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Design and Simulation of Hydrogen PEM Fuel Cell

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Abstract- This paper prioritize on Hydrogen Proton Exchange membrane fuel cell. Modelling and simulation of Hydrogen PEM fuel cell. Currently, PEM has emerged because of its higher energy conversion efficiency. Hydrogen is an especially attractive fuel. It is least polluting fuel available, its output clean source of electricity and simply water. This paper will open the possibility of replacing the existing power generation sources with fuel cells.

Keywords- Fuel cells, Proton Exchange Membrane (PEM), Modelling, Simulation.

1.Introduction

Fuel cell is one in every of the potential renewable energy resources with its main advantage like higher performance energy conversion and bigger at environmental compatibility. As of other conventional energy convertors fuel cells are not only limited to a single power supply it has ability to use different types of fuels as hydrogen, propane, gasoline, methanol, ethanol. Amongst various sorts of fuel cell types –Proton Exchange Cell (PEM) are mostly taken into consideration because of its fast initialization, low operating temperature and at par efficiencies as compared to others. A gasoline mobile electrochemical power conversion tool which converts the chemical compounds hydrogen and oxygen in water and convey electricity. Fuel cells have the potential to produce an abundance of current and energy but are desirable for continuous flow of the required reactants. Modeling of fuel cells is a complex as it involves studying of heat, electrostatics, fluid dynamics, chemistry reactions, electrochemical reactions. Fuel cell is considered a future energy source for defence, automoive, telecommunications, automobile, etc.

2. Model of PEM Fuel Cell

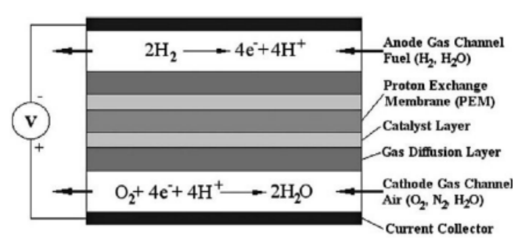
The primarily structure of a PEM fuel cell can be defined as two electrodes- cathode and an anode which are separated by solid membrane known as electrolyte. Fuel hydrogen flows from the anode, from where it seperates to protons that pass through the to solid membrane and then to the cathode and electrons and then collected by an electric current connected to an external circuit viz two electrodes.

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

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

Total cell reaction:

$2H_2 + O_2 \rightarrow 2H_2O$ + electricity + heat



The oxidant i.e air flows from channels to cathode in external circuit where oxygen combines with electrons. Electrochemical reactions occurring in the anode and cathode electrode of the PEM fuel cell shown above. The fuel cell is supplied with hydrogen and air but sometimes nitrogen is also used to supply fuel cell system, nitrogen is used as to clear the system. The pressure across the electrode is negligible as electrode are small enough. Electrons flow from anode to cathode providing loading energy, the cells are connected in series to form a stack which then carry out electricity. The polarization curve called as I-V is presented as to show characteristics of fuel cell.

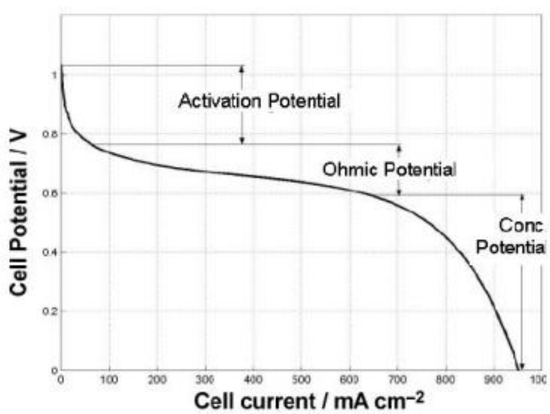


Fig: Polarization Curve

Fuel cell behaviour is non-linear and depends on the temperature, cell temperature, current density, pressure drop. The cellular voltage is inversely proportional to flowing current within. The ideal conditions of fuel cells are around 70-80 degrees and pressure at 3-5 atm.

3. Dynamic Modelling of PEM Fuel cell

A fuel cell comprises of a stack, reformer and power conditioning unit. Fuel cell input is hydrogen and output is DC power.

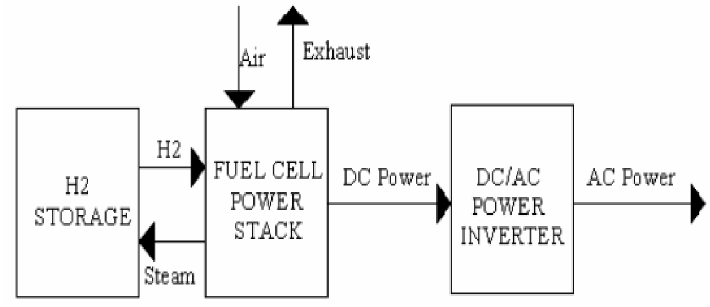


Fig : Fuel cell system components

In addition to the stack, sensible electrical cell systems require some sub-systems and other components; questionable crop balance (BoP) and stack, BoP builds a fuel cell system. The accurate arrangement of the BoP depends largely on the type of electrical cells, the choice of fuel and therefore the application. Additionally, specific in operating conditions and requirements for each cell and stack styles confirm BoP features. However, most cell systems contain:

• Fuel preparation- Several fuel cells using fossil fuels require pure processing, such as switching, when fuel is reacted with an oxidizing substance (usually steam or air) to form a hydrogen-rich anode mixture.

• Air provide- In most accurately cell systems, this includes air compressors or blowers and air filters.

• Thermal management- Cell stack temperature has to be cautiously managed by cell systems.

• Water management- Water is needed in some constituent of the cell, and total water can be a reaction product.

• Wattage acquisition instrumentality- Since cell stacks provide a differing DC voltage output that is usually ultimately usable for the load, wattage acquisition is usually needed.

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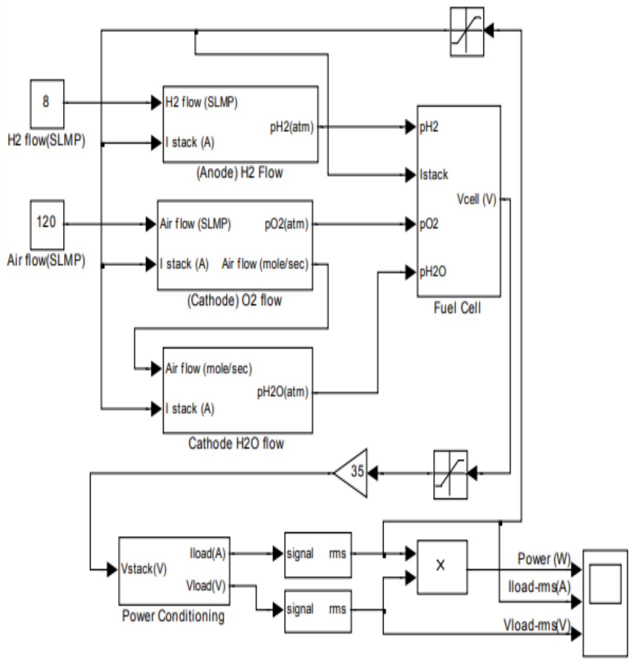


Fig: PEM fuel cell system block diagram

From V-I charasteristics of a fuel cell:

$$V_{cell} = E_N - V_a - V_c - V_{ohm} = V_{st} - V_{tr}$$

V_{cell} = output voltage

E_N =thermodynamic potential

V_a=activation overvoltage

V_c=concentration overvoltage

V_{ohm} =ohmic overvoltage

V_{st}=E_N – V_{ohm}, steady component

V_{tr}= V_{st}+ V_c, transient component

4. Simulation

Simulation of Fuel Cell to generate voltage in MATLAB | Simulink

$$v_{cell}(t) = \sum_{k=0}^{2} p_k (I_{cell} - I_{st})^k - \sum_{k=0}^{5} q_k \,(I_{cell} - I_{tr})^k - \left[\sum_{k=0}^{5} q_k (I_{cell} - T_{tr})^k - (I_{cell} - I_{tr})^k \right] (1 - e^{-t/T_c})$$

$$V_{st}(I_{cell}) = \sum_{k=0}^{2} p_k \,(I_{cell} - I_{st})^k$$

$$I_{st} = \sum_{m=0}^{N_{st}-1} \frac{I_{cellm}}{N_{st}}$$

$$V_{tr}(I_{cell}) = \sum_{k=0}^{5} q_k (I_{cell} - I_{tr})^k$$

$$I_{tr} = \sum_{m=0}^{N_{tr}-1} \frac{I_{cellm}}{N_{tr}}$$

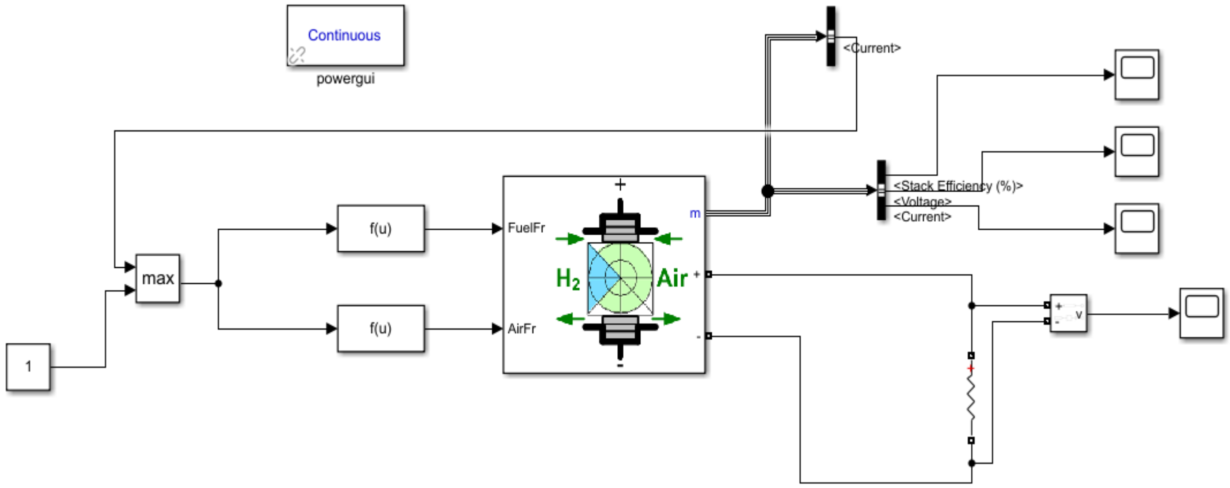
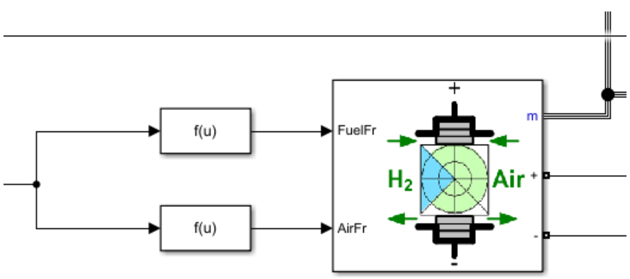


Fig: This is MATLAB model of fuel cell to generate voltage

This is fuel cell, fuel cell is basically a electrochemical cell that is used to convert chemical energy of fuel into electricity. How do we achieve that , so here it has been demonstrated in MATLAB.

Starting with Function Blocks:



Here, we will be entering expression w.r.t. fuel flow and air flow the input that we give is in particular order.

Function 1: For 1.36908036 atomic mass unit

6000*8.314*(273+95)*400*u(1)/(2*96485*(3*101325)*0.919*0.995)

Function 2: For 5.89420573 atomic mass unit

6000*8.314*(273+95)*400*u(1)/(4*96485*(3*101325)*0.5057*0.21), this is one of the most important aspect w.r.t matlab simulation.

Function 1 corresponds to 1.36908036 amu, if we search by this expression we will get the amount of atomic mass unit that is available and similarly Function 2 for air flow we will be entering 5.89420573 amu and expression corresponds to this 6000*8.314*(273+95)*400*u(1)/(4*96485*(3*101325)*0.5057*0.21).

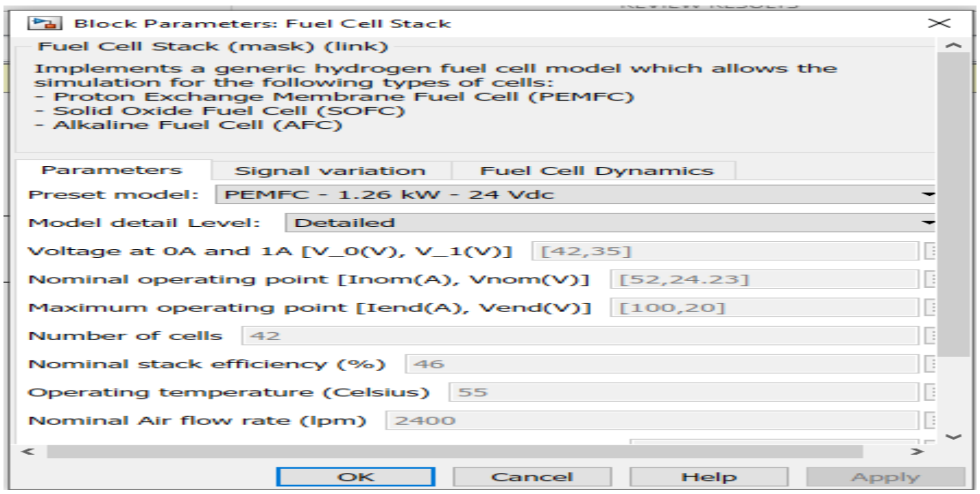
So consequently based on the atomic mass units it will be providing amount of electricity that is required. These atomic mass units that are given to fuel flow and air flow block will consequently given voltage of approximately close to 40%, will be cross checking that in MATLAB. Here, we will be doing comparative study between **PEMFC- 1.26 kW, 24Vdc** and **PEMFC- 6 kW, 45Vdc.**

The components are:

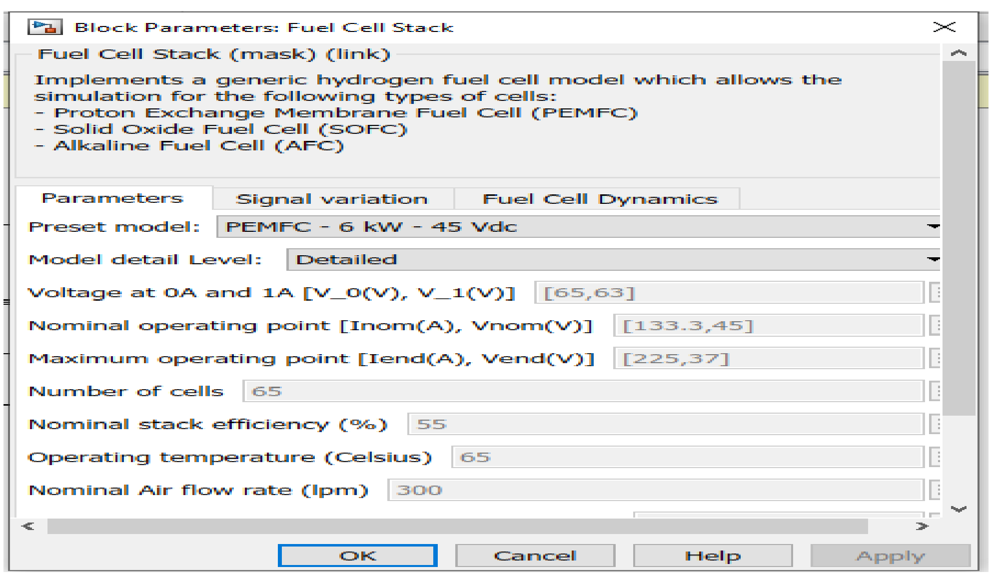
- Powergui
- Voltage measurement block
- Fuel cell stack

- min-max block
- constant block according to model that is simulated
- Bus Selector
- Series RLC branch(converted to resistive load)
- Scope-output waveforms

Based on our requirement-current, voltage and stack efficiency are placed on bus selector, therefore 3 outputs we are getting which are then aligned to scope to see the expected result waveform.



PEMFC- 1.26 kW, 24Vdc



PEMFC- 6 kW, 45Vdc

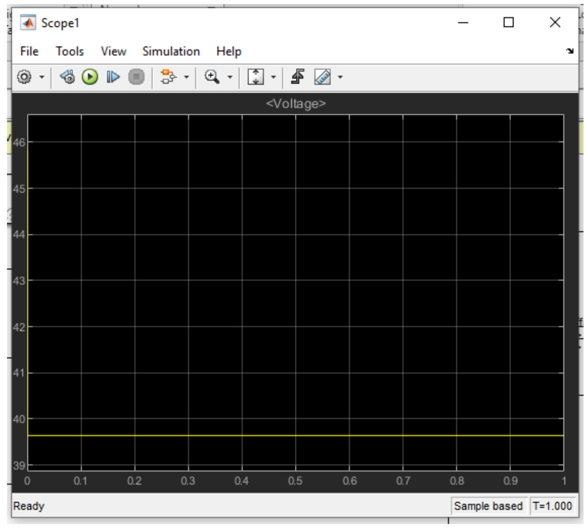
Bus selector is added to current only as to get the feedback signal. We are supposed to set PEMFC model w.r.t. what voltage we want and what power rating that it is supposed to be having.

We will be giving inputs w.r.t air flow rate and fuel flow rate via signal variation in Fuel cell.

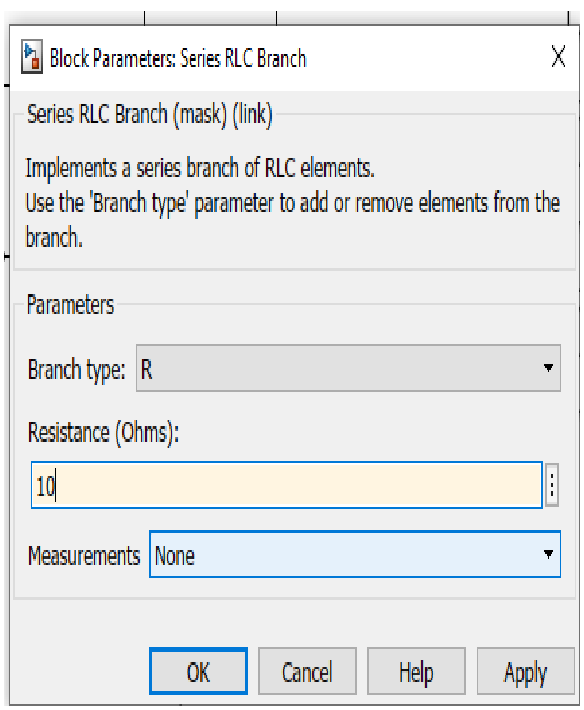
Resistance taken as 10 ohm.

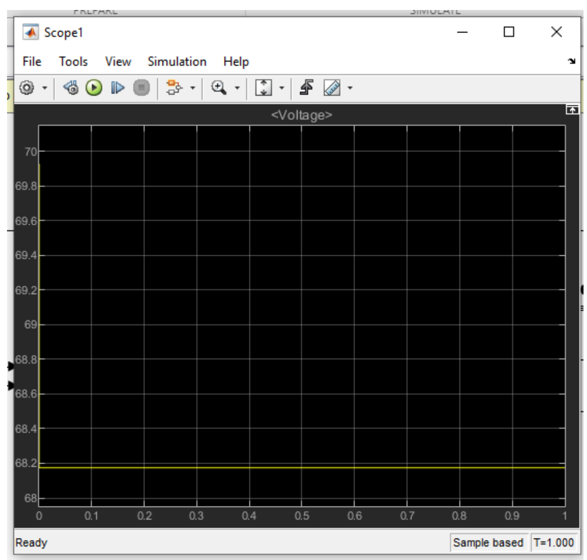
Once this is done the basic important aspect is the function block w.r.t. to fuel and air flow and based on that the MATLAB software will run code in background in order to Convert it to a specific voltage.

Here the comapative study has been done for PEMFC- 1.26 kW, 24Vdc and PEMFC- 6 kW, 45Vdc.



PEMFC - 1.26KW, 24Vdc



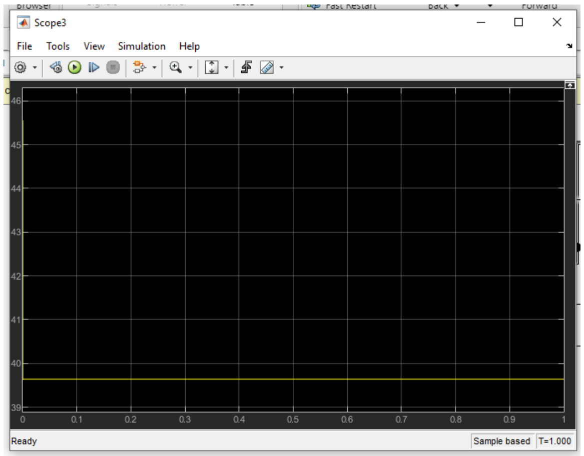


PEMFC - 6KW, 45Vdc

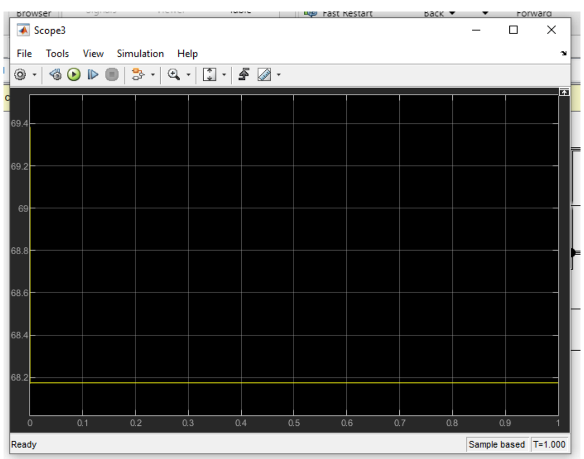
We can also check this w.r.t Resistive Load as well.

Fig: Voltage comparison between

Fig: Resistive Load Comparison between

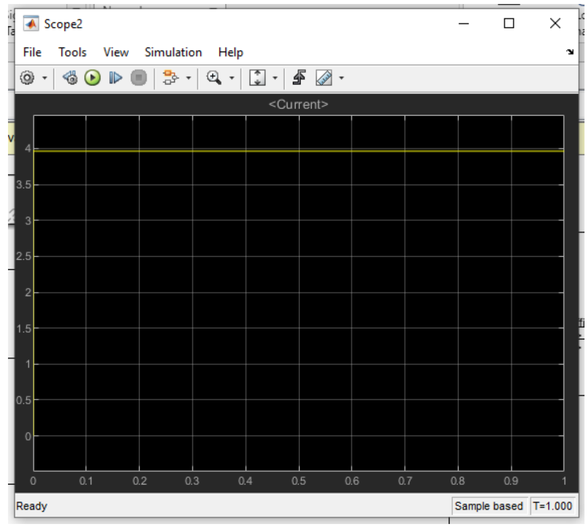


PEMFC - 1.26KW, 24Vdc

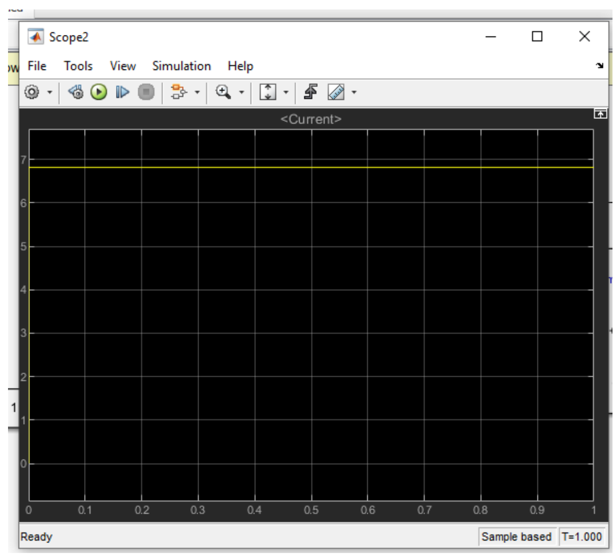


PEMFC - 6KW, 45Vdc

Fig: Current Comparison between



PEMFC - 1.26KW, 24Vdc



PEMFC - 6KW, 45Vdc

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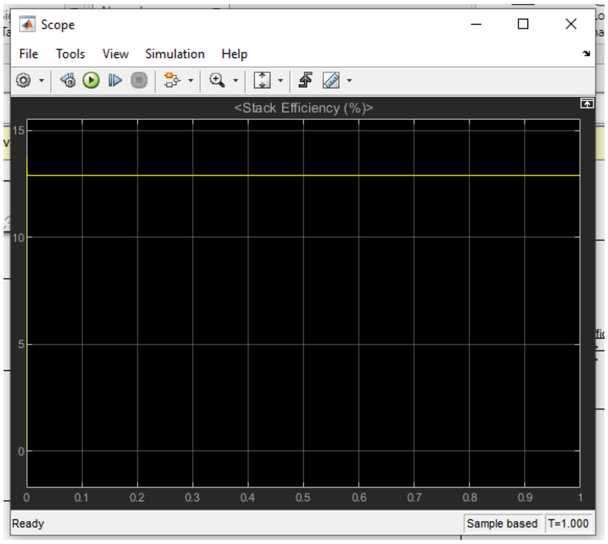
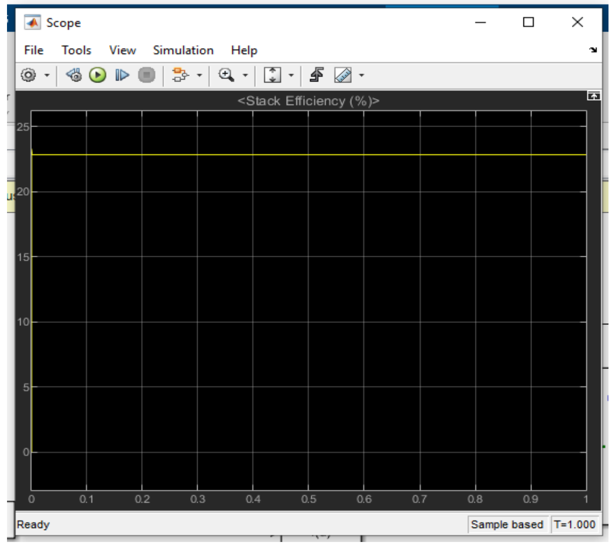
Fig: Stack Efficiency(%) comparison between



PEMFC - 1.26KW, 24Vdc



PEMFC - 6KW, 45Vdc

5. Conclusion

The paper describes Fuel cells, Proton Exchange Membrane (PEM), Modelling, Simulation study of a PEM cell system. The mathematical model of the cell system is designed for simulation and management analysis. Overall satisfactory results are achieved. Simultaneous analysis of flow changes by the mathematical model itself is currently being performed and therefore the results are being investigated to analyze the stability and management of the system. As a results of this study PEM cell system is appropriate for distributed generation. A comparative case study of PEMFC - 1.26KW, 24Vdc and PEMFC - 6KW, 24Vdc has been done using MATLAB Simulink.

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