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Experimental performance characteristics of 1 kW commercial PEM fuel cell

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Abstract. The aim of this paper is to analyze the performance of commercial fuel cell (rated capacity 1000W) with the help of resistive load and output power variation with change in H_2 flow rate and calculate the maximum power point (MPP) of the proton exchange membrane (PEM) while changing AC and DC load respectively. The factors influencing the output power of a fuel cell are hydrogen flow rate, cell temperature, and membrane water content. The results show that when the H_2 flow rate is changed from 11, 13, and 15 Lpm, MPP is increased from lower to higher flow rate. The power of the fuel cell is increased at the rate of 29% by increasing the flow rate from 11 to 15 lpm. This study will allow small-scale industries and residential buildings (in remote or inaccessible areas) to characterize the performance of PEMFC. Furthermore, fuel cell helps in reducing emission in the environment compared to fossil fuels. Also, fuel cells are ecofriendly as well as cost effective and can be the best alternative way to convert energy.

Keywords: hydrogen flow rate; MPP; PEM fuel cell; performance characteristics

1. Introduction

Fuel cells generate electricity and heat during electrochemical reaction which happens between the oxygen and hydrogen to form the water Nowadays, Fuel cell systems are widely used in both small and large-scale applications, including combined heat and power (CHP) systems, Portable power systems, portable computers, and military communication equipment are all examples of mobile power systems (Mekhilef *et al*. 2012). It has been depicted as the substance designing strategy for delivering energy is produced by electrochemical redox reactions that occur at the cathode and anode of the battery The power module ensures a low-polluting, highly efficient energy source that may be designed to employ an almost infinite amount of fuel excess. In contrast to sustainability, the transformation of the world's energy supply from wood to natural gas in the mid-nineteenth century. These transitions are in line with predictions of energy sources as a tool for long-term economic growth, based on the idea that there will come a time when global the battery, it is intended for the constant recharging of the reactant consumed, and generates power

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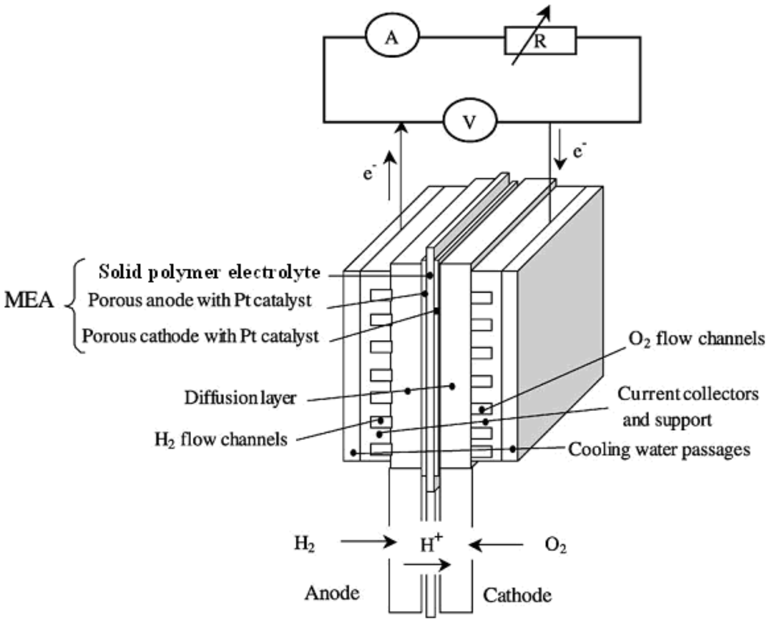

Fig. 1 Fuel Cell [3]

from an outside supply of fuel and oxygen. The new energy conversion technology should be more efficient than traditional heat engines, emitting little or no pollution, and be compatible with renewable energy sources for long-term sustainability (Lu *et al.* 2020). The mid-nineteenth-century transition of the world energy supply from wood to hay to coal, and nuclear to oil and gas.

The worldwide energy movement from solid to liquid, then from liquid to gases, and finally to non-polluting energy sources, as shown by hydrocarbon and eventually natural gas (Wang and Song 2020). These transitions are in line with predictions of energy sources as a tool for long-term economic growth, based on the notion that a time will come when global demand for non-polluting and efficient energy sources will be satisfied by non-fossil fuel sources (Twas 2008). According to recent additions to the literature, we have now reached the age of non-polluting energy sources. On a worldwide basis, fuel cells are expected to play a critical role in the development of non-polluting energy sources.

Fuel cells (as shown in Fig. 1) are projected to play a significant part in accomplishing these objectives to reduce greenhouse gas emissions by 40% relative to 1990 levels, achieve a renewable energy contribution of at least 27% in the EU, and increase energy efficiency by at least 27%. (Li *et al.* 2019).

Fuel cells have been identified as one of the most promising and potential clean energy technologies, meeting all of the requirements for energy security, economic growth, and environmental sustainability, and have gotten a lot of attention as a potential replacement for power generation systems (Mekhilef *et al.* 2012). The ability to emulate the ease of refueling and continuous working potential of internal combustion engines, as well as the exceptionally efficient and silent operation of batteries: As a result, fuel cells seem to be an ideal energy source (Haraldsson and Alvfors 2005). They don't require the same amount of recharging as batteries and don't produce the same amount of pollutants. Fuel cells use an electrochemical reaction to create electricity directly from fuel, which is a very efficient technique (Meng *et al*. 2022). Fuel cells can be utilized in a variety of ways because they generate electricity in such a simple manner, and they have been deployed among electricity consumers as a tactic to increase their market penetration (Dhathathreyan and Rajalakshmi 2001). When combustion occurs Engines produce power, but waste heat absorbs a significant amount of the energy generated by burning friction is to blame for their low efficiency.

To accomplish the commercialization of fuel cell innovation, particularly Proton Exchange Membrane Fuel Cell (PEMFC), there is a need to decrease the expense of the film and different parts of the energy component, as well as the restraining infrastructure of layer amalgamation advancements by a couple of organizations and countries. Pertinent writing uncovers that during the last many years an expense decrease of 10% has been accomplished; yet more examination is expected to lessen the expense of an energy unit's framework to a serious level. This will have the ideal consequence of tracking down additional applications for energy unit innovation, and is the focal point of this current research. The current research focusses on the performance analysis of commercial fuel cell (rated capacity 1000W) with the help of resistive load and output power variation with change in H_2 flow rate and calculate the maximum power point (MPP) of the proton exchange membrane (PEM) while changing AC and DC load respectively.

2. Experimental setup and methodology

In this section, full specification of the fuel cell used are mentioned. Also, the procedure for performing the experiments is explained in detail.

2.1 Performance characteristics of fuel cell with the help of resistive load

A PEM fuel cell's performance curve is not linear, but it does attain a maximum performance at a specific current. When fuel cells are employed in practice, it is critical that they be run at the current that produces the most power. For additional power, fuel cells are interconnected to form enormous stacks (fuel cell stacks). Each individual fuel cell must be run optimally in order for the stack to provide the maximum amount of power. The current voltage characteristic of a PEM fuel cell is recorded and studied in this experiment to find at which current the best performance can be obtained.

The arrangements for this experimentation are shown in Fig. 2. Fuel cell is connected with hydrogen cylinder through rotameter and pressure gauge and output of fuel cell is connected to the charge controller and battery through voltmeter and ammeter. Final connection is done by connecting battery to the inverter for AC output.

2.2 Output power variation of fuel cell with change in Hydrogen supply

The set-up of fuel cell will be connected with hydrogen cylinder through rotameter and pressure gauge and output of fuel cell will be connected to the charge controller, battery and DC load through DC voltmeter and ammeter. This experiment can also be done by connecting Inverter and AC load in place of DC load through DC and AC voltmeters and ammeters.

Fuel cell output voltage and current will be measured with the help of DC voltmeter and Ammeter just after the fuel cell and noted down in tabular form with varying hydrogen supply rate.

Table 1 Technical specification of fuel cell

Types of Fuel cell	**PEM**
Number of cells	48
Rated power	1000 W
Performance	28.8 V@ 35 A
H_2 Supply valve voltage	12V
Purging valve voltage	12 V
Blower voltage	12V
Reactants	Hydrogen & air
External temperature	5 to 30℃
Max. stack temperature	65℃
H_2 pressure	0.45 – 0.55 bar
Hydrogen purity	>= 99.995% dry H_2
Humidification	Self-humidified
Cooling	Air (integrated cooling fan
Stack weight (with fan and casing)	4000grams (+-100grams)
Controller weight	400 grams (+- 30 grams)
Dimension	23.3 cm x 26.8 cm x 12.3 cm
Flow rate at max output *	13 LPM
Startup time	<= 30S at ambient temperature
Efficiency of stack	40% @ 28.8 V
Low voltage shut down	24 V
Over current shut down	42 amp
Over temp shut down	65℃
External power supply **	13V (+- 1V), 8amp

2.3 Evaluation of Fuel cell system performances with only DC load connected to the charge controller with battery bank

The set-up of fuel cell is connected to the hydrogen piping through rotameter, pressure gauge and ball valve. Output of fuel cell is connected with Charge controller through DC ammeter and voltmeter and finally charge controller output is connected with battery bank and DC load (both in parallel) through DC voltmeter and ammeter.

2.4 Evaluation of Fuel cell system performances with only AC load connected to the inverter with battery bank

The set-up of fuel cell is connected to the hydrogen piping through rotameter, pressure gauge and ball valve. Output of fuel cell will be connected with charge controller through DC ammeter and voltmeter and finally charge controller output is connected with battery bank and Inverter (both in parallel) through DC voltmeter and ammeter. Inverter output is connected with AC load through AC voltmeter and ammeter.

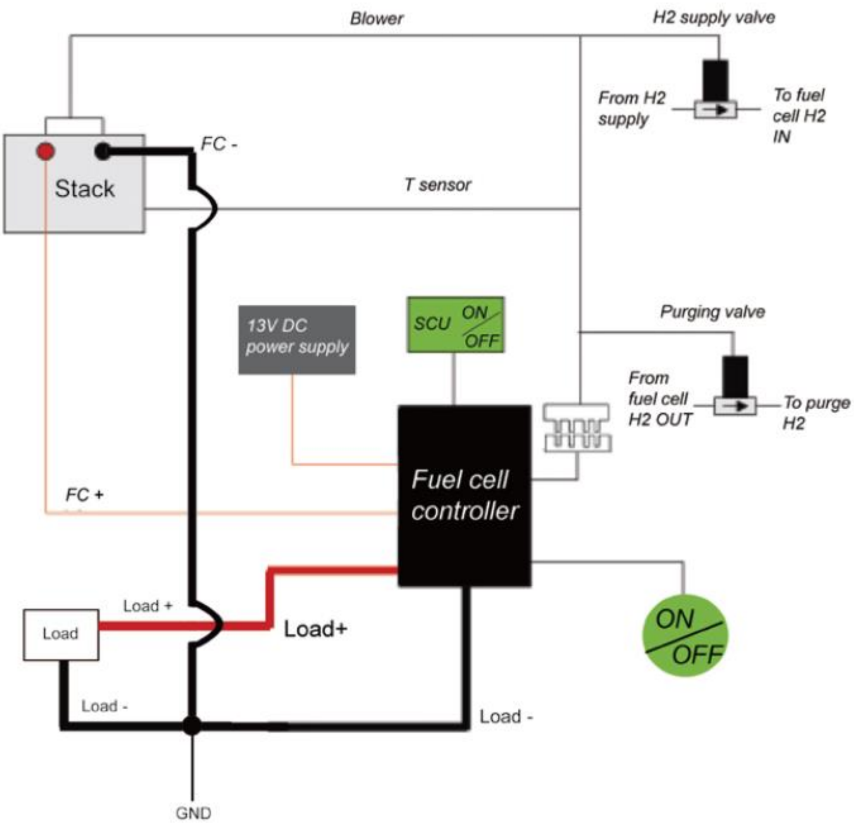

Fig. 2 System setup diagram

3. Results and discussion

3.1 Characteristics of fuel cell with the help of resistive load

Fig. 3 represents the V-I characteristics of the fuel cell at a hydrogen flow rate of 15, 13, and 11 liters per minute (LPM) respectively. This graph represents that the current is inversely proportional to the voltage as increase the load or resistance, the current of the fuel cell increases and the voltage drops slightly.

3.2 Output power variation of fuel cell with change in Hydrogen supply

Fig. 4 represents the relationship between power and voltage of fuel cell at a different hydrogen flow rate of 15, 13, and 11 liters per minute (LPM) respectively. Results indicated that the power of the fuel cell increased with decreasing in voltage of the fuel cell due to an increase in load or resistance. The maximum power is obtained at the flow rate of 15 LPM as compared to 11 LPM and 13 LPM. At 35V the current generated are 8.6A, 5.1A, and 2.5A, and the power obtained is 301W, 178.5W, and 87.5W respectively for 15, 13, and 11 LPM.

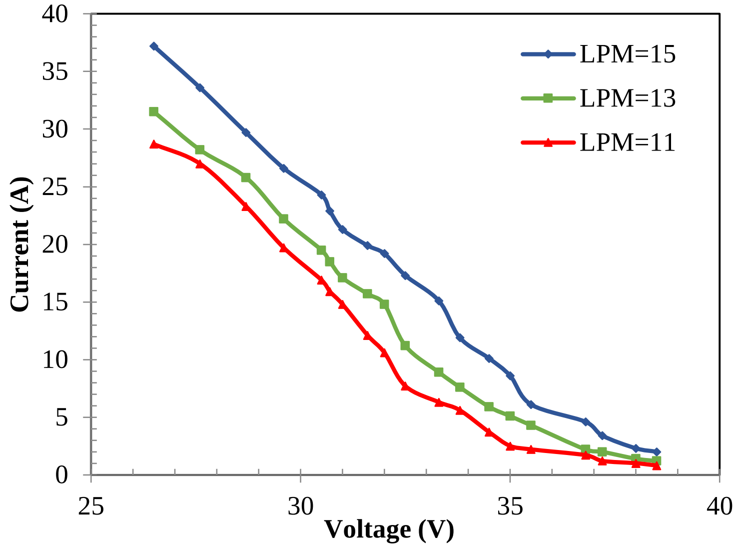

Fig. 3 V-I characteristics of fuel cell

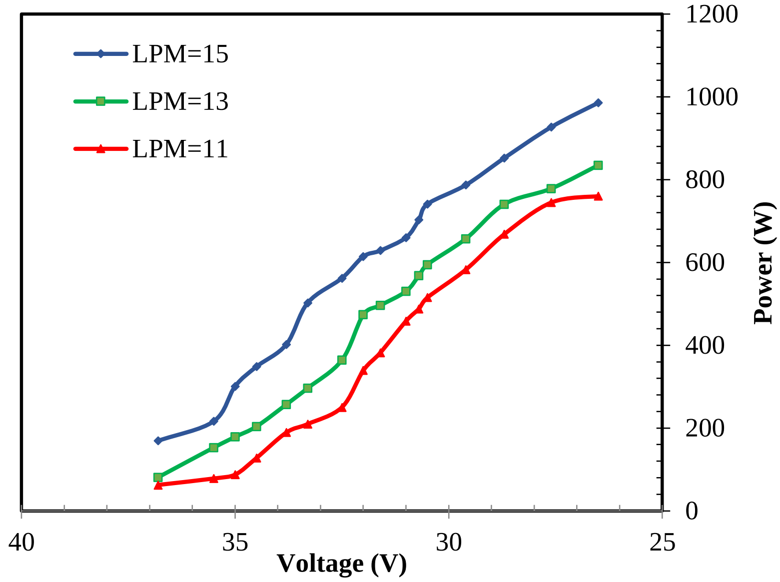

Fig. 4 Characteristics of fuel cell at different flow rate of hydrogen

3.3 Evaluation of Fuel cell system performances with only DC load connected to the charge controller with battery bank

Fig. 5 represents the curve between charge controller efficiency (η) and power at DC load in watt at constant of hydrogen supply which is followed by the no. of experiments done in the

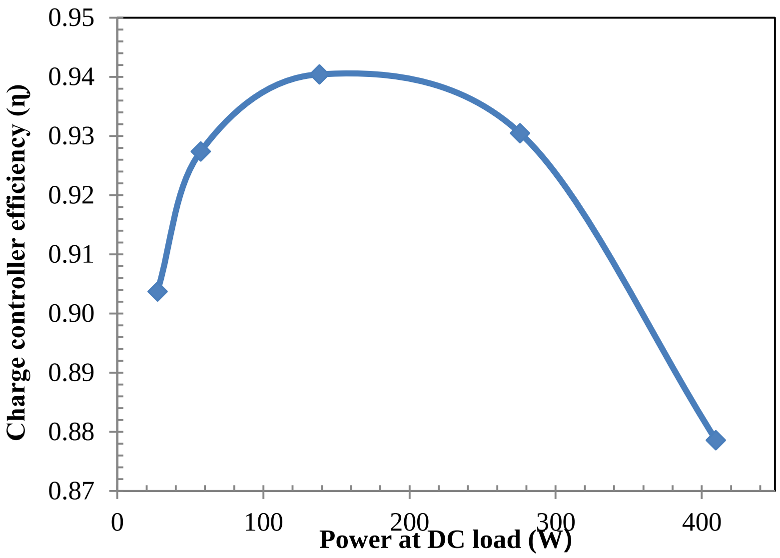

Fig. 5 Power at DC load vs Charge controller efficiency

system. This graph represents that as we increase the load or resistance the power of the fuel cell increases but the charge controller efficiency is firstly increasing and then after achieving the maximum efficiency it drops down slightly.

Regression Equation-
$y = -1E\text{-}06x^2 + 0.0005x + 0.8966$
$R^2 = 0.9669$

3.4 Evaluation of fuel cell system performances with only AC load connected to the inverter with battery bank

Fig. 6 represents the curve between charge controller efficiency (η) and power at DC load in watt at constant of hydrogen supply which is followed by the no. of experiments done in the system. This graph represents that as we increase the load or resistance the power of the fuel cell increases but the charge controller efficiency is firstly increasing and then after achieving the maximum efficiency it drops down slightly.

Regression Equation-
$y = -6E\text{-}07x^2 + 0.0004x + 0.8459$
$R^2 = 0.9908$

4. Conclusions

The experimentation work was conducted on a 1kW commercial fuel cell system. The entire experimental set-up is mounted at Green Energy Lab, DTU, Delhi. A number of set of experiments was

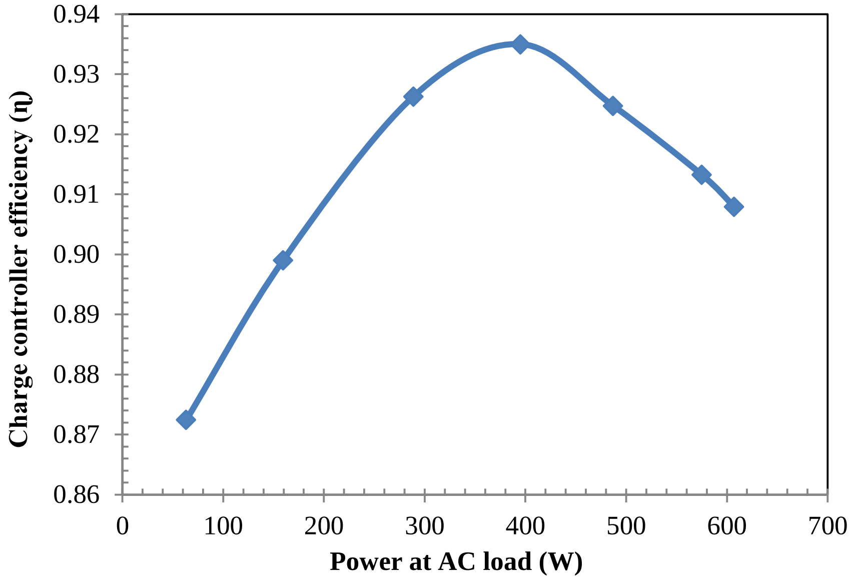

Fig. 6 Power at AC load vs Charge controller efficiency

done employing different variable hydrogen flow rate (11, 13 & 15 LPM). The outcomes of experiment are listed as:

- The current is inversely proportional to the voltage as load or resistance increases.
- The maximum power is obtained at the flow rate of 15 LPM as compared to 11 LPM and 13 LPM.
- Maximum charge controller efficiency for DC and AC load is 94% and 93.4% respectively, it shows initially efficiency increasing and the after achieving the maximum value it slightly drops down.
- The power of the fuel cell is increases by 29% when hydrogen flow rate was increased from 11 to 15 LPM.

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