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## Exergy Analysis of a Pem Fuel Cell System at Various Loads

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**Abstract**
The energy systems (off-grid, hybrid and stand-alone system etc.) are have to meet the general requirements of the power system that provide the stability of system, continuously produce power and work efficiently. In this study, we determined the exergy and energy efficiencies of a 1.2 kW Nexa™ PEM fuel cell stand-alone system used at various loads for stationary application. The fuel cell system was tested at loads from 25% to 75% of nominal power of module and non-constant pressure.
**Keywords:** exergy efficiency, energy efficiency, fuel cell

## Анализ эксергии системы pem топливных элементов при различных нагрузках

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**Аннотация**
Энергитические системы (вне сети, гибридные и автономные системы и т. д.) должны соответствовать общим требованиям энергосистемы, которые обеспечивают стабильность системы и эффективно вырабатывать энергию. В данном исследовании мы определили эксергию и энергетическую эффективность системы из 1.2 кВт Nexa™ PEM топливных элементов, используемых при различных нагрузках для стационарного применения. Систему топливных элементов испытывали при нагрузках от 25% до 75% от номинальной мощности модуля и непостоянном давлении.
**Ключевые слова:** энергетическая эффективность, эксергетическая эффективность, топливный элемент

### *Introduction*

Fuel cell is an energy generator that experienced a quick development track, especially in the second half of 20th century. This technology converts chemical energy directly into electricity by combining oxygen from air with hydrogen gas without combustion. The hydrogen can be defined as alternative fuel which have non-toxic in asset, have high power production, is environmentally friendly and is one of the major candidates nowadays world.

Energy analysis is based on first law of thermodynamics, whereas exergy analysis is based on both the first and second laws of thermodynamics, that it seeks to find out the true potential of thermal systems. In fuel cell system the exergy efficiency is the ratio of the electrical output power and maximum possible work output [1].

Sevjidsuren et al. [2] performed exergy analysis of 1.2 kW Nexa™ fuel cell module at variable operating temperatures, pressures, cell voltages, mass flow rates and air stoichiometrics. In this literature, the external loads were changed from 2A to 10 A with step of 2 A in every 5 min. The exergy flow and exergy efficiency of the distributed energy system using small-scale fuel cell is investigated in Shin'ya et al. [3]. They were determined the exergy flow and difference in efficiency at variable environmental temperatures and load factors.

Differing from the literature, the purpose of this study is to determine the exergy and energy efficiency of the stand-alone PEM fuel cell system, which has moderate capacity, is environmentally friendly and is used for partially supply a daily load of power users.

### *Experimental part*

We used the Nexa™ 1.2 kW PEM fuel cell system in this work, the Nexa™ 1.2 kW power module is a fully integrated system that produces unregulated DC power from a supply of pure hydrogen and oxygen (from ambient air). And with the use of an external fuel supply, operation is continuous, limited only by the amount of fuel storage [4].

Figure 1. The experimental system with Nexa$^{TM}$ PEM power module

The assumption of measurement was at 6 bar pressure for one hour, the external load was 25% of total power of 1.2 kW modules that equals to the minimum power demand of daily load and then increased it to 40%, 60% and 75%.

***Results and Discussion***

Figure 2 shows the variation of net power and cell voltage of module at various loads, the load operation condition was set to constant current mode. Therefore, the current density remains constant during measurement at variable loads. When load of the user is 300– 930 W that equals to 25 – 75% of total power, the module is working with net power of up to 350 –1069 W.

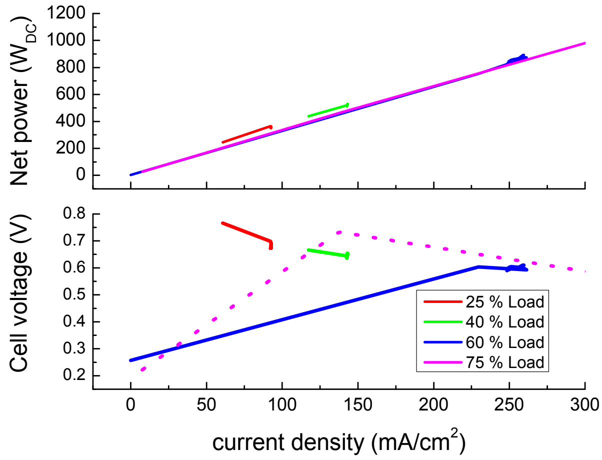


Figure 2. The net power and cell voltage of module at various loads

When the module was operating with 75% load, the cell voltage was sharply dropped from 0.75 V to 0.57 V at a current density of 0.14 A/cm$^2$, whereas it slightly reduced at other loads. The cell voltage is decreasing with increasing current density.

The variations of hydrogen and product water mass flow rates with current density are shown in figure 3. The hydrogen mass flow rate is ranged from -0.001 to 0.016 g/sec, whereas the product water mass flow rate was at 0.138 g/sec. The curves of hydrogen and product water mass flow rates are overlapped from a current density of 0.15 A/cm$^2$ and 0.13 A/cm$^2$ respectively.

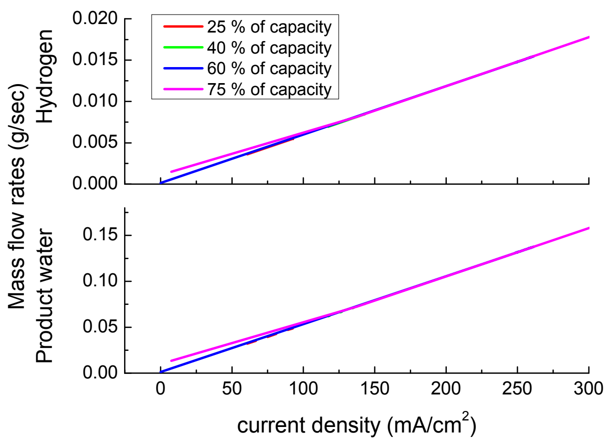


Figure 3. Variation of hydrogen and product water mass flow rates with current density

The variations of inlet and outlet air mass flow rates with current density at various loads are shown in figure 4. Inlet mass flow rate is increasing slightly from 1.25 to 1.35 g/sec and the outlet air mass flow rate is decreasing from 1.25 to 1.20 g/sec at 75% load, whereas these parameters are going up sharply at other loads. This shows that mass flow rates are proportional with the current density due to the hydrogen and inlet air mass flow rates sharply increasing with the increase of the external load.

The variations of energy and exergy efficiencies with current density at various loads are shown in figure 5. The system energy and exergy efficiencies both reach a maximum at low current density. After connecting a load, these parameters decrease with current density. These are sharp dropping from 52 to 32% at working with 60 and 75% loads, whereas, slightly decreasing from 51 to 43% at 25 and 40% loads. Therefore, the efficiencies are disproportional with current density.

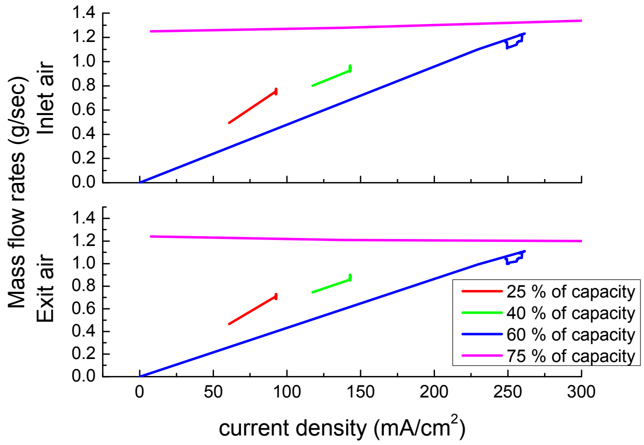


Figure 4. Variation of inlet and outlet air mass flow rates with current density

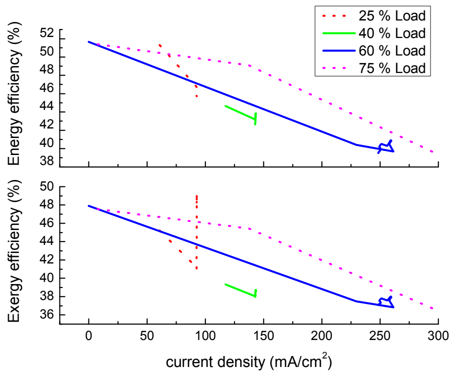


Figure 5. Variation of energy and exergy efficiency with current density

## Conclusion

There was a slight decrease in efficiency operating with low loads, whereas, it sharply dropped at high loads; caused by the mass flow rate of fuel consumed by the stack and the power required by auxiliary devices increased with the current density.

The 1.2 kW PEM fuel cell power module works efficiently with an external load of 0.75 kWh at a fuel pressure of 6 bars at a period of one hour. The using of the PEM fuel cell power system to supply the power demand of a house will be more suitable if we use it by stand-alone system.


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