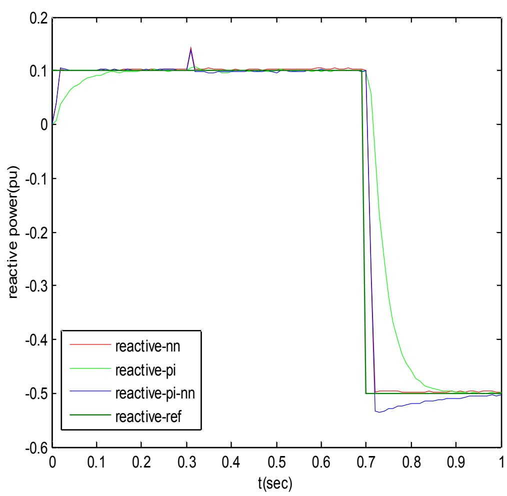

Figure 11) reference reactive power compared with the output controller PI, the neural network and PI-NN controller

5-2) disturbance rejection capabilities

In this section, the proposed controller is compared with the PI and NN for disturbance rejection. The entering disturbance is a 5 Kw resistive load which is connected to the network in 0.5sec.

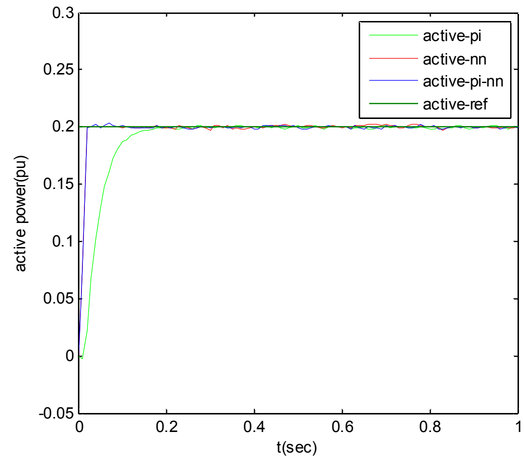

Figure 12) changes in active power transferred to the network for different controllers, as for added resistive load in 0.5sec

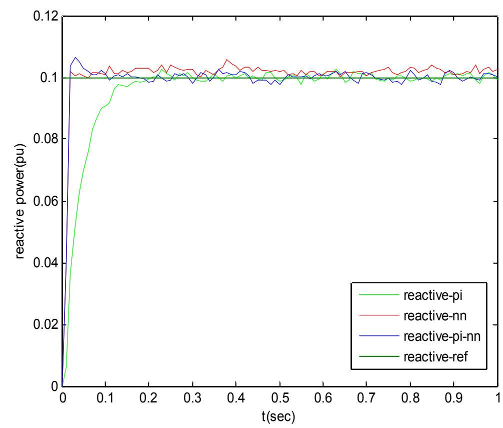

Figure 12) changes in reactive power transferred to the network for different controller, as for added resistive load in 0.5sec

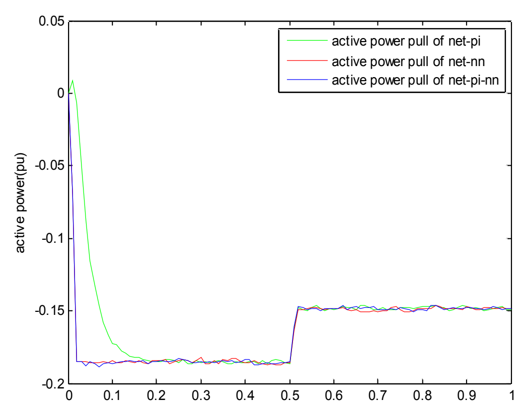

Figure 12) changes in delivered active power from the network for different controllers, as for added resistive load in 0.5sec

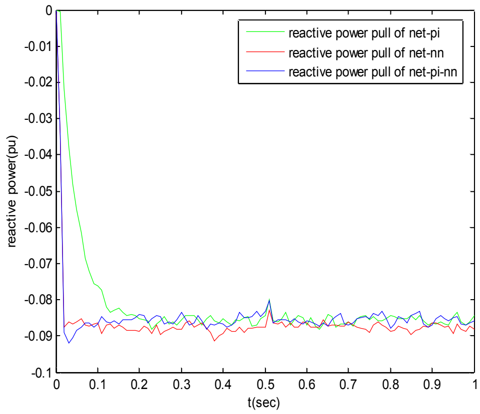

Figure 12) changes in delivered reactive power from the network for different controllers, as for added resistive load in 0.5sec

It is visible from the Figures 12-15 that if a load is added to system, between the inverter and the network, it is the network which prevents disturbance in the controllers by injecting power into the system. So elimination of such disturbances can be considered network connection properties.

5-3) Evaluation of the proposed controller robustness

Parameter changes can happen to any system and has negative effects on the controller and the goal to which the controller is designed. There for robustness of controller against system parameter changes can be considered as the benefits of a good controller. The considered parameter change for the system in Figure 1, is according to the change in the inductor which connects fuel cell to network. This parameter change applies to the system in seconds 0.5sec and results are shown in Figures 16 and 17.

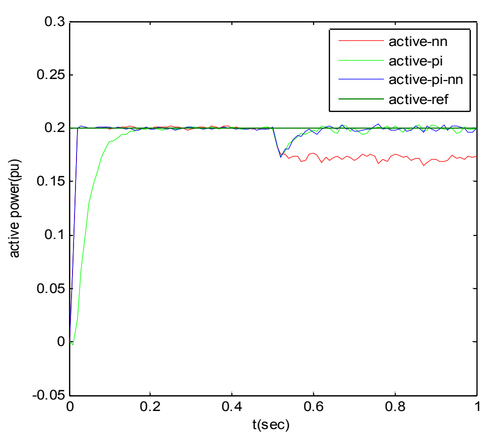

Figure 16) comparison of three controllers robust on following the active power after system parameter changes in 0.5sec

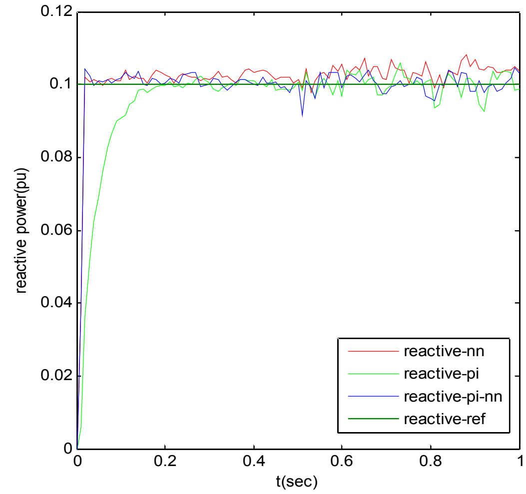

Figure 16) comparison of three controllers robust on following the reactive power after system parameter changes in 0.5sec

5-5) sensitivity analysis

The parameter, impressive in controller efficiency, is the value of ε. Output of PI-NN controller, when system parameter changes occur at 0.5 sec, by Values 0.1, 0.05 and 0.01 for this parameter, is shown in this figure.

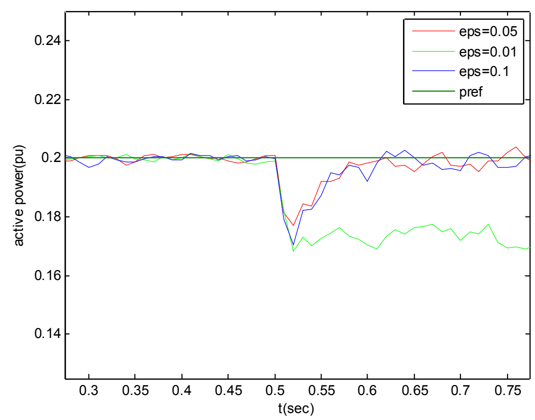

Figure 18) the impact of parameter ε in PI-NN controller efficiency

According to Figure 18, we can see that, low ε value, can increase the controller efficiency during the systems parameter change (ε =0.05).But the significant point is that excessive reduction of ε, leads to on robustness of controller faced with system parameter change(As happened for ε = 0.01 in Figure 18).

6) Discussion:

In this paper, PI-NN method for controlling the active and reactive power of fuel cell connected to network was offered. The controller results compared with the PI and NN controller show that:

Following the Set Point: The proposed Controller follows the set point changes in active and reactive power similar to NN and better than PI controller (Figures10, 11).

Disturbance rejection: Micro grid connection to network makes the system controllers still keep track set point _ if a disturbance occurs _and avoids disturbance to enter the controllers.

Robustness: Unlike the NN, the proposed controller robust to changes in system parameters well much like the PI, if the parameter (ε) is set appropriately.

7) Conclusions:

In this paper a new control strategy, PI-NN, for the fuel cell system connected to the network is presented. The controller consists of a NN to follow Set Point quickly and a PI controller for suitable disturbance removal and robustness of controller against the change in the system parameters. The results of simulation show that the system can deliver reference active power to the Network regardless of the amount power generated by fuel cell, and compensate reactive power of load, up to inverter power. Undesirable disturbance rejection and robustness against system parameter changes, based on the suitable choice of controller parameters (ε), and high speed in track set point changes can be considered as benefits of the controller.

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