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## Model and Experiment Analysis of 1.2 kW PEMFC Electrification

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### Abstract

This paper developed a model of PEMFC by using *MATLAB/Simulink* in order to analyze the operation performance of a Proton Exchange Membrane Fuel Cell of 1.2 kW. Also, the experimental is set up to study the performance of PEMFC. The results show that the operation performance of fuel cell depends on gas pressure, operation temperature, gas flow rate and gas humidity. All parameters which affected the system performance are evaluated. The results of both an experiment and model simulation are determined. The experimental results show the behavior of PEMFC when there is load changing. All aspects of PEMFC electrification will be fully investigated in order to develop the alternative sustainable PEMFC energy sources and to study the fundamental of fuel cell technology. The results of simulation and experimental will be compared.

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**Keywords:** Fuel cell; PEMFC; Efficiency of PEMFC; Simulation

### 1. Introduction

Energy and air pollutions are the most seriously problems and it is not only affected to only one country but also affected to whole the world. Now a day, electrical power demands increase continuously and due to the limitation of fossil-fuel resources and environment concerns. It is very important to talk about new power sources in order to stop the global warming and reducing air pollutions. One of that is Fuel Cell technology. It uses hydrogen as the fuel. The fuel cell (FC) is an energy-conversion device that can produce electricity without harmful emissions. FC uses chemical reaction process to convert chemical energy directly into electrical energy. Fuel cell systems use hydrogen and oxygen as a fuel which fed into anode and cathode side of fuel cell. One of the various existing fuel cell systems is a proton exchange membrane fuel cell (PEMFC) and it is the most popular type of fuel cell for electrical power generation.

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Many types of PEMFC have been studied and analyzed the performance. There are two types of PEM fuel cell that were studied, single and stack cells. Also, mathematical model of PEMFC are made in order to study some of parameters that effected to both single and stack cells. Not only the PEMFC's parameters but also loads changed have been evaluated. In order to understand the behavior and characteristics of PEMFC performance, the mathematical model is developed [1]-[6].

Mathematical model and an experimental of 1.2 kW PEMFC is presented. Performance of PEM fuel cell is studied by varying load current in order to show the behavior and characteristics of the PEMFC under various operation conditions. The objectives of this research are to compare the model results with experimental results when there is load current changing under various operation conditions.

## 2. Theory and Research Methodology

Physical structure of PEMFC is very important to understand how its work. Figure 1 shows schematic of a single PEMFC. Hydrogen and air are fed to anode and cathode channels in the active fuel cell section, respectively.

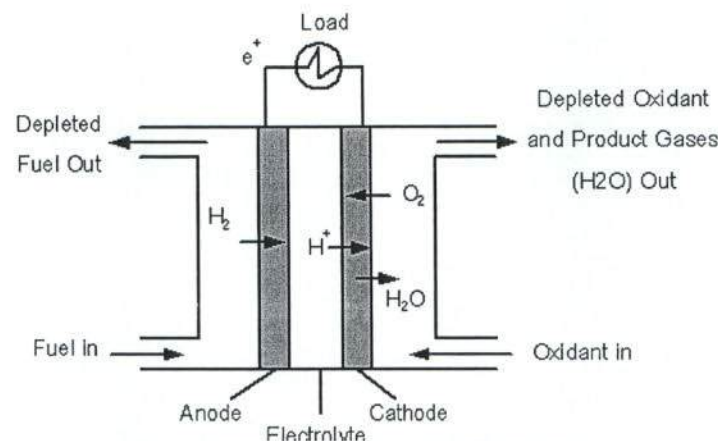
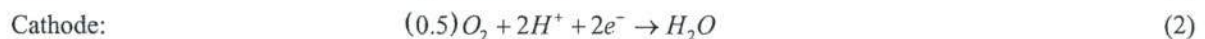
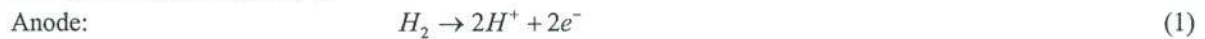
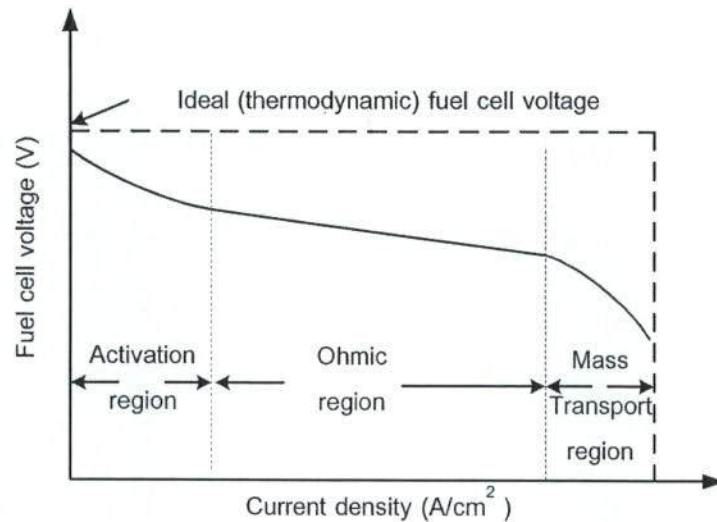


Fig. 1 Schematic diagram of a PEMFC [6].

PEMFC is constructed from a proton conducting polymer electrolyte membrane, usually a per fluorinated sulfuric acid polymer. The chemical reactions producing at the oxidation and reduction electrode of a PEMFC are shown in Equation (1) and (2) [5, 6]



Mathematical model of PEMFC is developed based on energy, mass, and electrochemical equation. Some of parametric has been studied to evaluate PEMFC's performance. The PEMFC performance can be expressed  $i-v$  curve as shown in Figure 2. The characteristic of this curve depends on the output voltage and current density. The output voltage of the PEMFC depends on parameters which shown in physical equations. The result of the model will be compared to the experiment results. The output voltage of developing fuel cell is depending on the thermodynamically predicted fuel cell voltage output and three majors losses which occurred in fuel cell as following: Activation losses, Ohmic losses, and Concentration losses. Activation losses are loss due to electrochemical reaction. Ohmic losses occur due to ionic electronic condition. Concentration losses are losses due to mass transport.

Fig. 2.  $i$ - $v$  curve schematic of FC [6]

Then, the output voltage of PEMFC can be expressed in equation (3).

$$V = E_{thermo} - \Delta E_{act} - \Delta E_{ohmic} - \Delta E_{conc} \quad (3)$$

where  $V$  is the real output voltage of fuel cell.  $E_{thermo}$  is the thermodynamically predicted fuel cell voltage output.  $\Delta E_{act}$  is the Activation loss due to reaction kinetics.  $\Delta E_{ohmic}$  is the Ohmic loss from ionic and electronic condition.  $\Delta E_{conc}$  is the concentration loss due to mass transport.

The result of chemical reactions inside a fuel cell is reversible single electrode potential,  $E_{thermo}$ , given by the Nernst equation as shown in equation (4).

$$E_{thermo} = E_{thermo}^0 - \left[ \left( \frac{RT}{nF} \right) \ln \left( \frac{p_{H_2O}}{p_{H_2} \times \sqrt{p_{O_2}}} \right) \right] \quad (4)$$

where  $E_{thermo}^0$  is standard electrode potential,  $R$  is gas constant (8.3144 J/mol K),  $T$  is temperature in Kelvin scale,  $n$  is number of electrons per reacting ion or molecule,  $F$  is Faraday's constant (96,500 C/mol),  $p_{H_2O}$  is the partial pressure of water,  $p_{H_2}$  is partial pressure of hydrogen, and  $p_{O_2}$  is partial pressure of oxygen.

The activation loss (mostly affect in initial part of curve) due to reaction kinetics at an electrode of a PEMFC is shown in equation (5). This equation is commonly known as Tafel equation.

$$\Delta E_{act} = \left( \frac{RT}{\alpha F} \right) \ln \left( \frac{i + i_{loss}}{i_0} \right) \quad (5)$$

where  $\alpha$  is an activity coefficient,  $i_{loss}$  is a current loss,  $i_0$  is an exchange current density for reaction with constant value, and  $i$  is an applied current density. The ohmic losses (mostly apparent in the middle section of the curve) is resistance of ions flow in electrolyte and resistance of the flow of electrons through electrically conductive fuel cell components,  $R_{ohmic}$ . Ohmic losses (which include ionic, electronic, and contact resistance,  $\Omega\text{cm}^2$ ) can be calculated from current density as.

$$\Delta E_{ohmic} = i(R_{ohmic}) \quad (6)$$

The effect of concentration losses due to mass transport (most significant in the tail of  $i$ - $v$  curve) is shown by equation (7).

$$\Delta E_{conc} = \left( \frac{RT}{nF} \right) \ln \left( \frac{i_L}{i_L - i} \right) \quad (7)$$

where  $i_L$  is limiting current density with constant value and  $i$  is an applied current density.

Activation and concentration polarization can occur in both anode and cathode. The cell voltage,  $V_{cell}$ , is therefore:

$$V_{cell} = E_{thermo} - (\Delta E_{act} + \Delta E_{conc})_a - (\Delta E_{act} + \Delta E_{conc})_c - \Delta E_{ohmic} \quad (8)$$

Subscript  $a$  and  $c$  denote the anode and cathode sides of FC membrane, respectively. [6]

### 2.1 Single Cell Voltage

By substitution equations (4), (5), (6) and (7) into equation (8), a relationship between fuel cell potential and current density, called fuel cell polarization curve, is obtained the single cell output voltage:

$$V_{cell} = E_{thermo} - \left( \frac{RT}{\alpha nF} \right) \ln \left( \frac{i + i_{loss}}{i_{o,c}} \right) - \left( \frac{RT}{\alpha nF} \right) \ln \left( \frac{i + i_{loss}}{i_{o,a}} \right) - \left( \frac{RT}{nF} \right) \ln \left( \frac{i_{L,c}}{i_{L,c} - i} \right) - \left( \frac{RT}{nF} \right) \ln \left( \frac{i_{L,a}}{i_{L,a} - i} \right) - i(R_{ohmic}) \quad (9)$$

where  $i_{o,a}$  and  $i_{o,c}$  are the exchange current density for the reaction of the anode and cathode side, respectively.  $i_{L,a}$  and  $i_{L,c}$  are the limiting current density of the anode and cathode side, respectively. Equation (9) is the single cell voltage, which calculated by vary the current density,  $i$ .

### 2.2 Stack Cell Voltage

This section presents the various equations that are necessary for overall modeling of fuel cell system. The total stack cell voltage is calculated as follows.

$$V_{cell} = N \left\{ \begin{aligned} & E_{thermo} - \left( \frac{RT}{\alpha nF} \right) \ln \left( \frac{i + i_{loss}}{i_{o,c}} \right) - \left( \frac{RT}{\alpha nF} \right) \ln \left( \frac{i + i_{loss}}{i_{o,a}} \right) \\ & - \left( \frac{RT}{nF} \right) \ln \left( \frac{i_{L,c}}{i_{L,c} - i} \right) - \left( \frac{RT}{nF} \right) \ln \left( \frac{i_{L,a}}{i_{L,a} - i} \right) - i(R_{ohmic}) \end{aligned} \right\} \quad (10)$$

where  $N$  is a number of cell. The parameters, such as  $i_o$ ,  $\alpha$ ,  $T$ , and  $i_L$ , are studied to determine the effect of PEMFC performance. Those parameters were presented in. The PEMFC performance will be shown as  $i$ - $v$  curve for a single cell.

### 3. Simulation Model

The mathematical model of PEMFC is developed based on the basis of the equations given in the previous section. Figure 3 shows the schematic of a PEMFC module in *MATLAB* with *Simulink*.

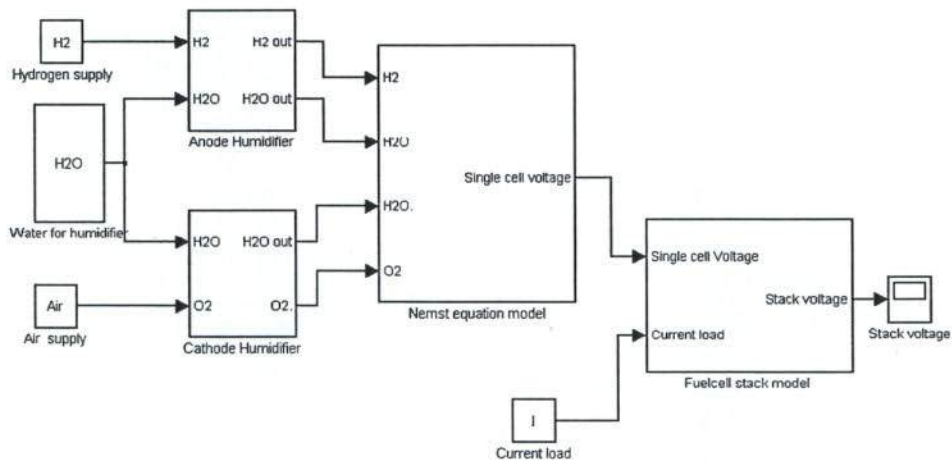


Figure. 3. The schematic of a PEMFC module.

#### 4. Experimental Setup

The experiment is set up as show in figure 4. The experiment used PEMFC with 1.2 kW, 46 A (Nexa™ Power Module User's Manual, model: MAN5100078). It consists of hydrogen tank, personal computer, PEMFC module, and electronic load.

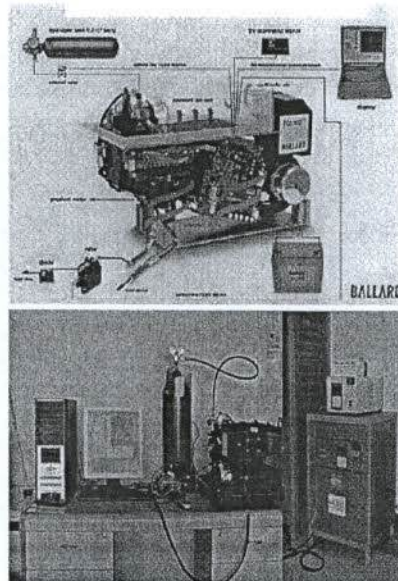


Fig. 4. Experiment Setup Schematic

The experiments are tested at difference pressure operation and varied the current load in order to study the behavior and performance of PEMFC.

#### 5. Simulation and Experiment Results

The experiment results show in figure 5 that indicates the output voltage of PEMFC with difference of pressure operation.

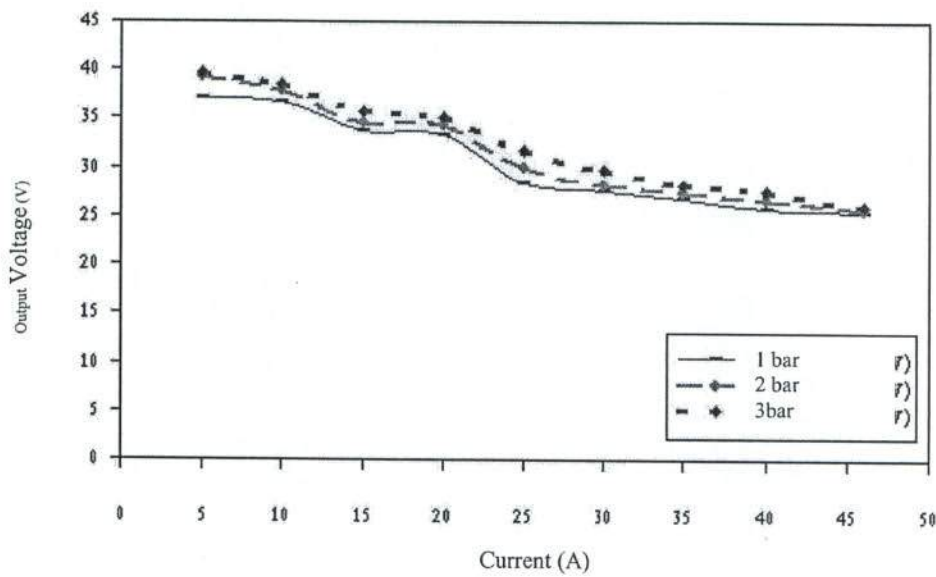


Fig 5. Output voltage of PEMFC with difference of gas pressure operation at 1, 2, and 3 bars

The experiment is taken at atmospheric pressure for air and changing the hydrogen pressure from 1 to 3 bars. The results show the output voltage of PEMFC trends to decrease when increased the load current from 5A to 45A for all difference pressure operation. Pressure operation was set up at 3 bars which gave higher output voltage. Figure 6(a) shows the fuel cell voltage when immediately changed the load current from 1A to 46A every 10 seconds. The load current increase sharply will cause the fuel cell voltage decrease. Figure 6(b) is the simulation results of a single cell. It shows the output voltage and current responses of PEMFC model with input load current. The simulation results take total simulated time about 1 second with 0.2 second per period.

Figure 7 shows the comparison of the output voltage of mathematical model and experimental. It shows that the output voltage from the model has little bit higher than the experiment. It is because of we keep some parameters in the model constantly but in the experiment there is some parameters will change when the operation temperature changed.

In Figure 8 is the comparison of power output of both model and experiment results. It shows that the output power of both model and experiment increased when increased the load current from 5A to 46A and the result has the same trend.

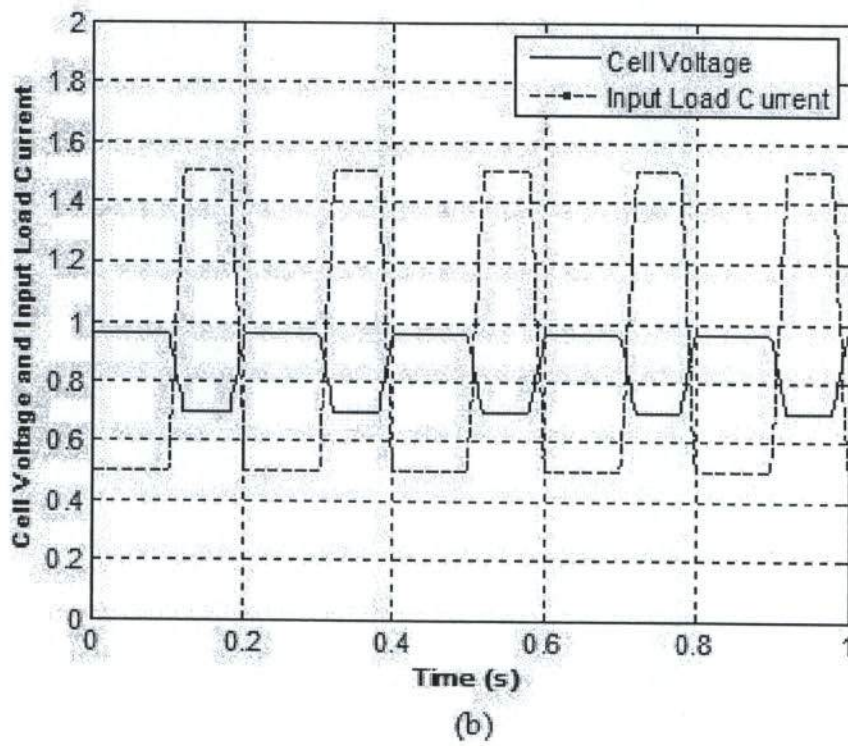
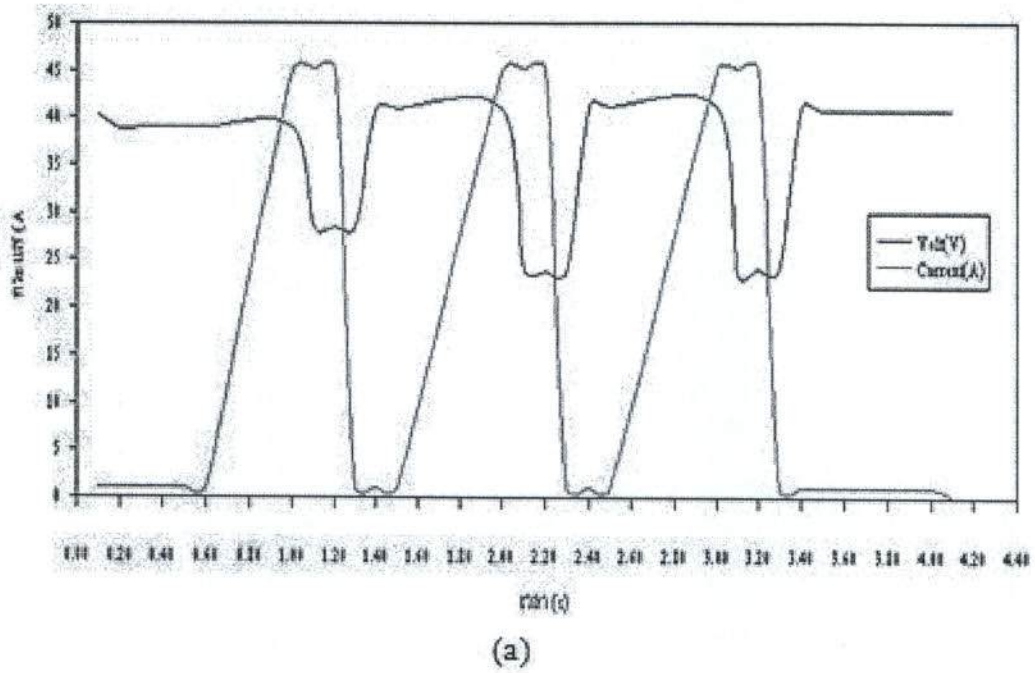


Fig. 6. The changing of load current and cell voltage.

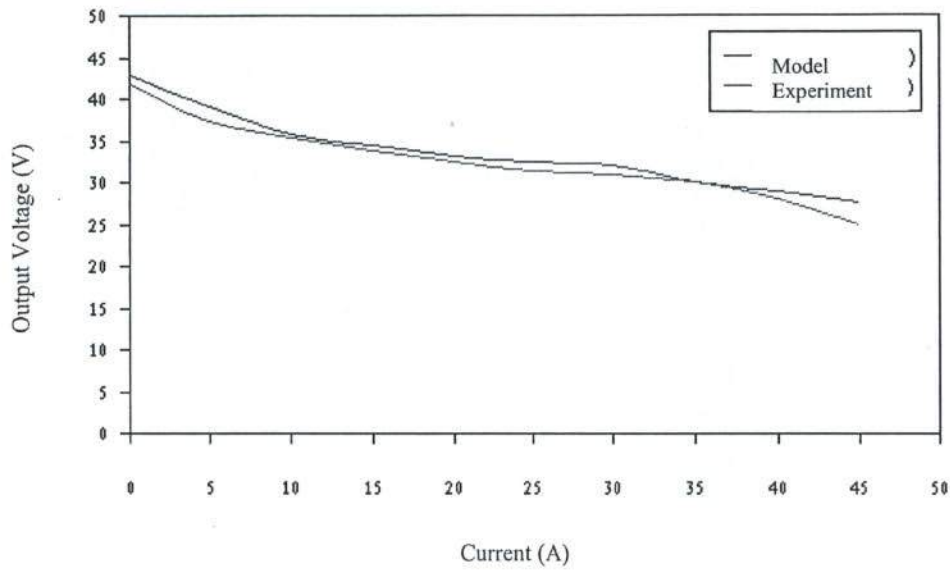


Fig. 7. The comparison of output voltage of mathematical model and experimental.

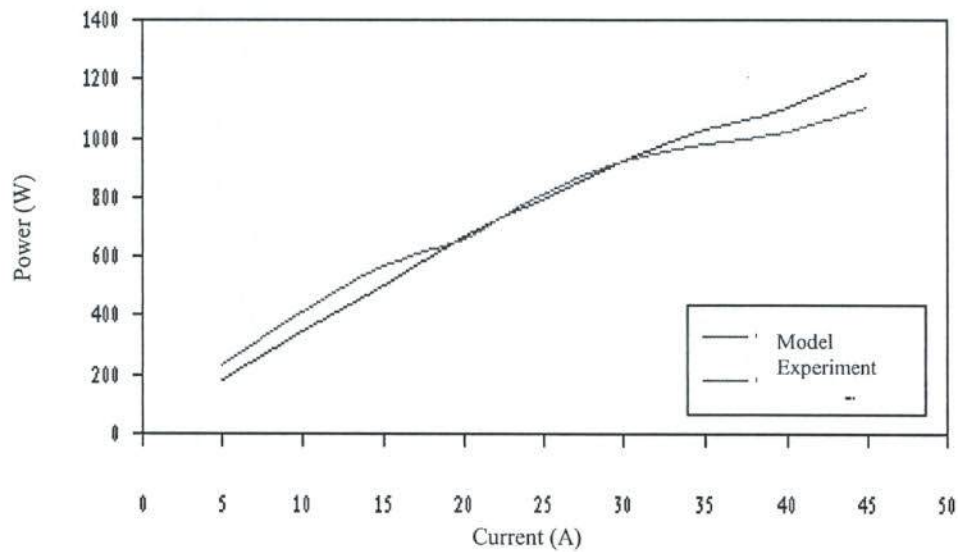


Fig. 8. The output power for both model and experiment results.

**6. Conclusions**

The study of PEMFC performance in this work show the hydrogen pressure has effected to the FC performance. The PEMFC's performance will increase when increased the pressure. The output voltage changed rapidly when the current load has been changed. Both results of mathematical model and experiment can be show the behavior of the PEMFC. The results are good agreement. The model of the study can be expressed the dynamic behavior of the PEMFC when there is load changing.