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Genetic Algorithm & Fuzzy Logic Based PEM Fuel Cells Power Conversion System for AC Integration

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Abstract

In the scientific environment, the leading variables such as voltage, current, power, heat from cooling system, membrane temperature and hydrogen pressure are uses as steady state and transient behaviors of Fuel Cells (FC). In the reproducing process of Fuel Cells (FC) variations, DC-DC converters are connected transversely its terminals, the efficiency, stability and durability are considered as operational problems for steady state. Since the Proton Exchange Fuel Cell is a non-linear process and its parameters change when it is delivering energy to the grid. The conventional controllers can't content the control objectives. In this paper, an intelligent DC-AC power optimization is proposed for Fuel Cell (FC) control system to produce energy in the grid stations and to improve the power quality when FC is supplying load to grid. Furthermore, a Genetic Algorithm (GA) based reactive power optimization for voltage profile improvement and real power minimization in DC-AC system. A fuzzy logic controller is also used to control active power of PEM fuel cell system. Fuzzy logic controller will modify the hydrogen flow feedback from the terminal load. At the end, we will simulate DC-AC converter for checking its efficiency, stability and durability on the basis of the genetic algorithm and fuzzy logic controller to control power generation.

Keywords: DC-AC converter, Genetic Algorithm, Proton Exchange Membrane Fuel Cell, AC Integration, Fuzzy Logic Controller, PEMPC Simulation, Proton Exchange Membrane Power Optimizer.

Contents

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1. Introduction

Proton Exchange Membrane fuel cells due to their compactness, low weight, high power density and clean, pollutant free operation are extensively used for mobile and portable applications. Proton Exchange Membrane (PEM) fuel cells is one of the auspicious technologies for converting power source into the AC integration in future. However, a fuel cell system is large, complex and expensive system. The designing and building prototypes of PEM fuel cell is very difficult as well as very expensive. The FC model is very important for power conversion as it helps to understand all the spectacles that involve in its modelling. The considerations in the operation of DC transmission system are to satisfy the need for reactive power at the terminals, maintain good voltage profile and voltage stability.

In the past, a number of models such as DC-DC converters have been proposed that have its own specificities and utilities following phenomena such as compactness, low weight, high power density and clean, free operation to simulate fuel cells for power conversion. The DC-DC converters were used to transform unregulated DC power of the fuel cell to regulated DC bus power in the grid [1], [2].

In this model, each spectacle has its own specificities and utilities. In the previous models, fuel cells were considered due its reliability, high efficiency and low emissions to the environment. In fuel cells, Proton Exchange Membrane fuel cell has many advantages such as low operational temperature, high power density, low noise and light weight. During a chemical reaction, FC is used for electrical power generation, hydrogen conversion to electrical energy. For burning fossil fuels, Fuel Cell (FC) technology is an alternative to the existing technologies because of its low content of harmful emissions.

2. Problem Statement

During the process of delivering energy to grid stations, the DC-DC converter isolates the fuel cell potential in the grid stations. In this process, the efficiency, stability and durability of DC-DC converter creates problems in the steady state as the fuel cell parameters change when it is delivering energy to grid. For high stability of the output current and input voltage, the DC-DC converter have to maintain high stability [3].

3. PEM Fuel Cell Power Conversion (PEMPC) System

In this paper, a Proton Exchange Membrane for Power Conversion (PEMPC) is presented which is more suitable for electrochemical purposes and predicts the FC stack performance against situations commonly encountered in electrical power generation systems such as insertion and rejection of loads, efficiency. When considering the injection of FC energy into the grid, the generation control system should decide which amount of power the FC will supply to the grid, as a function of the load demand. For this purpose, the dynamic response of the FC should be compatible with the fast variations of a random load curve.

The PEMPC can be used for calculating the voltage losses due to the activation and concentration losses as well as fluid dynamic chemical reactions in the Fuel Cell (FC). Fuel Cell has several units for hydrogen production and cleaning. This framework is also suitable for power generation. PEMPO is used to study the PEM fuel cell power plant for transient response and successfully modelled by the support of vector machine [4]. The conventional controllers can’t control the changes of non-linear relationships of multi-inputs and multi-output systems during the change of time. In this paper, a new control strategy using the intelligent methods is used in the adaptive control system to achieve the performance of the controller [5]. The output voltage of Fuel Cell (FC) is affected by hydrogen and oxygen pressures in the PEMCP, therefore, precise regulation of these gases can be retained constant by changing the current [6].

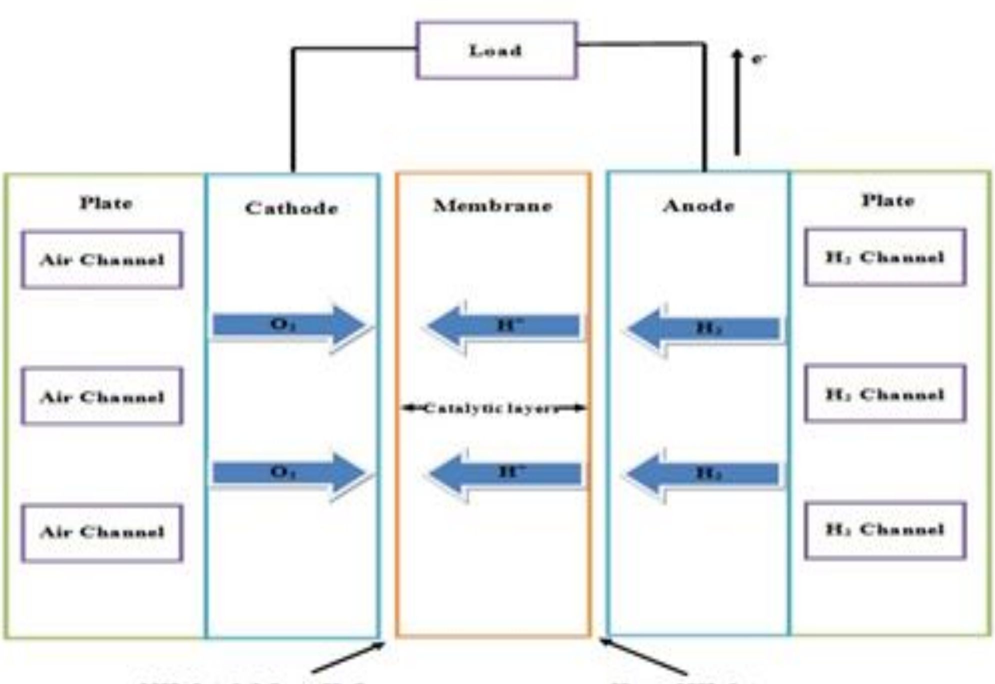

Fig-1. Basic PEMPC operation

PEMPC model is well adapted for PEM cells and it incorporates the essential physical and electrochemical processes that happen in the cells along its operation. A PEMPO converts the chemical energy of a fuel, just as the hydrogen H, and an oxidizer, just as the oxygen O, in electrical energy. In the Fig.1 one side of the cell is anode, the fuel 'H' is supplied under certain pressure. The other compositions of gases can also be used in this model. The fuel spreads through the electrode until it reaches the catalytic layer of the anode where it reacts to form protons and electrons as shown:

$$Anode\ side: H_2(g) \rightarrow 2H^+ + 2e^-$$
$$Cathode\ side: 2H^+ + 0.5O_2 \rightarrow H_2O \qquad \textit{Equation-1}$$

The protons are transferred through the electrolyte (solid membrane) to the catalytic layer of the cathode. On the other side of the cell, the oxidizer flows through the channels of the plate and it spreads through the electrode until it reaches the catalytic layer of the cathode. The oxidizer used in this model is air or O. The oxygen is consumed with the protons and electrons and the product, water, is produces with residual heat on the surface of the catalytic particles. The electrochemical reaction that happens in the cathode is:

$$H_2 + 0.5\ O_2 \rightarrow H_2O + heat\ electricity \qquad \textit{Equation-2}$$

During the previous some years, several analytical and experimental model have been introduced to measure the PEMFC internal behaviour. The output voltage of a single cell can be defined as the result of the following expression [7].

$$Vfc = ENernst - Vact - Vohmic - Vcon \qquad \textit{Equation-3}$$

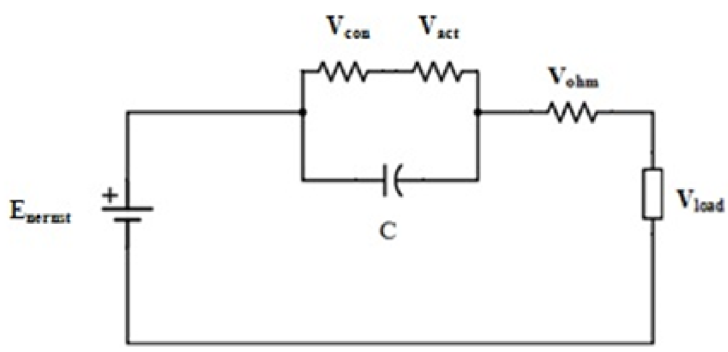

Fig-2. Electrical equivalent circuit of single fuel cell

In Fig.2 E_{Nernst} is the PEMPO open circuit voltage and indicated the reversible voltage. V_{act} is the activation voltage drop, including anode and cathode. V_{ohmic} is ohmic voltage drop that results from the resistance to the electrons transfers through the collecting plates and carbon electrodes and the resistance to the proton transfer through the solid membrane and V_{con} represents the voltage drop which is caused due to the reduction in concentration of the reactant gases.

3.1. Reversible Voltage Cell

The reversible voltage of the cell is the potential of the cell obtained in an open circuit thermodynamic balance that is calculated from a modified version of the equation of Nernst, with an extra term to take into account changes in the temperature with respect to the standard reference temperature as:

$$E_{Nernst} = \frac{\Delta G}{2.F} + \frac{\Delta S}{2.F}\left(T - T_{ref}\right) + \frac{R.T}{2.F}[\ln\left(P_{H_2}\right) + \frac{1}{2}[P_{O_2}] \qquad \textit{Equation-4}$$

Where ΔG is the change in the free Gibbs energy (J/mol); F is the constant of Faraday, its value is 96.487C; ΔS is the change of the entropy (J/mol); R is the universal constant of the gases, its value is 8.314 J/K mol; while P_{H_2} and P_{O_2} are the partial pressures of hydrogen and oxygen (atm), respectively. Variable T denotes the cell operation temperature K and T_{ref} the reference temperature. Using the standard pressure and temperature (SPT) values forΔG, ΔS and T_{ref} can be classified as:

$$E_{Nerset} = 1.229 - (T - 298.15)(0.85 \times 10^{-3} + 4.31 \times 10^{-5}T[L_{n(P_{H_2})} + 1/2L_{n(P_{H_2})}] \qquad \textit{Equation-5}$$

It has to be noted that membrane temperature and gases partial pressures change with cell current, with increasing current, partial pressure of hydrogen or oxygen decreases, where as temperature increases as:

$$V_{act} = -[\varepsilon_1 + \varepsilon_2 T + \varepsilon_2 T.L_n\left(C_{O_2}\right) + \varepsilon_4 T.L_n\left(I_{fc}\right)] \qquad \textit{Equation-6}$$

Where I_{f_c} is the fuel cell operating current (A), the ε are parametric coefficients for each cell and C02 is the consideration of oxygen in the catalytic interface of the cathode (mol/cm3).

$$\mathrm{CO}_2 = \frac{PO_2}{5.08.10^6.e^{\left(-\frac{498}{T}\right)}} \qquad \textit{Equation-7}$$

3.2. Ohmic Voltage Drop

The ohmic voltage drop results from the resistance to the electrons transfer through the collecting plates carbon electrodes and the resistance to the protons transfer through the solid membrane. For this purpose, a general expression for resistance is defined to include all important parameters of the membrane. The equivalent resistance of the membrane is calculated by:

$$V_{ohmic} = I_{fc}(R_m + R_c) \qquad \textit{Equation-8}$$

Where $R_m = \frac{\rho M.l}{A}$ represents the equivalent resistance of the membrane and Rc shows the resistance to the transfer of protons through the membrane usually considered constant. The mass transport affects the concentrations of hydrogen and oxygen which causes a decrease of the partial pressure of these gases. Reduction in the pressures of oxygen and hydrogen depend on the electrical current and on the physical characteristics of the system.

3.3. Mass Transport Voltage Drop

PEMPC has dynamic behaviour due to its charge double layer which. This charge occurs on the surfaces of two materials. The charge layer on the interface electrode/electrolyte acts as storage of electrical charges and energy and behaves as an electrical capacitor. Therefore, it can be considered as a first order delay that exists in the action and concentration voltage drops.

$$V_{con} = -\mathrm{b}L^{n}(1 - \frac{J}{J_{max}} \qquad \textit{Equation-9}$$

4. Genetic Algorithm for PEMPC

In this paper, genetic algorithm is used as search of space, optimum solution and as control strategy such as objective function, production of initial population, selection crossover, mutation and stopping criteria to control the voltage in PEMPC system. As the output voltage of fuel cell is affected by hydrogen and oxygen partial pressures, the output voltage can be retained constant when the current changes [8]. During changing the current, GA finds the optimal hydrogen and oxygen partial pressures to minimize the objective function which applies the PEMPC system that can be defined as [9]:

$$\text{Objective} - \text{Function} = |V_{ref} - V_s|| \qquad \textit{Equation-10}$$

Where V_{ref} is the reference voltage and V_s is the output voltage of the PEMPC stack.

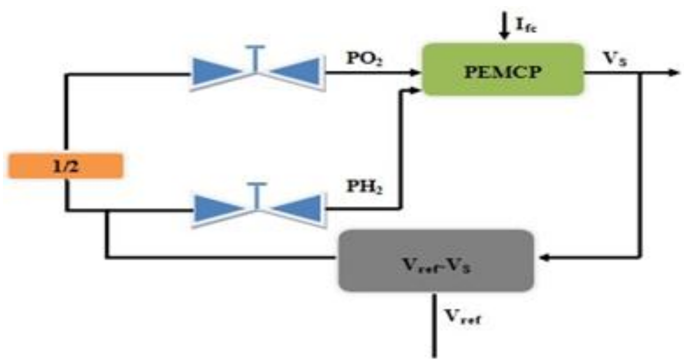

Fig-3. Schematic of proposed controller for PEMPC

An electrical energy generation using a stack of PEMPC is represented in Fig.3 which shows the stack with feeding of hydrogen, oxygen (air) and water for refrigeration, as well as its output product, represents the stack output voltage, which is obtained from the multiplication of the FC voltage and the number of cells [10]. The electrical output of energy of the cell can be linked to a certain load called generic load. There is no restriction related to the load type, since the power supplied by the stack is enough to feed it. E.g. in system used to inject energy into the grid, the load can represent a DC/AC converter, linked to the grid through a transformer. The instantaneous electrical power supplied by the cell to the load can be determined as:

$$P_{FC} = V_{FC} * i_{FC} \qquad \textit{Equation-11}$$

5. DC/AC Inverter

In this paper, a simple model of DC/AC inverter is considered for the dynamic time constant such as microseconds or at the most milliseconds. In the DC/AC inverter, output voltage and power are controlled by using the inverter modulation index and phase angle of the AC.

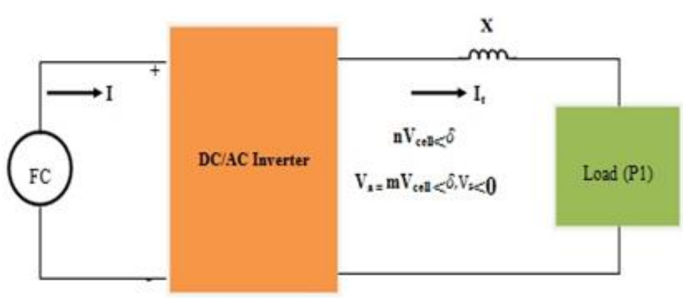

Fig-4. Fuel Cell Inverter and Load Connection

In Fig.4 a fuel cell as inverter and load connection is shown. The output voltage and the output power as a function of the modulation index and the phase angle can be written as:

$$Vac = m.\,Vcell < \delta$$

$$P_{ac} = \frac{m.V_{cell}}{X}.\sin(\delta)$$

$$Q_{ac} = \frac{(m.V_{cell})^2 - m.V_{cell}.V_s.\cos(\delta)}{X}$$

$$I_L = \frac{P_L}{V_s.\cos(\theta)}$$

$$I_{stack} = m.\,I_L.\cos(\theta + \delta) \qquad \textit{Equation-12}$$

Where

V_{ac} = AC output voltage of the inverter [V]
m = inverter modulation index
δ = phase angle of the AC voltage [rad]
P_{ac} = AC output power from the inverter [W]
Q_{ac} = Reactive output power from the inverter [VAR]
V_s = Load terminal voltage [V]
I_L = Load current [A]
θ = Load phase angle [rad]
P = Load power [W]
I_{stack} = Stack current [A]

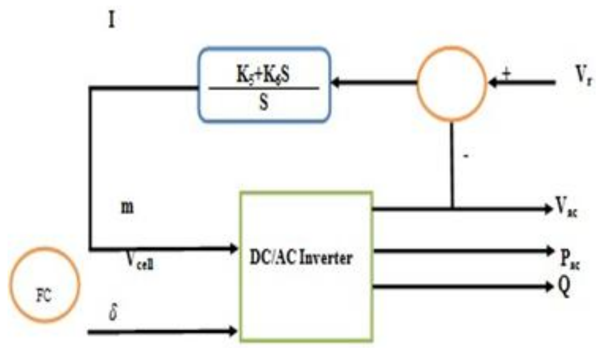

Fig-5. DC/AC Invertor

In Fig.5 the transfer function, $m = \frac{K_5 + K_6 S}{S}(V_r - V_{ac})$ is used to calculate the modulation index. Where K_5 and K_6 are the load PI gain and V_r is the reference voltage signal. The P_{ac} can be calculated by multiplying V_{cell} and $I_{stack.}$ According to electrochemical relationship between stack current and the molar flow of hydrogen can be obtained by $q_{H2} = \frac{N_0 . I_{stack}}{2F.U}$.

5.1. Fuzzy Logic Controller

Fuzzy Logic controller has high performance than any other controller and has numerous advantages for DC to AC conversion [11]. Fuzzy Logic controller can modify the hydrogen flow for controlling active power to the load change. The fuzzy logic controller inputs are the error and change of error in the cell. The output of the fuzzy logic controller is the duty ratio of hydrogen flow. The error, change of error, and the output of the controller are calculated as:

$$k = qH2 + qmeth\ ref - qH2b \qquad \textit{Equation-13}$$

Where $qH2$ is the flow of hydrogen from the current feedback signal and is proportional to the terminal load. $qmeth\ ref$ is the methane reference signal and $qH2b$ is the hydrogen flow feedback signal.

6. PEMPC Simulation

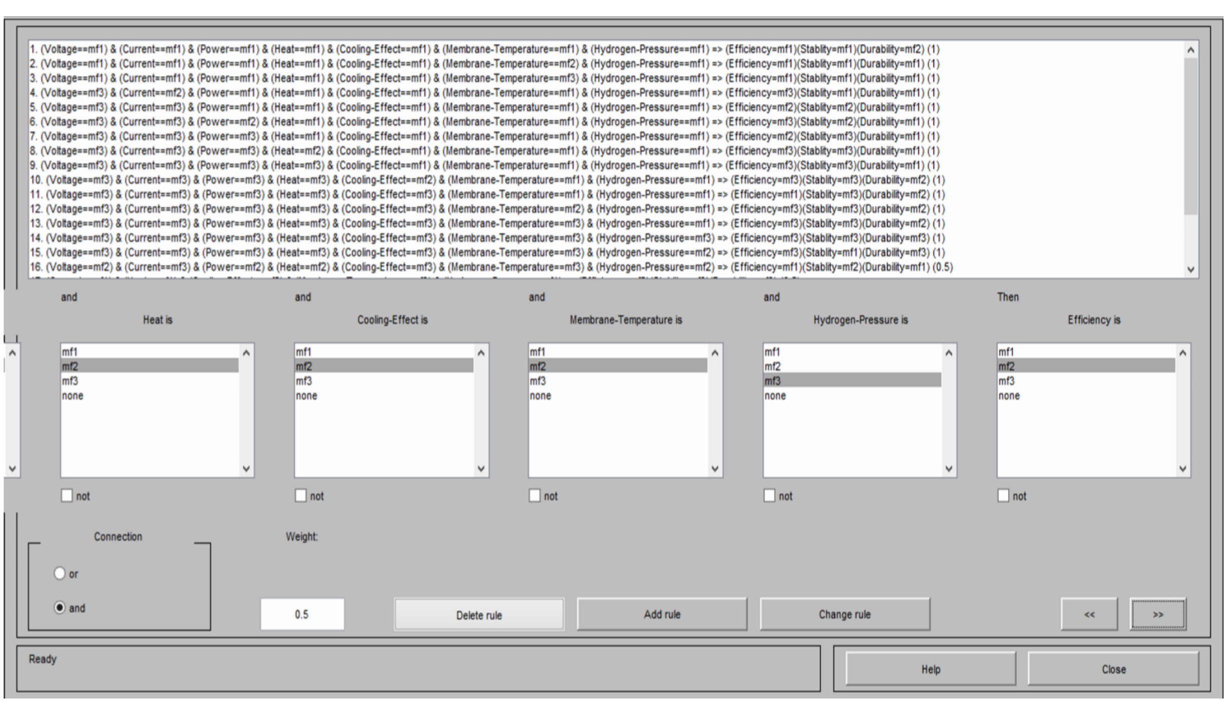

Fig-6. PEMPC Rule Editor

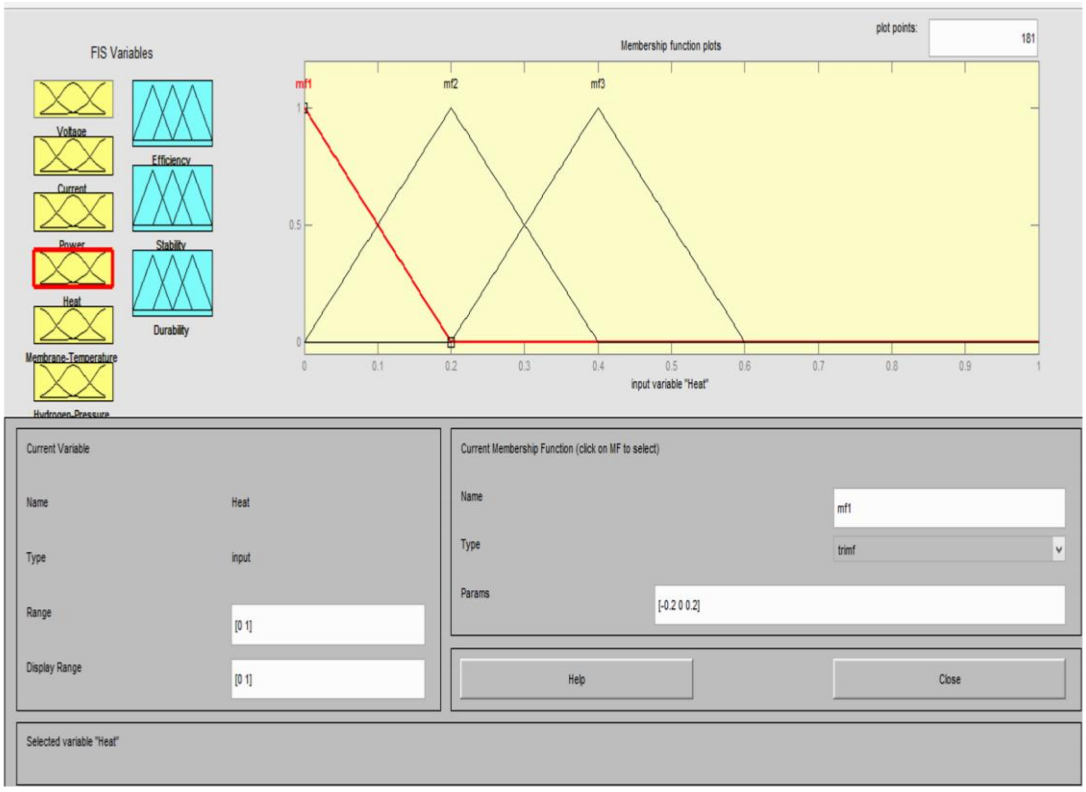

Fig-7. PEMPC membership functions

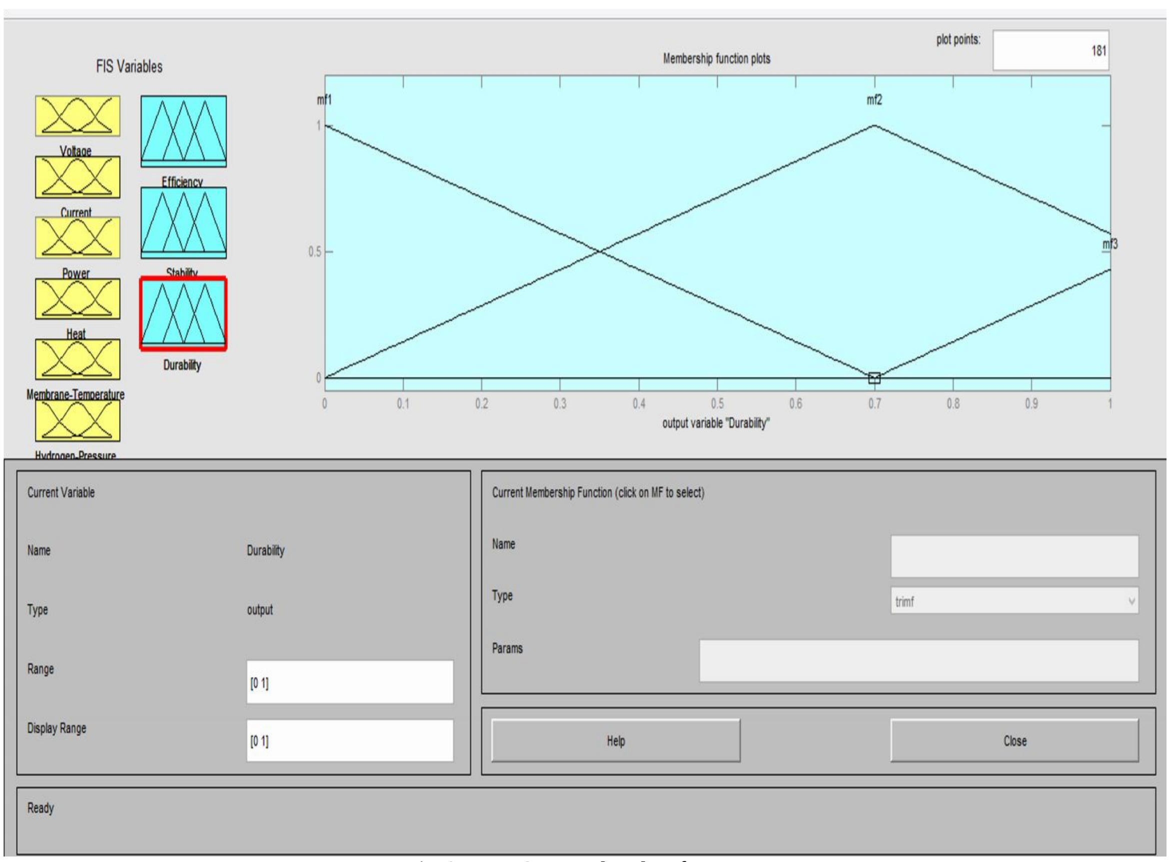

Fig-8. PEMCP membership functions

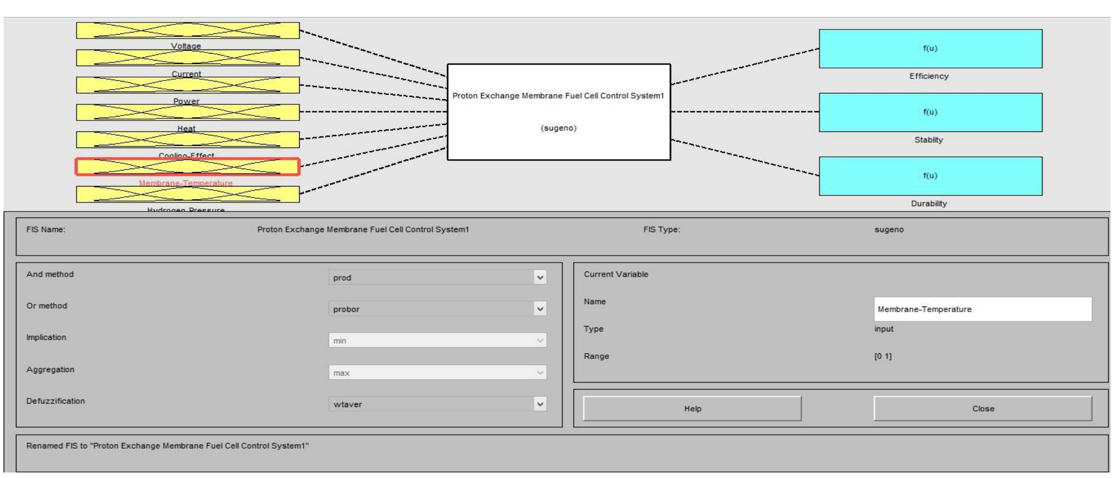

Fig-9. PEMCP FIS editor

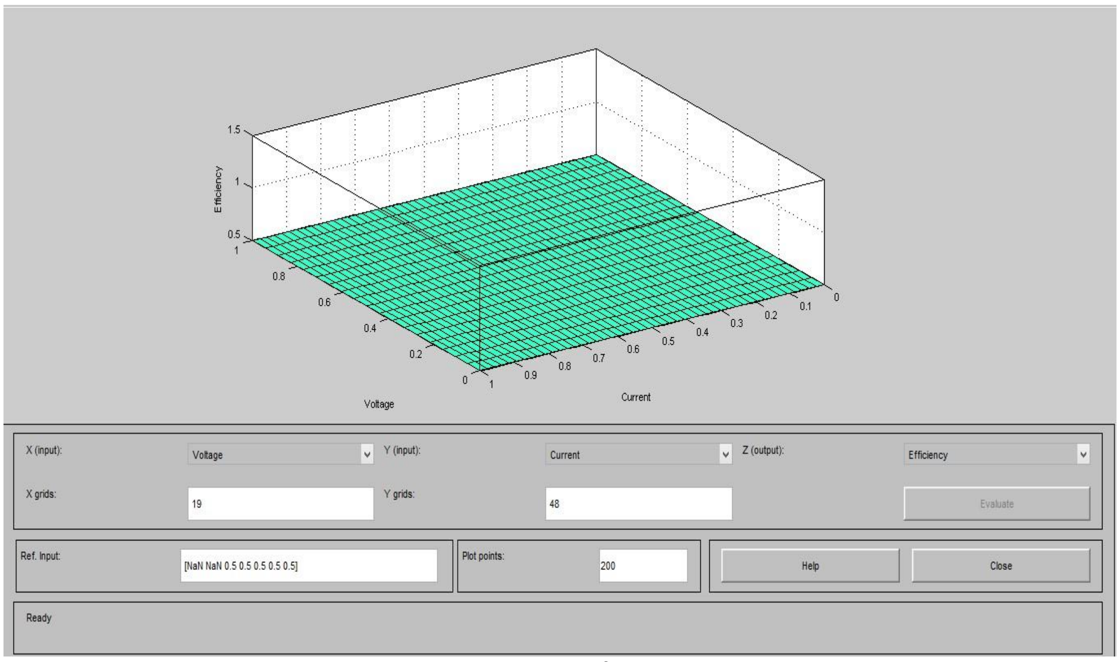

Fig-10. PEMCP Surface Viewer

7. Conclusion

Proton exchange membrane DC/DC fuel cell conversion process is a non-linear process because fuel cell parameters are changed when it is used to transfer energy to the grid station. In this paper, an intelligent proton exchange member DC/AC fuel cell conversion system is proposed to improve the power quality and then transfer the quantified energy to the grid station. In DC/AC converter, we have used Genetic Algorithm (GA) to find the optimal hydrogen and oxygen partial pressures to minimize the objective functions and to control the voltage stack in the PEMPC system. In PEMPC system, we have also used fuzzy logic controller to modify the hydrogen flow feedback signals on the basis of input parameters such as error and change of error. At the end, we have simulated PEMPC system to check efficiency, stability and durability of DC/AC converter after using genetic algorithm and fuzzy logic controller.

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