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CONTROL TECHNIQUE FOR PEMFC BASED ENERGY SYSTEM

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ABSTRACT

Fuel cells play an important role in renewable energy systems. It is the main power source for portable and standalone applications. Proton Exchange Membrane Fuel Cell (PEMFC) is the most emerging fuel cell. Variation in input and load results in output variation of PEMFC. So, PI control technique is suggested to control the fuel cell output. This paper focuses on mathematical modelling of PEMFC and applying control technique to overcome the stated problem and demonstration through simulation using MATLAB and Simulink.

KEYWORDS: *PEMFC, MATLAB and Simulink, Renewable Energy Systems, PI*

Article History

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1. INTRODUCTION

Safe, clean, low cost and reliable energy supply is essential requirement for Economic growth and development of human beings. In few years conventional energy sources like fossil fuels will be depleted which affects global economy. So renewable energy sources are gaining more concentration in power generation. One among them is the fuel cell, which is becoming more popular as they provide uninterruptible power supply throughout all the seasons. Benefits of hydrogen fuel cells are less noise and high-power quality. Fuel cell-based systems have clean and efficient energy conversions. The characteristics of fuel cells are “1) High energy density 2) zero gas emission 3) internal losses of a fuel cell is more for a low frequency ripple current4). Output of a fuel cell is around 0.7V5). The dynamic performance of a fuel cell is poor, for high output currents, with “dropping of output voltage and slow response” [5] [10]. Fuel cells are more suitable for vehicular applications as they provide high power density and less operating temperature [7]. Moreover because of more efficiency and less emission” fuel cells form agreeable selection for energy sources. Usage of Power electronics in fuel cell systems make possible to use fuel cell in many applications. Fuel cells are popularly known as the “microchip of the hydrogen age”. PEMFC is an electrochemical device which produces electricity by using oxygen and hydrogen as fuel. Converter transfers dc voltage properly from fuel cells to loads. PEMFC is estimated as important remedy for existing ecological issues, as it produces “almost zero emission, operate at low temperature and respond quickly as load changes [8]”. Because of “low noise, quick start up, robustness, high efficiency, low operating temperature PEMFC are suitable for stationary and transportation applications [1][6][9]. Because of low voltage output characteristic, there is a need of “high step-up DC-DC converter” in Fuel Cell based Energy System. Increase in load decreases the fuel cells output voltage.

Mathematical modelling and simulation are necessary tools for fuel cell stack design and fuel cell power systems. Constant output voltage of PEMFC can be achieved by using many control techniques [12].

Section 2 gives explanation about Mathematical modelling of PEMFC**,** Section 3 mentions about Boost Converter Modelling, Section 4 indicates about PI Controller tuning, Section 5 about Simulation results, Conclusion and future scope has been discussed in Section 6.

2. Mathematical Modelling of PEMFC

PEMFC has anode and cathode electrodes. Hydrogen and oxygen are the basic fuels. At the electrodes chemical reactions takes place, this results in production of electricity.

In PEMFC there are three main sources of losses. They are Activation losses, Ohmic losses and Concentration losses. Hence the output voltage of a single cell E_{cell} is

$$E_{cell}=E_{Nernst}-V_{act}-V_{ohmic}-Vcon \quad (1)$$

Where

$$E_{Nernst}=1.229-8.5x10^{-4}x(T-298.15)+4.3085x10^{-5}xTx(\ln P_{H2}+0.5\ln P_{O2}) \quad (2)$$

$$Vact=-[\xi_1+\xi_2T+\xi_3T\ln(C_{O2})+\xi_4T\ln(I)] \quad (3)$$

Where

$$C_{O2}=P_{O2}/5.08X10^6Xexp(-498/T)$$

$$V_{ohmic}=I(R_m+R_c) \quad (4)$$

Where

$$R_m=r_m xl/A$$

Where

$$rm=\frac{181.6[1+0.03\frac{I}{A}+0.062\left(\frac{T}{303}\right)^2\left(\frac{I}{A}\right)^{2.5}}{\left[\lambda-0.634-3\left(\frac{I}{A}\right)\right]\exp[4.18(\frac{T-303}{303})}$$

$$V_{con}=-B\ln(1-\frac{J}{Jmax}) \quad (5)$$

$$\frac{I}{A}=J$$

A stack voltage with n cells is given by the equation

$$E_{stack}=nE_{cell} \quad (6)$$

Output power is given by the equation

$$P_{stack}=E_{stack}I \quad (7)$$

The efficiency is

$$\eta=\frac{E_{cell}}{E_{Nernst}} \quad (8)$$

Table 1: Parameters for PEMFC

Parameter	Description
n	Number of cells in a stack
Vact	Activation Voltage loss
V_{ohmic}	Ohmic loss
V_{con}	Concentration loss
T	Temperature of stack /K
A	activation area/cm^2
l	membrane thickness /µm
P_{H2}	Hydrogen Pressure/atm
P_{O2}	Oxygen Pressure/atm
B	coefficient for computing Vcon
λ	membrane moisture content
ξ_1,ξ_2,ξ_3,ξ_4	curve fitting parameter
C_{O2}	Concentration of oxygen at cathode (mol/cm^3)

2.1 Boost Converter Modelling

The input voltage is boosted up by using this converter [3]. This is also called as "Step Up Converter". There will be complement in function between diode and MOSFET during switching process.

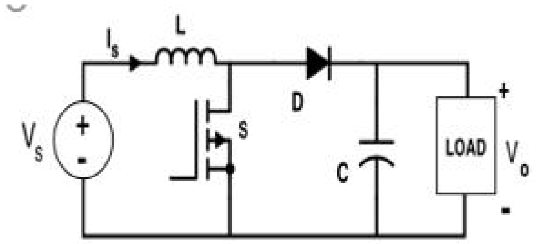

Figure 1: Boost Converter Circuit Diagram.

Also it possesses storage elements such as capacitor and inductor. The inductor voltage and capacitor equations are given below [11]

$$V_{L=}L\frac{di_l}{dt} \quad (9)$$

$$i_c = C\frac{dV_c}{dt}(10)$$

During the switching process, i.e.

Case (i) When MOSFET is in "**ON**" condition

$$Vs=V_L \quad (11)$$

Case(ii) When MOSFET is in "**OFF**" condition

$$-V_{out} +Vs =V_L \quad (12)$$

Inductor current is given by the equation

$$i_{L=}\frac{1}{L}\int V_L dt \quad (13)$$

The current through capacitor can be obtained by the equation

$$i_C = i_{L-}i_R \quad (14)$$

$$V_C = \int i_c dt \frac{1}{C} (15)$$

Boost converter duty cycle is given by

$$1 - \frac{V_S}{V_0} = D \quad (16)$$

2.2 PI Controller Tuning

PI controller tuning is simple method to achieve stability of the system and to obtain desired system's output response. The following steps are used for PI controller tuning

- Start to set Ki parameter to zero.
- Increase **Kp** parameter until system start to be unstable.
- This gives the maximum stable **Kp** parameter that must stay below an half of this value.
- Finally, increase progressively the **Ki** parameter, and decrease of the same amount the **Kp**.

3. Simulation Results

By using Matlab and Simulink, PEMFC and Boost converters are modelled and results are tabulated.

3. 1. PEMFC Characteristic Curve

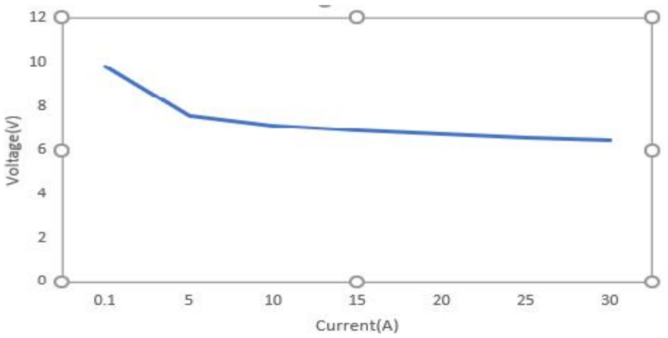

Figure 2: Polarization *Curve* of PEMFC.

Figure 2 gives the voltage verses current characteristic of PEMFC i.e. polarization curve of PEMFC for operating temperature 298.15K.From the above figure it is clear that increase of load current decreases output voltage of PEMFC.

3.2 Effect of Variable Load on Output of PEMFC Boost Converter Energy-Based System

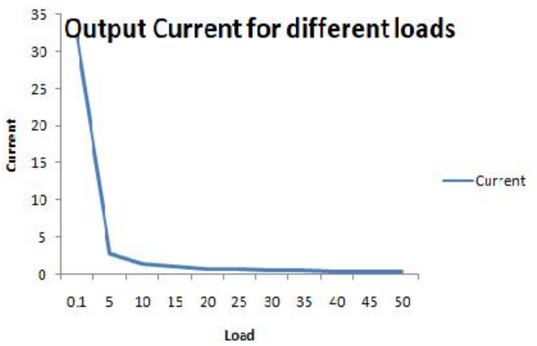

Figure 3: Output Current for Variable Loads.

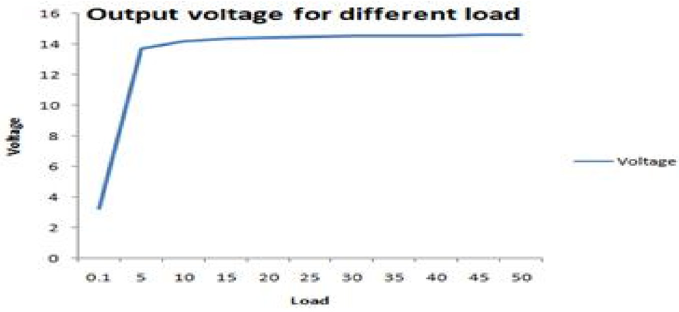

Figure 4: Output Voltage for Variable Loads.

Figure 3 and 4 shows the output voltage and current of PEMFC Boost Converter energy-based system for variable loads. Increase in load decreases the output current and increases the output voltage.

3.2 For Variable Load without PI Control Technique

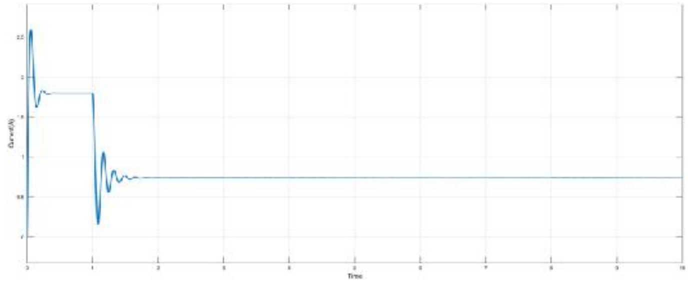

Figure 5: Fuel Cell Current for Variable Load without PI Controller.

3.3 For Variable Load with PI Control Technique

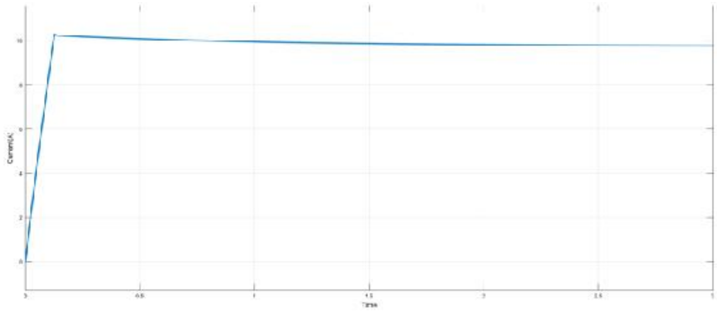

Figure 6: Fuel Cell Current for Variable Load with PI Controller.

Figures 5 & 6 show PEMFC current for variable load without PI and with PI controller respectively. From the above figures it is clear that with the implementation of control technique such as PI there will be gradual and smooth rise of fuel cell current to reference value.

4. CONCLUSION

Fuel cells are playing vital role in renewable energy systems as fossil fuels are depleting in few years. Among different types of fuel cells, PEMFC is gaining more interest because of low noise, quick start up, robustness, high efficiency zero emission, operate at low temperature and respond quickly as load changes. In PEMFC applications, huge step-up ratio, small ripple input current can be on obtained by using dc to dc conversion. Presence of input ripple current results in hysteresis power losses in the fuel cell stacks. [2]. Simulation results show that variable in load results in variation in fuel cell constant voltage. These drawbacks can be overcome by using control technique such as PI controller.

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