Computational Fluid Dynamics Analysis of Permeable Membrane Electrolyte Fuel Cell System For Power Generation

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Abstract*- Now a days the transformation towards electric vehicles from the traditional fueled vehicles is most common. During this transformation engineers keep on doing research on the area of Electric Vehicles. The main theme behind the Electric Vehicle is the methodology or the process carried out behind the thermal storage system. The electricity which is the driving force for this electric vehicles plays an existing role for the production of electric current using Fuel Cell. When compared to Internal Combustion Engines Fuel Celled Vehicles (FCV) are more efficient and reliable to the users. The most commonly used fuel cell is polymer electrolyte membrane fuel cell where the membrane separates the anode and cathode. The electrons are forced to travel through an external circuit to perform work then recombine with the protons on the cathode side, where the protons, electrons, and oxygen molecules combine to form water. The work mainly focus on the analysis of the fuel cell using the CFD software to estimated the experimentation results and finally the results are validated. This working of Fuel Cell is analyzed using CFD analysis in ANSYS FLUENT and found out that the heat generation rate is higher at the interstitial points. The Computational Fluid Dynamics analyze the 3D fuel cell structure and results that the heat generation rate is higher at the interstitial points. In this paper the Thermal analysis of a designed Fuel Cell is thoroughly analyzed. The further extended future work is to reduce the heat generation rate by means of miniature Heat Pipe and to find out the efficiency of the Heat Pipe.*

Keywords- Fuel Cell ; CFD analysis; Heat Generation Rate; Heat Pipe ;Thermal Storage

I. INTRODUCTION

Considering the environmental problems caused by the use of fossil fuels, polymer electrolyte fuel cells (PEFCs) have become one of the most promising power sources with a wide range of applications due to its high electrical efficiency, fast start-up, no emission of pollutants and low operation temperature . However, there is still a long way to go before PEFCs get fully commercialized. This is mainly because of its life length and high cost issues. Transient possibilities of PEFC system is one of the key requirements for further advancements of PEFC technology, especially in the transportation sector, where the operating conditions generally change rapidly with time. Besides, a dynamic system model helps to test the system’s overall performance and may improve the coordination between each subsystem. It also allows researchers to get further insight and understanding of the highly nonlinear and coupled physical and chemical aspects of PEFC system, which would finally lead to cost and time reduction for PEFC development. Moreover, a deep understanding of PEFC’s dynamic response could be helpful for the system’s real time control design in practical automotive applications which would improve its performance further. Therefore, it is important to develop an effective system scale model, which is capable of charactering the dynamic properties of a PEFC system. Various models have been proposed to study the specific aspects of PEFCs, and a solid foundation for PEFCs’ system level dynamic modelling have been established. Proposed the empirical generalised steady state electrochemical model (GSSEM) to characterize the output voltage of PEFC as a function of current, which could be applied to cells with different characteristics, dimensions, etc. Developed a first principle dynamic PEFC model, where the dynamic equations are solved for a typical but simplified quasi-three dimensional geometric representation of a single cell repeat unit of a fuel cell stack. Presented governing equations of the transient behaviour of a PEFC, and showed the influence of the operating conditions on the internal parameters, especially the ohmic resistance. Discussed the behaviour and performance of a PEFC under fast load changes and it was shown that a fuel cell system can be used to produce electricity under load changes. Improved the small-signal modelling of a PEFC’s dynamic behaviour as an initial step toward prescribing internal design modifications and/or external controller designs to improve its transient behaviour, which allows for reducing energy storage and increasing the number of suitable storage technology options.Derived a semi-empirical equation to describe the performance curves of PEFCs, which is based on the observation.

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Then, it gives recommendation on how to improve the overall performance of the PEFC system by selecting proper gas as the cathode input in the real application. Additionally, the mass transfer of the water vapour was included, which further increase the understanding of the water behaviour inside the PEFC, i.e., it will finally help understand the water management.

The aim of this paper is to develop a complete system scale dynamic PEFC model, addressing the difference in system performance concerning different species in the cathode control volume. Notably, the temperature for two gas channels and the fuel cell body are separated in our model. The model is additionally modified to compare with the experimental data, studying start-up, power step-up and shut-down processes of a PEFC system. Our model is capable of characterizing the transient properties such as output voltage, reactant gases mass and pressure changes as well as channel/stack temperature changes. This rest of the paper is organized as describes the model assumptions and the development of the PEFC system model. The simulation results are analysed illustrates the model validation.

II. EXPERIMENTATION

A PEM fuel cell can be described as a static device that converts the chemical energy of a fuel directly, isothermally, and continuously into electrical energy. In this process, only the reaction between hydrogen and oxygen occur. The only by-products are water and heat. Similarly to a battery, a fuel cell consists of two electrodes (anode and cathode) and an electrolyte. Whereas a storage battery contains all the substances in the electrochemical oxidation-reduction reactions involved and has therefore a limited capacity, the fuel cell is supplied with its reactants externally and operates continuously as long as it is supplied with fuel. The basic scheme for a single cell is represented in Figure. 1 .

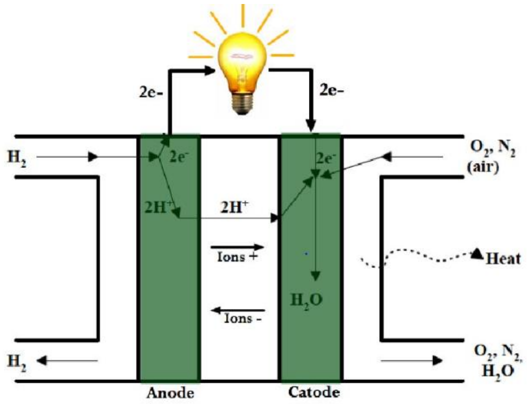

Figure. 1 Scheme of a single cell.

$H_2 \rightarrow 2H^{+} +2e-$

$2H^{+} + \frac{1}{2} O_2 + 2e \rightarrow H_2O$

$H_2 + \frac{1}{2} O_2 \rightarrow H_2O$

III. MODELLING OF THE PEM FUEL CELL

Many proton exchange membrane (PEM) fuel cell models have been investigated and presented in the literature. The process of selecting the fuel cell model needs to clarify what are the necessary features to take into account in the model .

The model selection differs for each application and user and the initial decisions are important to avoid changes later in the model evaluation process. The theoretical models are normally detailed, complex and usually require large computation time. The semi-empirical models give a general voltage-current relationship without examining in depth the physical and electrochemical phenomena involved in the operation. These models are usually characterized by simple implementation and faster simulation.

The electrical equivalent circuit represented Figure 2 corresponds to the semi-empirical model adopted for this study. This circuit is the electrical equivalent of the static and dynamic behaviour of the PEM fuel cell and includes the effects of the thermodynamic potential of the fuel cell and the losses. The represent the static behaviour of the PEM while the dynamics is represented. The capacitor C corresponds to the fuel cell phenomenon known as "charge double layer" on which the interface electrode/electrolyte acts as storage of energy element. The electrical power and efficiency are represented by respectively.

IV. POWER ELECTRONIC CONVERTERS FOR PEM FUEL CELLS

Power electronic converters are used in fuel cell systems to convert the DC electrical power generated by the fuel cell into usable AC or DC power through power electronic circuits. The power electronic converter plays an important role on the interface of the fuel cell system as power generating system and many solutions are already presented in the literature [14-30]. The output voltage of the fuel cell varies normally in the range of 20 V to 50 V and the possible converter topologies that can be used are such as; DC-DC together with DC-AC, DC-AC interfacing directly the fuel cell to the grid, or DC-DC together with AC-AC isolated by a transformer.

That the DC-DC power converters can be divided according to the operation mode into tree types: the linear mode, the switching mode and the soft switching or resonant mode. The main difference between them is caused by efficiency. The soft-switching or resonant has some advantages compared to the linear like; the high switching frequency, which enables the use of a small ferrite transformer core, it may operate in a much larger DC input voltage range than the linear regulators, and it often has a higher efficiency. However, there are some drawbacks associated too, the noise at the supply may be increased according to different power switching techniques, and the control circuitry is more complicated compared to the linear one. Figure 8 also shows that the switching-mode topologies are divided into two types, the isolated and the non-isolated. Non-isolated DC-DC converter topologies are the Buck, Boost and Buck-Boost converters; and further, the Cuk converter. For many applications, isolation between the input and the output is a necessary requirement within the converter. By inserting isolation transformers into the four basic non-isolated switching topologies presented above, four single-ended isolated switching DC-DC converters can be obtained, namely; Forward, Boost, Flyback and Cuk converters. Nonetheless, the single switch topology is not an ideal solution for higher power converters, since these converters need a higher power transformer. Therefore, another group of DC -DC isolated converters utilizing more than one switch are identified: Push-pull, Half-bridge and Full-bridge converters.

In switched-mode topologies, finite duration of the switching transitions will cause high peak pulse power dissipation in the devices, degradation of the converter efficiency and, also can lead to transistor damage during the turn-off transition. Employing load-line snubbers can reduce this problem. When using snubbers the stress of the switches are minimised, as However, with the appearance of new power electronic converters based on soft-switching technologies the reduction of switching losses and the continual improvement of power switches allow at being able to increase the switching frequency. In this type of converter the turning on and turning off of the converter switches appears when the switch voltage or the switch current is zero,

To create conditions for the converters, the resonance or soft switching approach can be used. The can be obtained by re-arranging the resonant component whose combinations offer several possibilities for resonant action as follows: If the parts are chosen so that are very small and have minimal effect on the circuit action. With and forming an series combination, the transistor operation can take advantages of current zero crossing. If the values of are small, then the transistor supports It is also possible to use all four parts to support action together, called multi-resonance, but this is not a common technique topologies can eliminate the switching losses at turn-off and reduce the switching losses at turn-on. If a relatively large capacitor is connected across the output diode during resonance, the converter operation becomes insensitive to the diode's junction capacitance. The major limitations associated with when Mosfet's are used are the capacitive turn-on losses. Thus, the switching loss is proportional to the switching frequency, during turn-on, considerable rate of change of voltage can be coupled to the gate drive circuit through the Miller capacitor, thus increasing switching loss and noise. Another limitation is that the switches are under high current stress, resulting in high conduction loss. eliminates the capacitive turn-on loss. It is suitable for high-frequency operation. For single-ended configuration, the switches could suffer from excessive voltage stress, which is proportional to the load. The output regulation of the and resonant converters can be achieved using variable frequency control. The Operates with constant on-time control, while operates with constant off-time control.

V. RESULT AND DISCUSSION

In this paper work the Computational fluid dynamics (CFD) is a branch of fluid mechanics that uses numerical analysis and data structures to solve and analyze problems that involve fluid flows. Computers are used to perform the calculations required to simulate the interaction of liquids and gases with surfaces defined by conditions. With high speed supercomputers,

Better solutions can be achieved. Ongoing research yields software that improves the accuracy and speed of Complex simulation scenarios such as transonic or turbulent flows. Initial experimental Validation of such software is performed using a wind tunnel with the final validation coming in full-scale testing,

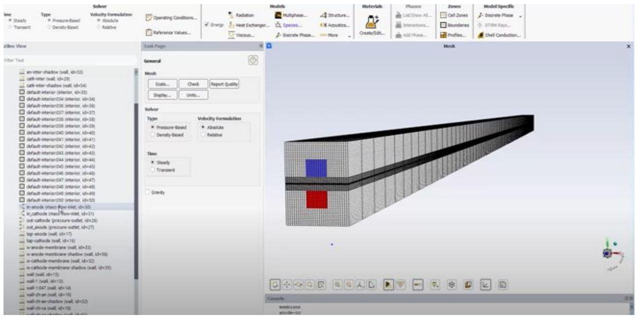

Figure 2. Modelling of PME's

Like solving any problem analytically, you need to define (1) your solution domain, (2) the physical model, (3) boundary conditions and (4) the physical properties. You then solve the problem and present the results. In numerical methods, the main difference is an extra step called mesh generation. This is the step that divides the complex model into small elements that become solvable in an otherwise too complex situation. Below describes the processes in terminology slightly more attune to the software

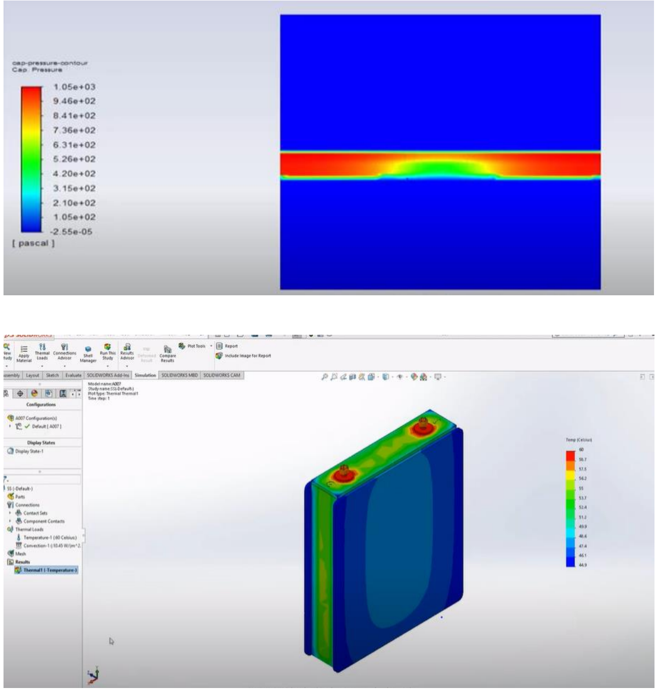

Figure 3. Heat transfer rate of PME's

Build Geometry Construct a two or three dimensional representation of the object to be modelled and tested using the work plane coordinates system within ANSYS.

Define Material Properties Now that the part exists, define a library of the necessary materials that compose the object (or project) being modelled. This includes thermal and mechanical properties.

Generate Mesh At this point ANSYS understands the makeup of the part. Now define how the Modelled system should be broken down into finite pieces. The figure 6.2 shows the geometry of meshing in ANSYS fluent.

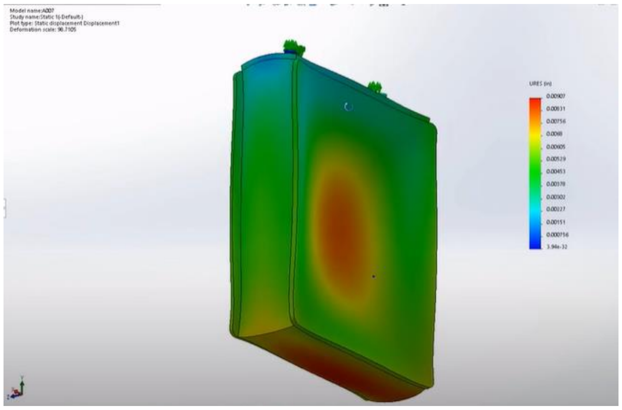

Figure 4. Heat transfer rate of PME’s

Define Boundary Conditions Once the system is fully designed, the last task is to burden the system with constraints, such as physical loadings or boundary conditions. Figure 6.3 shows the setup initialization in Ansys workbench for definingthe boundary conditions.

By using the formulae stated above the properties of nanofluid with base fluid mixture was calculated for different volume concentrations of nanofluid so they are entered as customized values according to the respective volume concentrations of the nanofluid as shown in the figure 6.7. These customized values of nanofluid properties helps the inlet fluid to flow over the complete radiator design in the steady flow process so that the total heat conducted from the fluid to the surface of the radiator walls can be analysed using the Ansys Fluent Software.

The main boundary condition include, a mass flow rate inlet boundary condition where used in the inlet nozzles. The cylindrical shaped geometries are the wall. At the outlet, the pressure outlet (atmospheric pressure) boundary condition was used. And all other portions are considered as the wall boundary with convective heat transfer surfaces

VI. CONCLUSION

This paper presents results from a three-dimensional, steady state, single-phase model of a PEM fuel cell that has been developed using the fluent CFD software as a basic tool. The fuel cell specific sub-models have been developed which incorporate the electrochemical kinetics and multi-dimensional fluid flow and multi-component species transport. Water management and electric fields under typical PEMFC operation conditions have been simulated. For the two test cases presented, reasonable predictions have been obtained for both the reactant distributions, including water formations across the cell as well as the cell potentials predictions. The model is now under further development to improve its capabilities and under going further validations. It is appreciated that the CFD modelling of fuel cells is, in general, still facing significant challenges due to the limited understanding of the complex physical and chemical processes existing within the fuel cell. However, with the further development of the modeling capabilities, the modelling of fuel cells using CFD techniques can be an important alternative to the experimental measurements in providing information that is critical to the fuel cell design and optimization.

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