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Simulation of PEMFC for Isolated Applications

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Abstract— **In this paper, the dynamics of a polymer electrolyte membrane fuel cell system is modelled, simulated and presented. Recent and Modern application of PEMFC is for uninterrupted power supply and stationary power generator. It is replacement of traditional methods of generation and also pollution free source. Matlab-Simulink™ is used for the modeling and simulation of the fuel cell system. Also, characteristic of 6kW PEM fuel cell system is obtained by simulation. Paper has made an attempt to use PEMFC for three phase load. PEMFC generation is converted in to three phase AC source using power converters. Simulation results which includes waveforms of current, voltage and power are presented in this paper. The analysis of stand alone applications of PEM fuel cell generator system can be achieved with this dynamic simulation model.**

***Index Terms*— Fuel Cell, Proton Exchange Membrane Fuel Cell, Simulation, uninterrupted, Power supply**

I. INTRODUCTION

Rapid growth in energy consumption during the last century on the one hand, and limited resources of energy on the other, has caused many concerns and issues today. Although the conventional sources of energy, such as fossil fuels, are currently available in vast quantities, however they are not unlimited and sooner or later will vanish. Moreover, environmental concerns, such as global warming, are becoming increasingly serious, and require significant attention and planning. Renewable energy sources are the answer to these needs and concerns, since they are available as long as the sun is burning, and because they are sustainable as they have no or little impact on the environment.

One technology which can be based upon sustainable sources of energy is fuel cell. Fuel cells are devices that directly convert the chemical energy stored in some fuels into electrical energy and heat. The preferred fuel for many fuel cells is hydrogen, and hydrogen fuel is a renewable source of energy; hence fuel cell technology has received a considerable attention in recent years. However, this is only one reason, among many reasons, for the recent come back to this technology.

Fuel cells can have higher efficiencies than more conventional devices that convert chemical energy into other forms of energy such as electricity. They are inherently simpler, and have other social, economical, and engineering advantages over other types of machines for energy conversion. PEM fuel cells are suitable for portable, mobile and residential applications. In most stationary and mobile applications, fuel cells are used in conjunction with other power conditioning converters. In the last decade a great number of researches have been conducted to improve the performance of the PEM fuel cell, so that it can reach a significant market penetration. Mathematical models and simulation are needed as tools for design optimization of fuel cells, stacks, and fuel cell power systems. In order to understand and improve the performance of PEMFC systems, several different mathematical models have been proposed to estimate the behavior of voltage variation with discharge current of a PEM fuel cell.

Development in the field is cited at [14] for use of PEM fuel cell for grid connectivity through inverter, transformer and ANN controller for improving efficiency of inverter. THD component is well below 5% making it suitable for grid interface as well as standalone application. [15] Discusses mathematical modelling and simulation of a PEM fuel cell based system for residential application. It explains it in two stages, 1st stage includes DC-DC converter with the input source as fuel cell and the 2nd stage includes a 1φ H bridge inverter which feeds the 1φ AC supply to load. Also [16] has proposed PEM fuel cell simulator composed of two parts, power circuit and control circuit. Digitally controlled DC-DC buck converter is proposed for main power circuit and control is performed by the micro controller PIC165877. Micro controller is in feedback loop for auto correction of output voltage. Thus paper has described realization of PEM fuel cell simulator.

Recent work highlights application of PEMFC as stationary generator for isolated application. It has obtained application of PEMFC for three phase load using power converter devices.

II. HYDROGEN FUEL CELL

Hydrogen fuel cell is defined as an electrochemical energy conversion device. It converts chemicals hydrogen and oxygen into water & in process generates electricity. Fuel cells are different from batteries in that they require a continuous source of fuel and oxygen/air to sustain the chemical reaction whereas in a battery the chemicals present in the battery react with each other to generate an electromotive force(EMF).

The most important design features in a fuel cell are listed below.

- The electrolyte substance. The electrolyte substance usually defines the type of fuel cell.
- The fuel that is used. The most common fuel is hydrogen.

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- The anode catalyst breaks down the fuel into electrons and ions. The anode catalyst is usually made up of very fine platinum powder.
- The cathode catalyst turns the ions into the waste chemicals like water or carbon dioxide. The cathode catalyst is often made up of nickel but it can also be a nanomaterial -based catalyst.

III. TYPES OF HYDROGEN FUEL CELL

Fuel cells come in many varieties; however, they all work in the same general manner. As the main difference among fuel cell types is the electrolyte, fuel cells are classified by the type of electrolyte they use. The main types of fuel cells are as follows:

- Proton Exchange Membrane Fuel Cell(PEMFC)
- Solid Oxide Fuel Cell (SOFC)
- Molten Carbonate Fuel Cell (MCFC)
- Phosphoric Acid Fuel Cell(PAFC)
- Alkaline Fuel Cell (AFC)

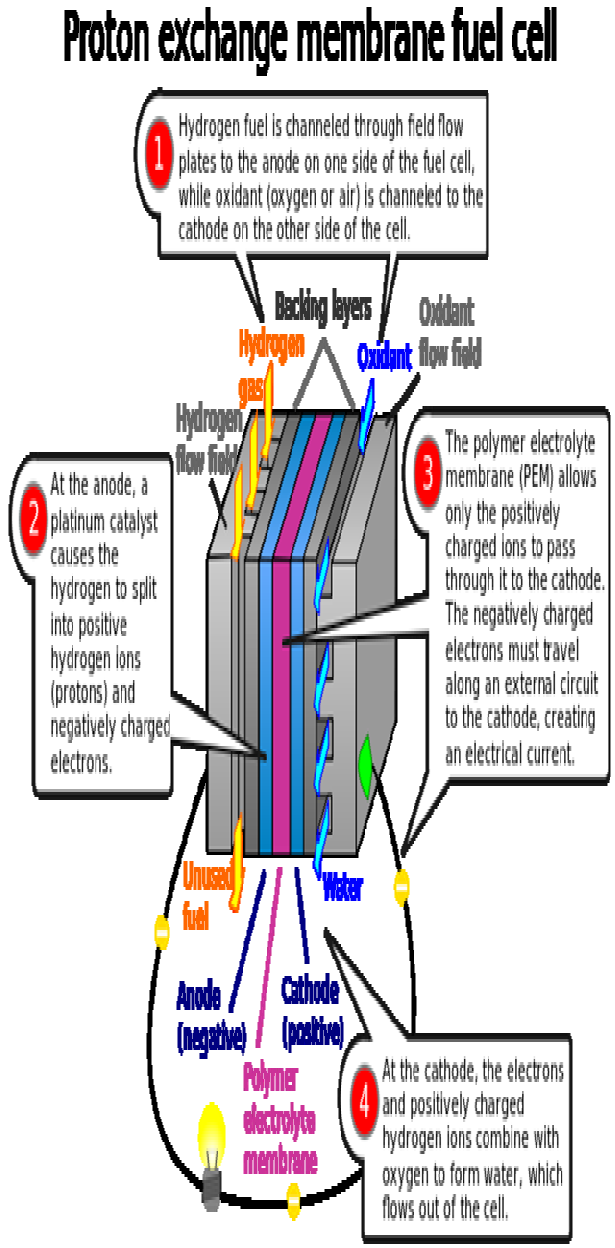
IV. PEMFC

In the proton exchange membrane fuel cell design, a proton-conducting polymer membrane (the electrolyte) separates the anode and cathode sides. The materials used for different parts of the fuel cells differ by type. The bipolar plates may be made of different types of materials, such as, metal, coated metal, graphite, flexible graphite, C–C composite,carbon–polymer composites,etc The membr ane electrode assembly (MEA) is referred as the heart of the PEMFC and is usually made of a proton exchange membrane sandwiched between two catalyst-coated carbon. Platinum and/or similar type of noble metals are usually used as the catalyst for PEMFC. The electrolyte could be a polymer membrane.

It has efficiency of 40 percent. It has operating temperature of approximately 80 degrees celsius. It can be used as backup power, portable power source, electrical vehicle, generation of power ,etc.

WORKING:

On the anode side, hydrogen diffuses to the anode catalyst where it later dissociates into protons and electrons. These protons often react with oxidants causing them to become what are commonly referred to as multi-facilitated proton membranes. The protons are conducted through the membrane to the cathode, but the electrons are forced to travel in an external circuit (supplying power) because the membrane is electrically insulating. On the cathode catalyst, oxygen molecules react with the electrons (which have traveled through the external circuit) and protons to form water.



ENERGY CONVERSION PROCESS

Hydrogen and oxygen are combined in a non-combustion process electricity, heat and water are produced.

$$2H_2 + O_2 \longrightarrow 2H_2O + energy$$

Reduction-Oxidation (redox) reactions takes place as follows:

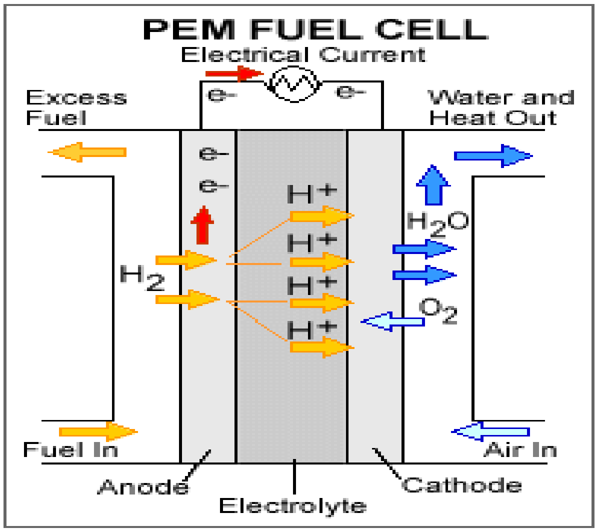
$\text{Reductant} \longrightarrow \text{Product} + e$: Oxidation- loss of electron (at anode)

$\text{Oxidant} + e^- \longrightarrow \text{Product}$: Reduction- gain of electron (at cathode)

The anode is the electrode where oxidation occurs and mass is lost whereas the cathode is the electrode where reduction occurs and mass is gained.

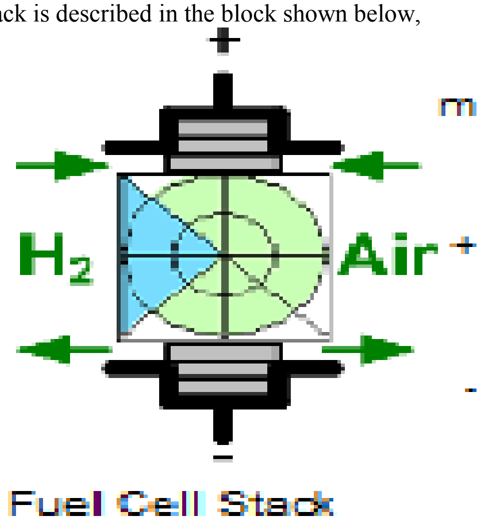
Anode : $2H_2 \longrightarrow 4H^+ + 4e^-$

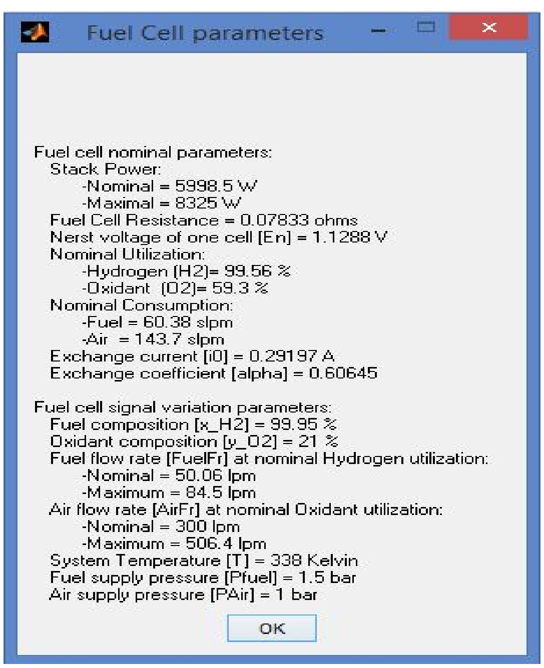
Cathode: $O_2 + 4H^+ + 4e^- \longrightarrow 2H_2O$



V. SIMULATION

Various parameters during the simulation PEM fuel cell stack is described in the block shown below,



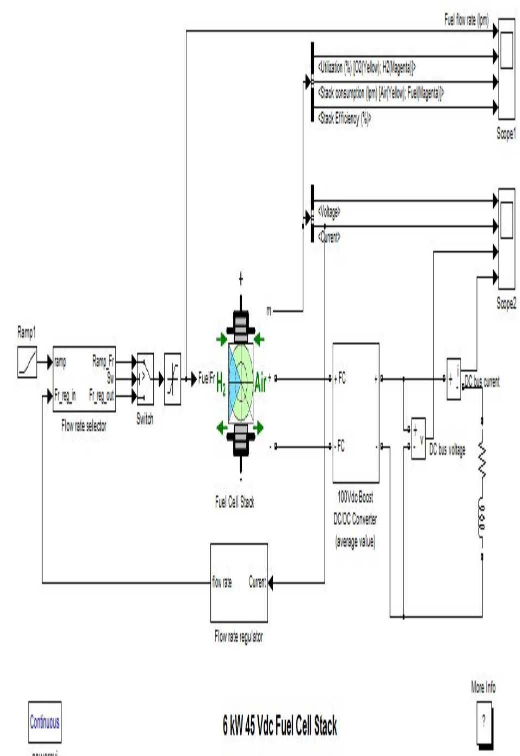


Here a 6 kW fuel cell stack is feeding a three phase load at 100 V. We used a 3 arm bridge MOSFET inverter to convert d.c. voltage into a.c. and a harmonic filter to reduce the harmonic content of the waveform. Then we used a three phase transformer to step up the voltage level to 100 V. Here we are using series R-L-C load.

MODEL ASSUMPTIONS

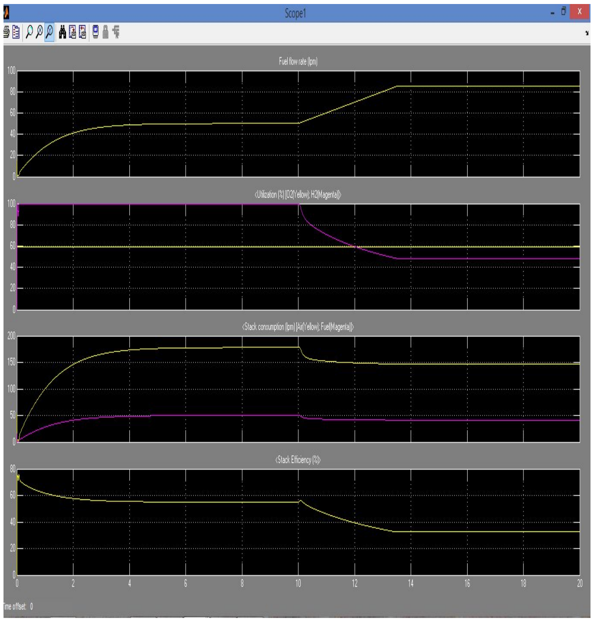
- The gases are ideal.
- The stack is fed with hydrogen and air.
- The stack is equipped with a cooling system which maintains the temperature at the cathode and anode exits stable and equal to the stack temperature.
- The stack is equipped with a water management system to maintain the humidity inside the cell at appropriate level at any load.
- The cell voltage drops are due to reaction kinetics and charge transport as most fuel cells do not operate in the mass transport region.
- Pressure drops across flow channels are negligible
- The cell resistance is constant at any condition of operation.

MODEL LIMITATIONS

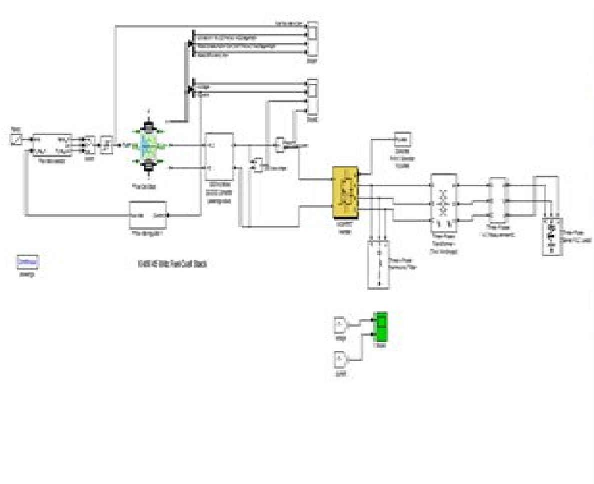


- Chemical reaction dynamics caused by partial pressure changes of chemical species inside the cell are not considered.
- The stack output power is limited by the fuel and air flow rates supplied.
- The effect of temperature and humidity of the membrane on the internal resistance is not considered.

The flow of gases or water through the membrane is not considered.

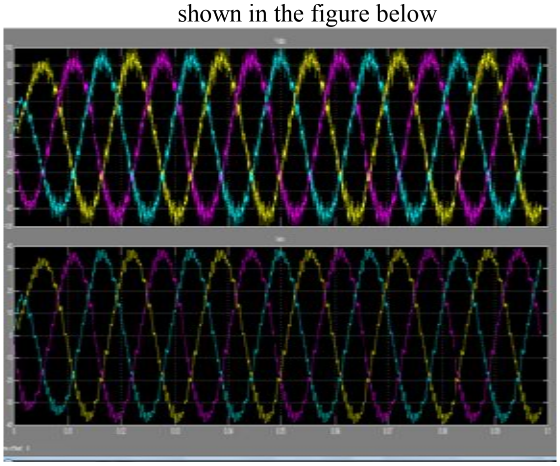


The simulation circuit for the three phase application of pem fuel cell is shown below.

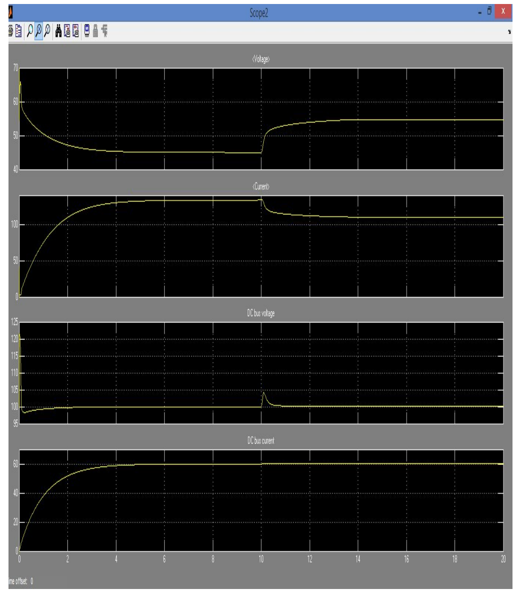


VI. RESULTS

Waveforms for voltage and current on the load side are shown in the figure below



waveforms for output voltage and current at pemfc are shown in the figure above



Waveforms for stack efficiency,utilisation of hydrogen and oxygen,flow rate and stack consumption of air and fuel are shown in the figure above.

CONCLUSION

In this paper the dynamic simulation of a PEM fuel cell system and simulation results are presented. PEMFC stack efficiency, the output current and the stack output voltage have been plotted. These results allow to foresee the behavior of the PEMFC stack and, more generally, its working conditions.

There are several issues to be solved before PEMFC can be properly commercialized. The first is the stable and economical supply of high purity hydrogen. the second is on the scale of the application object i.e. whether there is sufficient space for satisfying the first issue. The third is the existence of more efficient competitive power sources than the PEMFC system .

It is possible to conclude that the simulated PEMFC circuit here developed represents an useful tool which allows to evaluate, in the theoretical phase, the stack's behavior for different loads. Thus we can conclude that PEMFC can be applied for several ac and dc applications and also in some isolated conditions.

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