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Modelling and Performance Analysis of Neural Network Based PEM Fuel Cell

Dhanush M[1], Dr. V G Sangam[2]

PG Student, Dept of Electronics & Instrumentation Engg, Dayananda Sagar College of Engineering, Bangalore[1]

Professor& HOD, Dept of Electronics & Instrumentation Engg, Dayananda Sagar College of Engineering, Bangalore[2]

Abstract: Analysis of electric vehicle fed with fuel cell requires a modelling of fuel cell. This modeling of fuel cell with driving pattern is not easy to achieve. This paper deals with neural network rained fuel cell for driving pattern of electric vehicles. With this pattern the trained output voltage and power of the fuel cell can be decided. The multi-layer perceptron neural network is used to predict the output voltage and power of the PEM fuel cell. The modelling and simulation work is carried using Matlab/Simulink in order to verify the reliability of the electric vehicle.

Keywords: PEM Fuel cell; Electric Vehicle; Neural Network; Multi-Layer Perceptron.

I. INTRODUCTION

Rapid Increasing population, energy consumption in the world, increasing oil and natural gas price, rice in emissions and depletion of fossil-fuels are the main reason for using the electric vehicles. The EVs are proposed as potential and attractive solutions for the transportation applications to provide environmentally friendly operation with the usage of clean and renewable energy sources. One such energy sources of electric power provide a clean energy with low emission is the fuel cell whose only by product is water and heat. Fuel cell is an electro chemical device that converters chemical energy into electrical energy into a controlled manner. Recently emerging new type of fuel cell is proton exchange membrane fuel cell (PEMFC) which is used widely in vehicular application because of its attractive features like high efficiency, high energy density, low operating temperature (52-100◦ C), rapid start-up, good power weight ratio, fewer maintenance and long life. Also, the electrolyte used in the PEM fuel cell is Platinum like material. Platinum is the solid electrolyte and hence corrosion problem will be avoided and also there is no need of liquid management in the system as there is heat produced in the system will evaporates the by-product water. Thus high efficiency and high power and high power density make PEM fuel cell an attractive alternative to conventional automobile engines. The application of PEM fuel cell includes distribution generation and transportation. A several approaches have been used to understand the PEM fuel cell behaviour. In this paper, artificial neural network technique is used to predict the stack voltage and power of PEM fuel cell. This paper is focused on design, modelling and simulation of the neural network based PEM fuel cell operated vehicle model.

II. PEM FUEL CELL

Proton Exchange membrane fuel cells, also known as polymer electrolyte membrane fuel cells (PEMFC), are the type of fuel cell developed for transport application as well as for stationary fuel cell application. PEMFCS are built out of membrane electrode assemblies (MEA) which includethe electrodes, eletrolyte, catalyst and gas diffusion layers as shown in the figure 1.

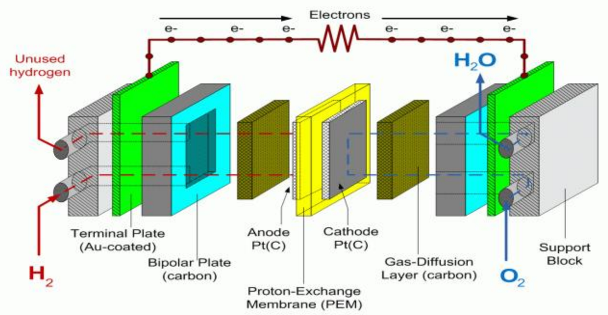

Figure 1 Proton exchange membrane fuel cell

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A proton exchange membrane fuel cell transforms the chemical energy liberated during the electrochemical reaction of hydrogen and oxygen to electrical energy. A stream of hydrogen is delivered to anode, at the anode side it is catalytically split into proton and electrons given in the equation (1)

$$H_2 \rightarrow 2H^+ + 2e^- \ldots\ldots (1)$$

The newly formed protons permeate through the polymer electrolyte membrane to the cathode side. The electron travel along an external load circuit to the cathode side of the MEA, thus creating the current output of the fuel cell. Meanwhile, a stream of oxygen is delivered to the cathode side of MEA. At the cathode side oxygen molecules react with the protons permeating through the polymer electrolyte membrane and the electrons arriving through the external circuit to form water molecules given in the equation (2).

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

Overall reaction given in the equation (3)

$$H_2 + \frac{1}{2}O_2 \rightarrow H_2O\ldots\ldots (3)$$

III. PEM FUEL CELL MODELING

The performance of the fuel cell stack system is highly affected by the various polarization losses and also various electrochemical, thermodynamic and thermal processes takes place inside the fuel cell which makes the system to behave highly non-linear. Hence it is very difficult to perform mathematical modelling. Therefore neural network approach is used to overcome the complexity in the conventional mathematical modeling [13].

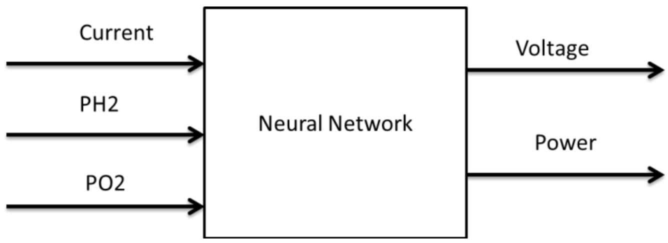

Figure 2 Input-Output parameter set

The input parameters chosen for the neural network are current density, partial pressure of hydrogen and oxygen and the outputs from the network are stack voltage and power. The neural network with the defined inputs and outputs is shown in the figure 2. The specifications of the proposed fuel cell are given in the Table 1. The data required to train the neural network is generated from the simulation model of Ballard 6KW PEM fuel cell developed in MATLAB/SIMULINK environment [5] which is shown in the figure 3.

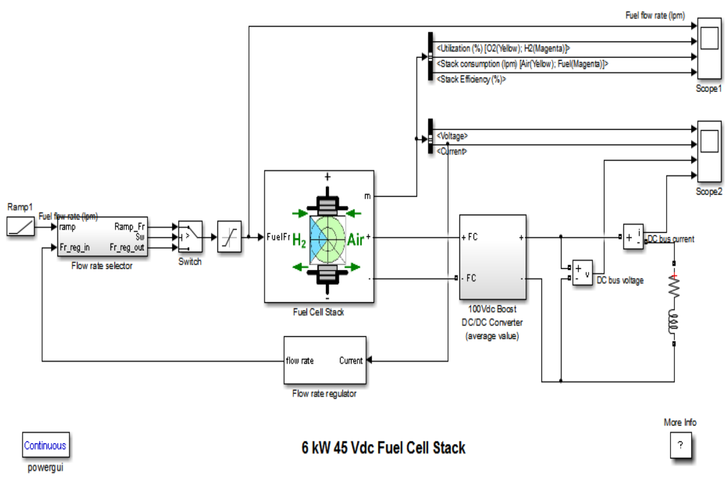

Figure 3 Ballard 6KW PEM Fuel Cell

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Table 1 Fuel cell parameters

SL No	Parameters	Specifications
1	Number of fuel cells in stack	65
2	Maximum power output (KW)	6
3	Nominal cell voltage (V)	0.6923
4	Nominal stack voltage (V)	45
5	Fuel supply pressure (bar	1.5
6	Air supply pressure (bar)	1

IV. MULTI-LAYER PERCEPTRON NEURAL NETWORK

A multi-layer perceptron (MLP) is feed forward artificial neural network model that maps sets of input data onto a set of appropriate outputs. An MLP consists of multi layers of nodes in directed graphs, with each layer fully connected to the next one. Except for the input nodes, each node is a neuron (or processing element) with a nonlinear activation function. MLP utilizes a supervised learning technique called back propagation for the training the network. MLP is a modification of the standard linear perceptron and can distinguish data that are not linearly separable. MLP network architecture is shown in the figure 4.

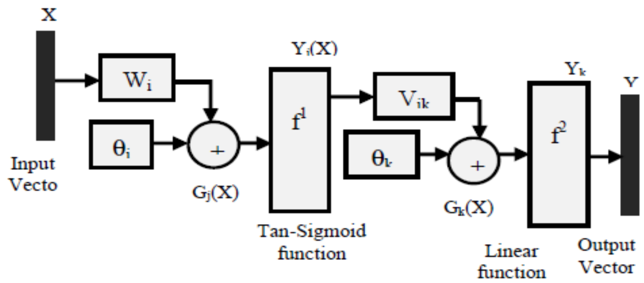

Figure 4 MLP Neural Network Architecture

Network with single hidden layer is used in this paper, in order to reduce the network complexity. The net input to the hidden layer is the function of input, weights and bias it is shown as in equation (4).

$$G_K(X) = \left[\sum_{i=0}^{n}\left(X_i * W_{ij}\right)\right] + \theta_j \ldots\ldots (4)$$

Activation Function:

If a multilayer perceptron has a linear activation function in all neurons, that maps the weighted inputs to the output of each neuron, then it is easily proven with linear algebra that any number of layers can be reduced to the standard two layer input-output model. What makes a multilayer perceptron different is that some neurons use a nonlinear activation function which was developed to model the frequency of action potentials, or firing, of biological neurons in the brain. This function is modelled in several ways. Since the input range is normalized in between [-1, 1]. Hence the activation function used in this paper is tangential sigmoidal (tansig) equations given in the equation (5).

$$Y_j(X) = \tanh\left(G_j(X)\right) = \frac{e^{G_j(X)} - e^{-G_j(X)}}{e^{G_j(X)} + e^{-G_j(X)}} \ldots\ldots (5)$$

The obtained result from the hidden layer is propagates towards the next layer is given in the equation (6).

$$G_k(X) = \left[\sum_{j=0}^{n}\left(Y_j(X) \times V_{jk}\right)\right] + \theta_k \ldots\ldots (6)$$

In order to provide linear output function is performed at the output layer and it is expressed as in equation (7).

$$Y_k = G_k(X) \ldots\ldots (7)$$

The prediction performance of the proposed MLP network in terms of performance indices such as mean squared error (MSE), Regression analysis, epoch and number of neurons in the hidden layer is analysed. The Levenberg-Marquardt training algorithm for the optimum training of the neural network. By varying the hidden neurons from 1 to 15, it is observed that with 10 hidden neurons we will get the less MSE and yields good prediction performance with minimum MSE value of 1.3207*$e^{-0}$with 249 epochs and the response of the MLP network is shown in the figure 5. Table 2 shows the training results of the training algorithm attained using MLP network with 10 neurons in a hidden layer.

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Table 2 Training result of 10 hidden neuron in a layer

Performance Measure	Hidden Neurons
MSE	$1.3207*e^{-0}$
Regression	0.9999
Iteration	297

The obtained neural network block is connected to the Ballard PEM fuel cell to check the correctness in the output obtaining from the neural network block. The figure 6 shows the simulation of neural network connected to the fuel cell. The simulation is made to run for 20seconds and obtained waveform is shown in the figure 7. The output voltage and power of the neural network block is matching with the PEM Fuel cell model, and is shown in the figure 7.

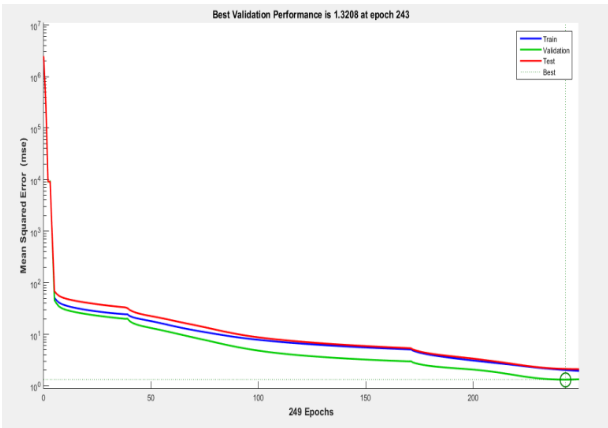

Figure 5 Response of the MLP network

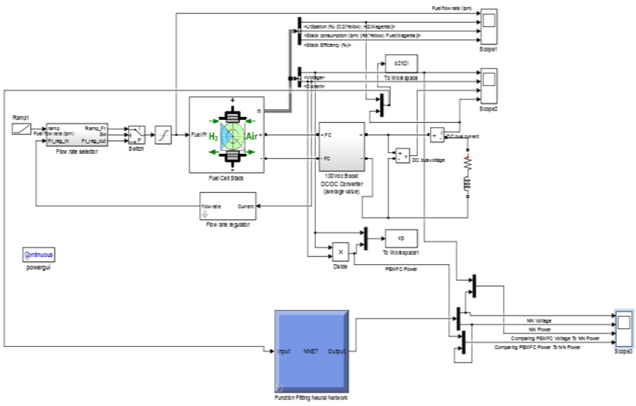

Figure 6 Neural network imparted to Ballard PEM fuel cell

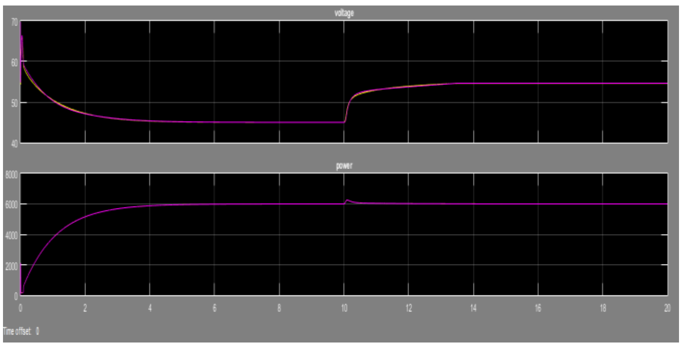

Figure 7 output waveform of neural network block

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V. CONCLUSION

The complexity in developing the conventional mathematical modelling of fuel cell is defeated with the advent of an artificial intelligent technique. The Multi-Layer Perceptron neural network technique is used in the estimation of the stack voltage and power of the PEM Fuel cell model. The waveform shown in the figure 7 shows that the result obtained from the neural network such as voltage and power follows the exact path of the PEM fuel cell module. The modelling and simulation work is carried using Matlab/Simulink in order to verify the reliability of the electric vehicle.

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BIOGRAPHY

Dhanush M M.Tech in Microeletronics and Control System Engineering from Dayananda Sagar college of Engineering Bangalore.