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3D Sensitive Modeling of PEM FC for Automotive Applications

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ABSTRACT – In recent years, the faults diagnosis in PEMFC becomes challenging issues in order to increasing performance of FCEV. In fact, the occurrence of faults on different operation conditions into the FC unavoidable thus, lead up to malfunctions in the FCEV and consequently reduces its performances. The main purpose of this paper is to propose evaluated the faults effect on stack PEM fuel cell on diving cycle test and with regard to various operation conditions in 3D dimension sensitive model.

INDEX TERMS– fault diagnosis, driving cycle, PEM fuel cell.

1. INTRODUCTION

Over the last years, the excessive increase of the number of automobiles in use around the world has caused serious problems for environmental and human life. As the matter of fact, the use of internal combustion engine vehicles leads to increase of the greenhouse effect, responsible of global warming [1]. In Table I, an assessment of exploitation duration of fossil resources is given basing on BP statistical review of world energy [2]. In order to cope with air pollution problems and the depletion of the Earth's petroleum resources [2], FCEVs seem to be the most promising vehicles in the future by providing clean and enabling zero emission transportation.

Fossil resources	Oil	Natural gas	Coal
Exploitation duration	53 years old	56 years old	109 years old

FCEV consist of many components (FC, DC/DC converter, motor, DC/AC inventor, etc.). Indeed, FC as main power source in FCEV is essential role for generating energy. But, FC is electro chemical power source consist of many components, including catalysts, catalyst supports, membranes, and gas diffusion layers (GDLs), bipolar plates, sealing, and gaskets. Each of these components can degrade or fail to function, thus causing the fuel cell operation conditions. In previous works, a thorough study on characterize different faults by the means of variations of the different resistances and capacitors of this circuit according to the variations of temperature, pressure and humidity for diagnosing and localizing faults in the sensitive model of the PEMFC [3]. Starting from this study, focuses on faults diagnosis based on driving cycle with different operation conditions into the FC automotive application. The durability and life time of FC is affected by many parameters, including the material properties, fuel cell operating conditions (for example various humidification, temperature, pressure, etc.), impurities inlet gases, environmental conditions (e.g., subfreezing or cold start), operation modes (such as start-up, shut-down, potential cycling, etc.) But, the most important degradation is due to driving cycles of the real vehicles allowing to considering the actual operation conditions during FC work. [4,5]. Due to uneven distributions of temperature, humidity and pressure the FC could be affected by voltages losses such as ohmic, activation, concentration and Nernst voltage. This paper focus on faults sensitive modeling in 3D dimensions of a PEMFC stack. The proposed model is validated on two real measured driving cycles. In the following, the faults in PEMFC due to different operation condition are represented in section I. Then a review of faults diagnosis on the basis of different operation conditions is introduced in section III. Afterward, 3D sensitive model and validation study of this model on the basis of different measured driving cycles is represented in section III.

2. FAULTS IN PEM FC ACCORDING TO OPERATION CONDITION

PEM FC is electro chemical system that based on electro-catalytic reaction, hydrogen oxidation in anode side and oxygen reduction at cathode side. FC operations depend on many phenomena that occurred in FC. Some of these phenomena common source fault in FC. Specifically, Improper water management (flooding, Drying) [6], catalyst degradation and fuel starving [7], membrane electrode assembly (MEA) contamination [5], different faults happened in FC. These faults causes to voltage drop and reduce life time of a fuel cell. Indeed, different operation conditions causes to be occurred of these faults. Fig.1. shows a simplified scheme for process fault classification with several levels of information processing. The lower level contains the processing data indeed, data of system collected with sensors. Faults extracting from healthy mode and faulty mode can be assigned to a medium level. The higher level is belonged to faults classification in order to distinction different faults in the system [9].

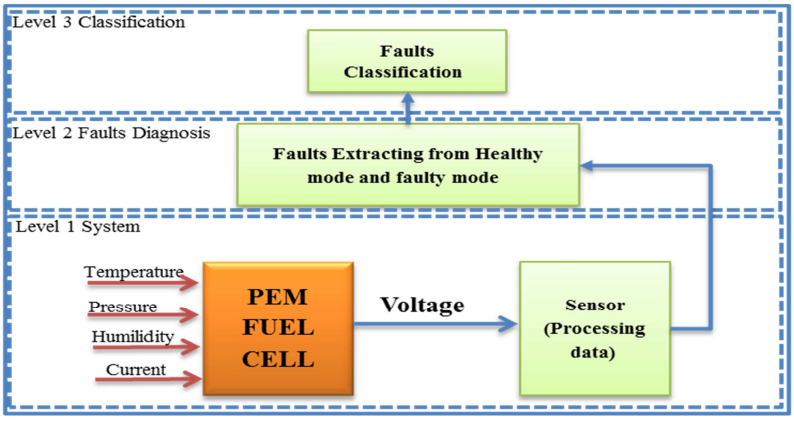

Figure 1. Faults classification process in PEM FC.

Moreover, fuel cell performance degradation can be occurred under different operating condition, for instance, variations temperature, humidity and pressure. FC function generally improves with raise temperature. But, increase of temperature has negative effect in Nernst voltage. [10]. However, increase temperature results to reduce of activation and concentration losses. It is obviously that voltage gain with increased temperatures [11], [12]. It should be noted that rising of internal temperature of the FC make reduce of performances and irreversible damage of the FC. Increasing humidity cause to improve of the conductivity in membrane therefore, FC performance will be improved.[3] The aim of the raising the pressure is because of increasing of FC voltage. FC is operated at ambient pressure (1 bar) or it may be pressurized. A FC potential voltage is improved when the pressure is increased.

3. 3D FAULT SENSITIVE MODELLING OF PEMFC

Besides, during the operation conditions performance of each cell have different values. Because of, the temperatures are distributed inhomogeneous during the z axis; various factors are affected such as, contactor resistance and heat conduction from one cell to another cell. Hence, stack temperature in middle of the stack have highest values to the sides. In addition, based on interior design of each cell and uneven distribution of the gases during the stack length, the pressure will be dropped. Consequently, each cell has different voltage values due to, taking place in the FC stack (z axis). As illustrated in Fig.3 experimental measurements of a PEMFC stack voltage and current have been compared to simulation and experimental results. In this test the PEMFC supplied an electronic active load reproducing the power of the DC-bus of an electrical vehicle during a real driving cycle.

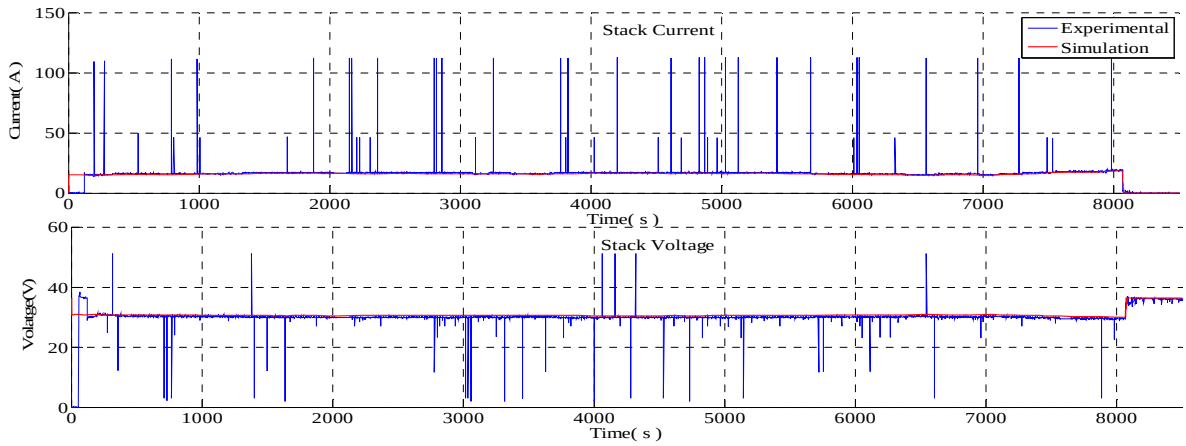

Figure 3. Stack voltage of FC

$$C\frac{d_{VC}}{dt}+\frac{V_C-V_o}{R_{act}+R_{con}}=i_{cell} \tag{1}$$

$$V_{fc}=E-V_c-i_{cell}R_{ohmic} \tag{2}$$

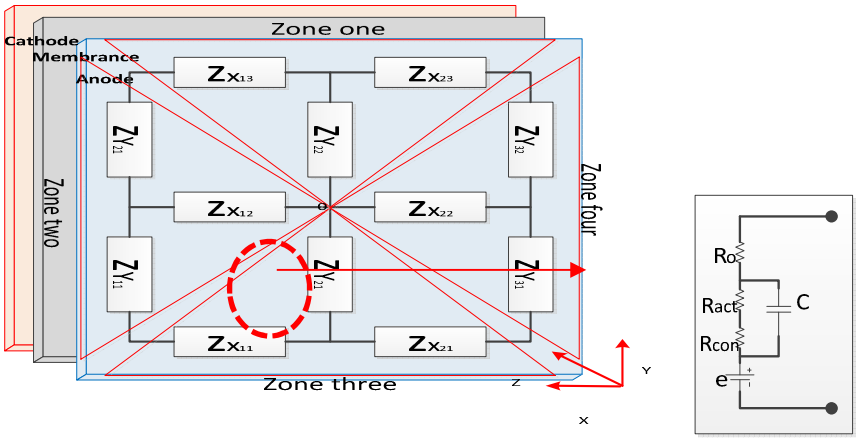

Figure 4. Elementary cells in one cell of the PEM FC (2D model).

In order to, consider the effect of operation conditions in z axis new model are introduced as illustrate in Fig.5. Sensitive model are used by adding new element in z axis from each node to adjacent cell node that demonstrate changing voltage drop in each cell based on the variation of operation conditions (pressure, humidity and temperature).

It should be noted that voltage Nernst and voltages losses change due to variations of operation conditions (Temperature, Humidity and pressure). As explained above faults diagnosis are considered in x and y axis in pervious articles [3]. But in this paper z axis have been determined in the both healthy and degradation mode. As shown in Fig.6 temperature in middle of stack has 5 °C warmer than two sides. Thus, in middle of the stack FC performance according to variations of temperature and pressure have different values compare to other sides.

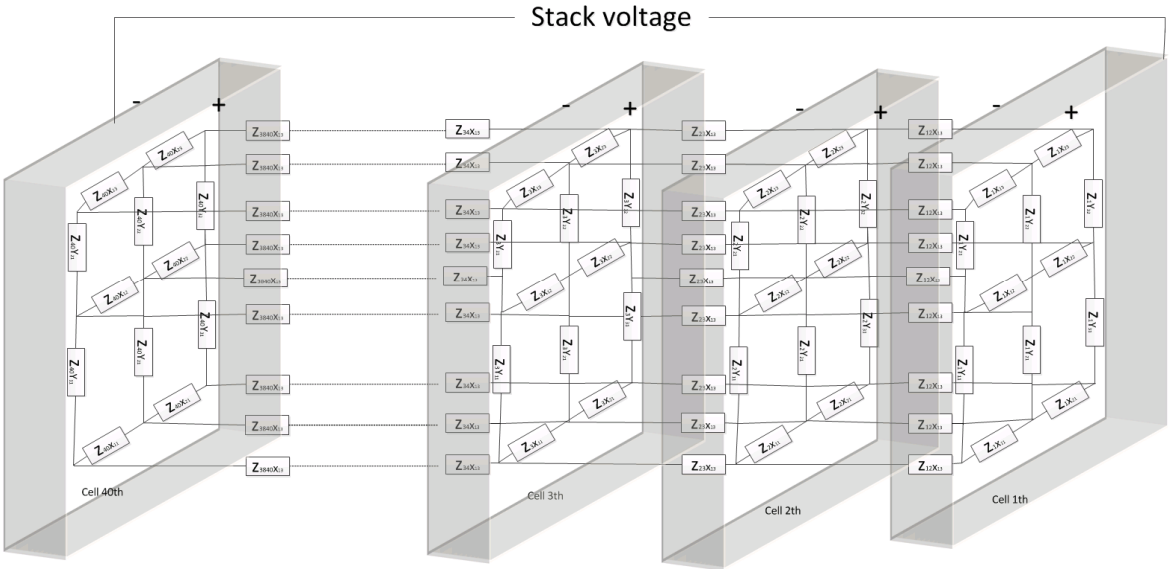

Figure 5. Stack PEM FC based on elementary cell in three dimensions (3D).

4. CONCLUSION

The purpose of this work is to present a fault sensitive modeling approach for PEMFC stacks taking into account the operation conditions in 3D of cell regarding to different driving cycles. Basing on the results obtained by simulation with a driving cycle, it has been noticed that a difference of 5°C temperature exists between the middle and the two extremities of the PEMFC stack. This means a lot of changing of the FC actual performances regarding to the rated values. Therefore, to evaluate this variation a new developed 3D model is proposed in this paper. In full paper more details about the modeling process, the model calibration, and how its use in healthy and faulty operating modes will be given. Also, Temperature, pressure and humidity will be taken into account in that investigation.

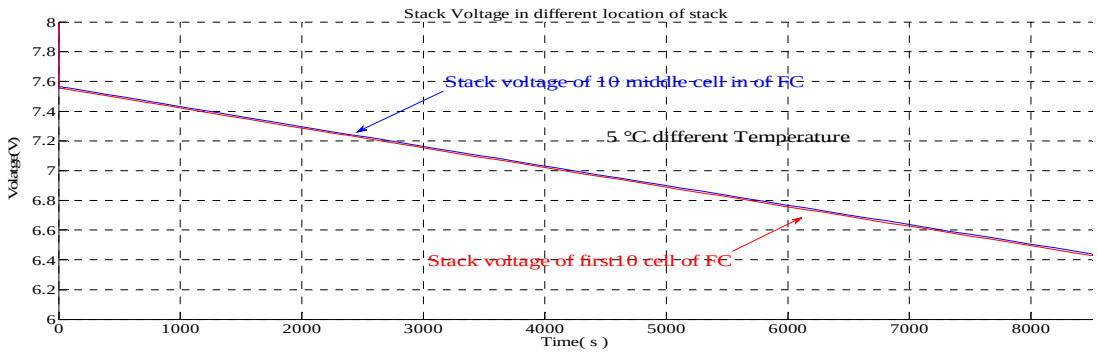

Figure 6. Stack voltage of the FC

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