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Experimental Analysis of the Performances of Proton Exchange Membrane Fuel Cell Based Electric Vehicle

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Abstract- The aim of this paper is to analyse the performances of the fuel cell directly connected to a variable load. The hydrogen represents one of the main green energy of the future. The fuel cell is the engine responsible of converting hydrogen into electrical energy. Thanks to its higher efficiency, low operating temperature and its easy maintenance, the Proton Exchange Membrane Fuel Cell is used in transportation such as hybrid vehicles and Fuel Cell Electric Vehicles. Power converters are used in fuel cell systems to control the flow of the power and regulate the load voltage. In addition, power converters are designed to reduce the voltage and current ripple of the fuel cell. In aim to investigate the fuel cell performances in case of converter fault and direct connection to the load, this work is conducted. Experimental tests were performed using the Fuel Cell Nexa 1.26 kW system. The experiments are performed under diverse operating situations representing the load current profile of the New European Driving Cycle of the electrical vehicle whether static and dynamic ones. The experimental results show good performances of the fuel cell connected directly to the load to provide the required load current. However, the same results prove the need to the power converter to reduce the current ripples.

Keywords- Fuel cell, electric vehicle, statistic operation, dynamic operation, experimentation.

1. Introduction

The global energy concern about eco friendly sources of energy as well as the grow demand of electricity has motivated authorities and non-governmental associations to focus on new methods of production and storage of electrical energy from renewable energy resources [1, 2]. The hydrogen can produced by different technologies using renewable energy such as solar, wind and tidal power [3, 4]. The produced electrical energy from renewable resources is converted into hydrogen by using electrolyzes technologies [5-7]. The storage of hydrogen has many advantages such as unlimited storage capacity and the low cost of storage tanks [8-10]. Thereafter, the hydrogen is converted into electrical energy whenever this energy is required to feed loads. Despite, the low efficiency of the conversion of power to gas and gas to power, this process is used in many industrials applications, especially the electrical transportation. Hydrogen represents a sustainable solution for the storage of electrical energy produced from renewable energy sources. The Fuel cell installed in Electrical and Hybrid cars allows the transformation of hydrogen into electrical energy to run the electrical motors.

Nowadays, the Proton Exchange Membrane Fuel Cell is used in Electric Vehicle (EV) and hybrid cars to convert hydrogen into electrical energy [11–14]. The system has good efficiency and makes the EV very interesting transportation technology [15–19]. The regulation of the DC bus and the control of the PEMFC voltage ripple are usually performed by the power converter and controllers' systems [20]. The interleaved boost converter connected to the PEMFC for industrial applications and EV allows reducing the voltage ripple and controlling the DC bus voltage[15, 21]. The isolated DC-DC converters consists an adequate solution for the EVs. Fuel cell is a prospective clean energy solution to cure the rising ecological pollution issues [22, 23, 24]. The polymer electrolyte membrane fuel cell (PEMFC) shows advantage in the automobile manufacturing [25]. The general configuration of power sources and power converters in EVs, is depicted in Fig.1[20]. The main source of the electrical energy is the PEMFC [26]. The super capacitor is used as energy backup energy storage system [4]. The two sources are connected to the DC bus through bidirectional DC-DC converters [27]. The power converters are designed to control the flow of the power and regulate the DC bus supply according to the load dynamic requirements [28].

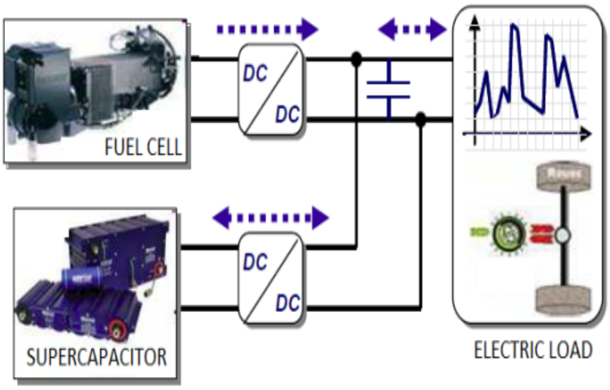

Fig. 1. Fuel Cell Electrical vehicle

The design and the analysis of the power converters show a good reliability of the both power converters and PEMFC [29]. However, the PEMFC should be analyzed in case of converter' fault and direct connection to the load. Indeed, faults can take place. Many questions are supposed to be asked here. Is it possible to connect the PEMFC directly to the load? What are the performances of the PEMFC when it is directly connected to the load? This paper is proposed to provide clear answers to these questions through an experimental study.

Therefore, the objective of this paper is to investigate the dynamic and static performances of the PEMFC connected to the load. The experimental test bed consists of the Ballard Nexa 1200 fuel cell module and a mainly electronic load. Special software was developed to emulate the European driving cycle. The static and dynamic responses of the PEMFC are recorded and discussed in details in this paper. The five sections of the paper are organized as follow. The dynamic model of the fuel cell vehicle is presented in section 2. In section 3, the detailed model of the PEMFC is described. Section 4 presents the experimental test bed and the results of different tests performed on the PEMFC. The experimental test is based on the emulation of reference driving cycle covering all modes of driving such as the normal driving, the braking and the start-up. Also, tests describing strong acceleration are performed on the hardware. Discussion of experimental results is presented in the same section. Finally, conclusions and recommendations are provided in section 5.

2. Dynamic Model of the Electric Vehicle

In order to model the dynamic performance of the vehicles, all the forces useful to the vehicle must be known. Fig. 2 shows all the forces applied to the vehicle hiking a grade [26].

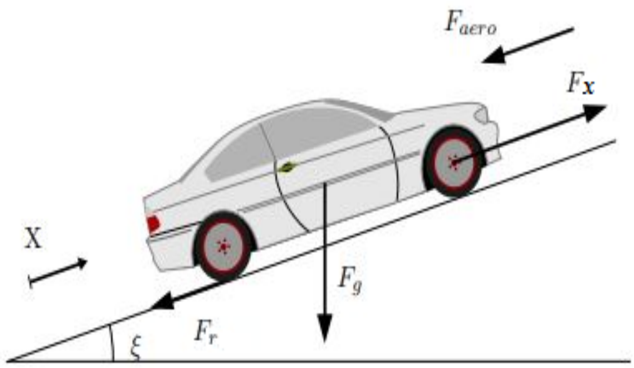

Fig. 2. Forces acting on the vehicle

Based on the second Newton's law of motion, the circulation of the vehicle at a speed v(t) requires a developed force Fx to compensate the applied load force Fg added to the friction force Fr. In the case of linear displacement, the mechanical power developed by the vehicle is expressed as [20]:

$$P_m(t) = \frac{dW(t)}{dt} = F_x V(t) \qquad (1)$$

The fundamental principle of dynamics allows expressing the required mechanical power Pm at wheel to drive the vehicle as [20, 28]:

$$P_m(t) = V(t) M \frac{dV(t)}{dt} + Mg\sin(\xi) + \frac{\rho C_x S_f V(t)^2}{2} + MgC_r \qquad (2)$$

In this expression, the term Faero represents the aerodynamic friction. The factor $Mg\sin(\xi)$ is defined as the rolling force Fr,. The force Fg is caused by the car gravity effect in the case of a slope road. These forced are defined by the expressions (3), (4) and (5).

$$F_g = Mg\sin(\xi) \qquad (3)$$

$$F_{aero} = \frac{\rho C_x S_f V^2}{2} \tag{4}$$

$$F_r = M.g.C_r \tag{5}$$

The parameters ρ, M and A represent the air density, the mass of the vehicle and the vehicle's front surface, respectively. The drag coefficient and the aerodynamic coefficient are denoted C_x and C_r. The road slope is modeled by the angle δ.

3. Fuel Cell Basic Characteristics

The PEMFC is an electrochemical system that converts hydrogen energy to electrical power [30]. The process takes place without intervention of external operator or machine. Hence, the operation of the PEMFC is described by a chemical reaction that blends up hydrogen and oxygen in organized way to create electrical energy, warmth and water consequently. The Schematic of the working principle of a FC Nexa system is presented by Fig.3 [31].

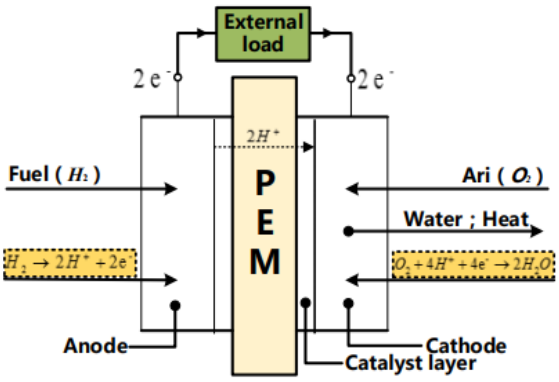

Fig.3. The working principle of a Fuel Cell

When the FC operates, it supplies fuel (hydrogen) to the anode and oxidant (air, the useful ingredient is oxygen) to the cathode. On the anode side, the reaction that hydrogen splits into protons (H^+) and electrons (e-) is a hydrogen oxidation reaction (6). The protons enter the electrolyte, while electrons move to the cathode along the external circuit, which is connected to the load. The electrical load is connected to the external circuit. On the cathode side, the reaction that oxygen (O2), protons and electrons form water is an oxygen reduction reaction (7). This is the reverse process of water electrolysis [32].

$$H_2 \rightarrow 2H^+ + 2e^- \tag{6}$$

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \tag{7}$$

Taking in consideration the voltage drop due to the Ohmic, activation and concentration effects, the PEMFC's total voltage is expressed as follow [24]:

$$V_{FC} = E_{Nernst} - V_{Act} - V_{Ohm} - V_{Con} \tag{8}$$

Where:

$$E_{Nernst} = 1.229 + \frac{RT}{n_e F} ln\left(\frac{PH_2\sqrt{PO_2}}{PH_2O}\right) \tag{9}$$

$$\Delta V_{Act} = \frac{RT}{n_e F} ln\left(\frac{i_{FC}}{i_0}\right) \tag{10}$$

$$\Delta V_{Ohm} = R_{FC} i_{FC} \tag{11}$$

$$\Delta V_{Con} = -\frac{RT}{\alpha n_e F} ln\left(1 - \frac{i_{FC}}{i_l}\right) \tag{12}$$

A simplified equivalent circuit of the PEMFC is given in Fig.4. This model allows simulating the dynamic and static characteristic of the PEMFC [5].

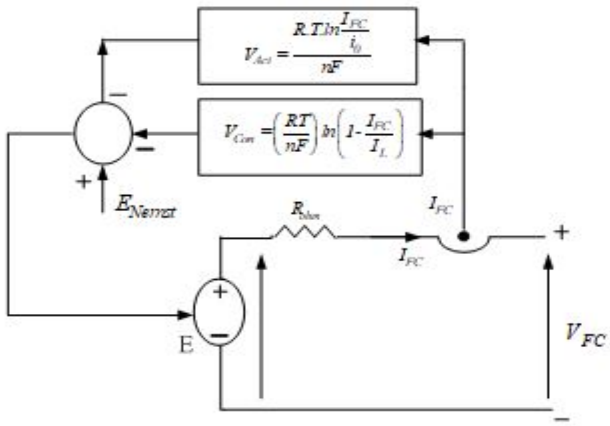

Fig.4. Equivalent circuit model for the FC system

The simulation results of the model implemented in Matlab-Simulink shows an improvement of the PEMFC performances when working at higher temperature, as shown in Fig.5. Indeed, increasing the temperature leads to reducing the electrical conductivity of metals and an increase of the ionic conductivity of the electrolyte.

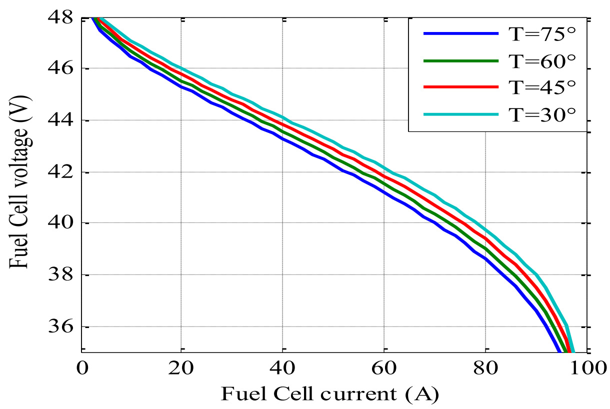

Fig.5. V–I characteristics of FC system for different temperatures

The electrochemical reaction velocity is relative to the pressures of both oxygen and hydrogen feeding the PEMFC.

Certain, if the provided hydrogen pressure increases, the performance of the FC are improved as shown in Fig. 6.

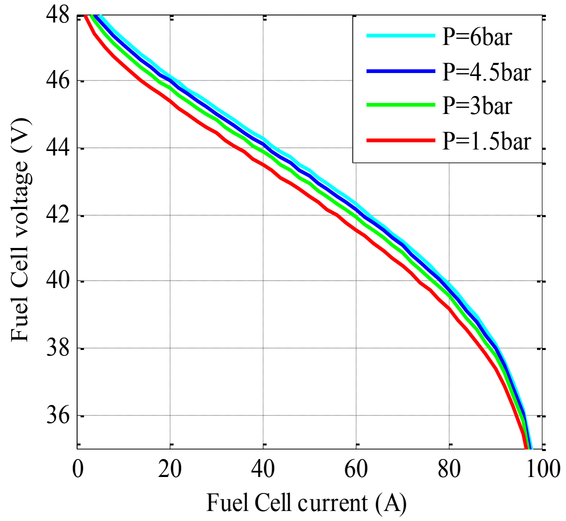

Fig.6. V–I characteristics for different hydrogen pressure

4. Practical Operating Modes of the Fuel Cell Nexa System

4.1. Materials

In this study, experiments are conducted with Ballard Nexa 1200 fuel cell module under diverse operating situation, whether static and dynamic ones. A symbolic representation of PEMFC test bed is shown in Fig.7. The test bed is mainly composed of PEMFC Ballard Nexa, hydrogen tank equipment with all components i.e. inlet valve, pressure regulating valve and exhaust gas electromagnetic valve. An electronic controlled load is used to emulate the electric vehicle behavior. A photograph of the test bed is depicted in Fig.8.

4.2. Methods

The New European Driving Cycle is characterized by a defined current required by the electric vehicle when it starts up and circulates at different speeds. Then, the programmable electronic load is used in this test bed to draw a specific current similar to the current absorbed by the electric vehicle for a complete driving cycle. At the same time, the PEMFC's current and voltage are recorded using electronic oscilloscope. Then, the experiment consists at the same time of measuring the current and the voltage supplied by the fuel cell using a programmable electronic Load. This firstly produces the current profile variation ranges from 0 to 45A in a way alternating and secondly a load current profile from an NEDC type speed cycle. The supervisor chunk includes the user interface. It collects measured information, transmits the operational orders and manages security processes. The software "Nexa Mon OEM" interface allows the user to choose the FC system function mode and the parameters to be regulated. The system is capable of sprint automatically, next either a computed profile charge or a manual function, according to the user's need. The electronic charge can be computed to oblige a known time progression of the FC current [4.2]. The PEMFC's parameters are given Table 1.

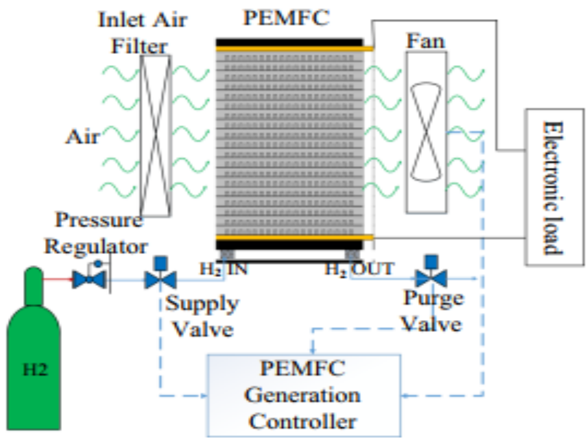

Fig.7. Schematic representation of PEMFC test bed

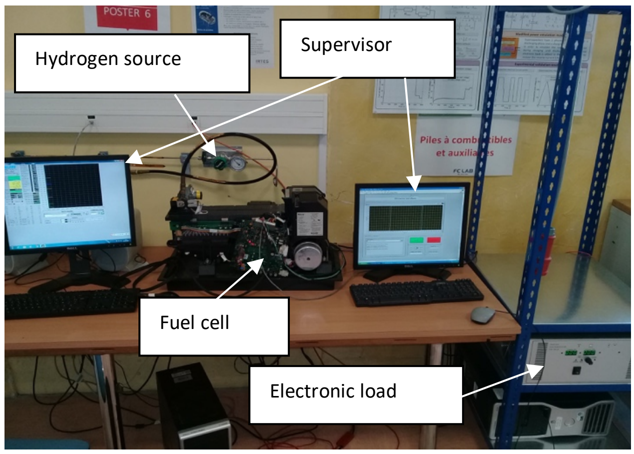

Fig.8. Experimental FC Nexa system.

Table 1. Fuel cell parameters

Parameters	Value
Stack voltage	26V
Stack power	1.2 kW
Stack temperature	328 °K
Hydrogen partial pressure	1.5 atm
Oxygen partial pressure	1 atm
Water partial pressure	1 atm
Area of the membrane	0.0825m2
Number of cell	42

5. Results

5.1. Statistic regime operation

To determine the static characteristic of the PEMFC, several measurements have been performed by controlling the electronic load and measuring the performances of the PEMFC. The electronic load is controlled to make the PEMFC producing a current varying from 1 A to 45 A. Thereafter, the voltage and the current variations are recorded as shown in Fig.9 and Fig.10, respectively. The increase of the load current from 1 to 45 A during a time of 140 second was completely sufficient to measure the PEMFC current and voltage. Indeed, the voltage and the current of the fuel cell have a settling time of some milliseconds. The responses are characterized by oscillations until the commutation to second value of the load current.

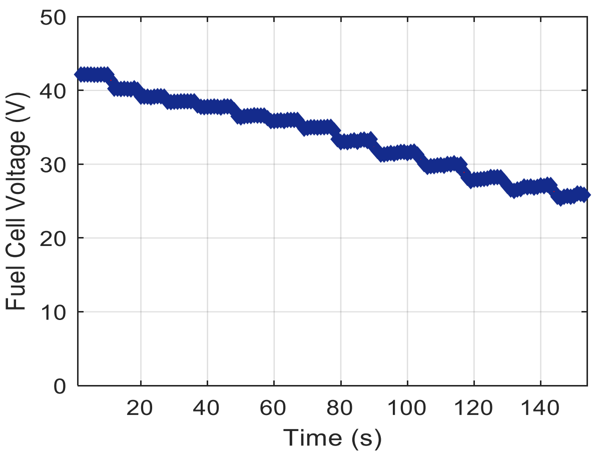

Fig.9. FC system voltage, run up operation

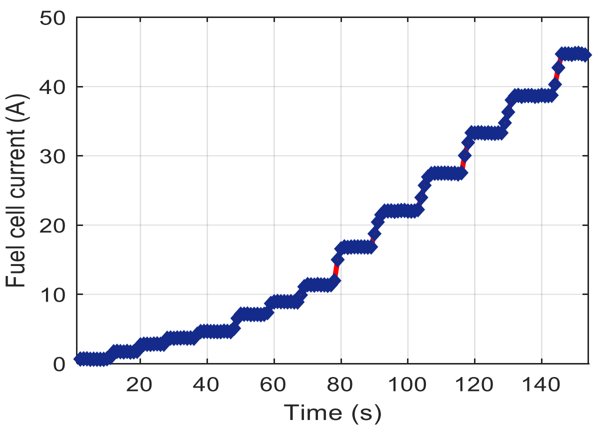

Fig.10. FC system current, run up operation

The polarization curve of the PEMFC is deduced from Fig.9 and Fig.10. When the current varies from 0 to 45 A, the voltage decreases from 42 V to 26 V. Indeed, any increase of the load current leads to an increase of the fuel cell current and a decrease of the fuel cell voltage. Fig. 11 illustrates the polarization characteristics, of the PEMFC. The obtained polarization curve is identical to the characteristic provided in the datasheet. The open circuit voltage and the short-circuit current can be easily determined from the Fig.11.

The produced output power by the PEMFC is calculated using the values of the voltage and the current. The obtained results of the power are presented in Fig.12. The maximum power of the PEMFC, 1.2 kW, corresponds to a maximum current of 45 A. Despite the decrease of the voltage values, increasing the current allows to increase the power of the fuel cell. The PEMFC's temperature depends to the load current and power. The temperature is measured for different values of the current. The obtained results are given in Fig.13 which shows the variation of the temperature versus the time. A minimum of temperature is recorded at 78 second. This corresponds to a current and power of 10 A and 700 W, respectively. After that, increasing the current induces an increase of the temperature. The main recommendations obtained from this test are to keep working at rated current and power. Indeed, this allows keeping the PEMFC temperature at a minimum value. The maximum value of temperature 37°C, corresponds to the highest requested current (I=45A).

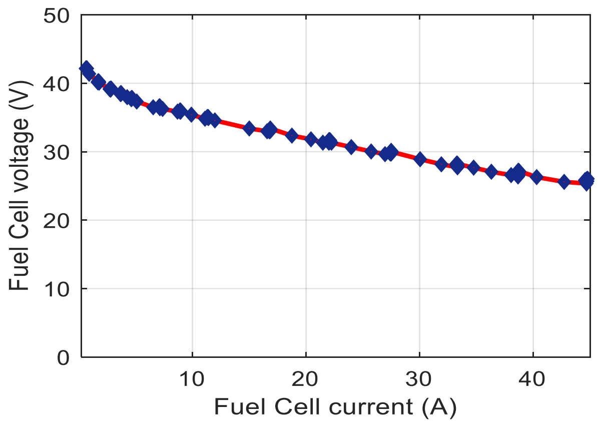

Fig.11. V–I experimental characteristics of FC system

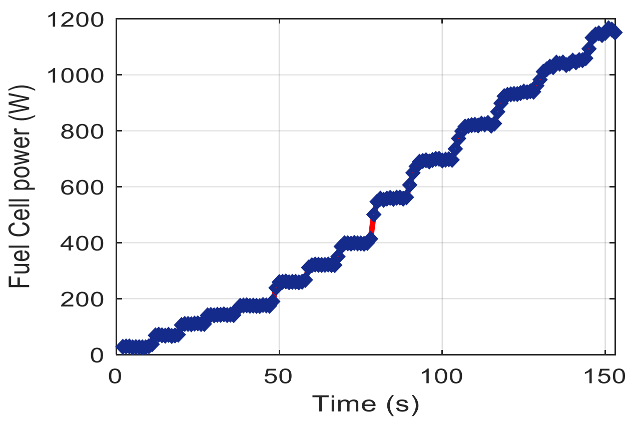

Fig.12. FC system power, run up operation

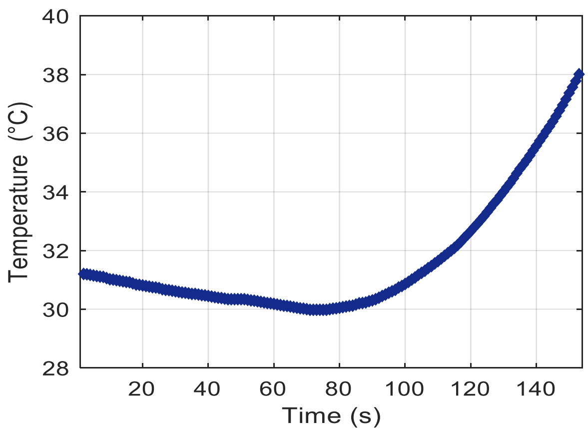

Fig.13. FC system temperature, run up operation

5.2. Dynamic regime operation: Automotive application

The dynamic operation corresponds to the analysis of the PEMFC performances during the variation of the load current using an automatic load representing the current profile variation of an electric vehicle according to the New European Driving Cycle (NEDC). In addition to the obtained experimental results for static operation, the dynamic behavior of the PEMFC is investigated in this section. Then, the load current profile is based on the NEDC of electrical vehicle as illustrated in Fig.14. The parameters of electric car subject of this dynamic study are given in Table 2.

Table 2. Parameters of the Vehicle

Parameters	Value
The mass of the v M	300 kg
Coefficient of rolling resistance CR	0.001
Front section of the vehicle Sf	1 m2
Slope tan(ϴmax)	10%
Gravitational field g	9.81 ms-2
Air density ρ	1.2 Kg/m3
Wheels radius Rr	0.14 m

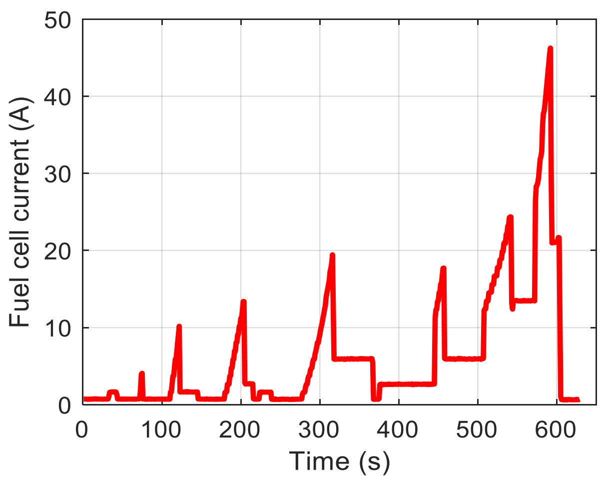

Fig.14. Load current profile for dynamic operation

The PEMFC voltage response regarding the load variation is given in Fig.15. The increase of the load current leads to a decrease of the PEMFC's voltage, immediately. Then, the dynamic voltage variation depends to the load current. The results show that the PEMFC is a fast system having good response time. Fig. 16 illustrates the variation of the PEMFC's current versus the time when the specific load current is applied. The dynamic polarization characteristics, representing the variation of the voltage versus the current of the fuel cell, are provided in Fig.17. The Nexa PEMFC system output voltage varies between 21 V to 43 V. The output current varies randomly from zero to 46 A athwart the operating range of the Nexa system. The produced power by the PEMFC is measured during this test. The results are given in Fig. 18. The power varies from zero to 1.15 kW during the NEDC.

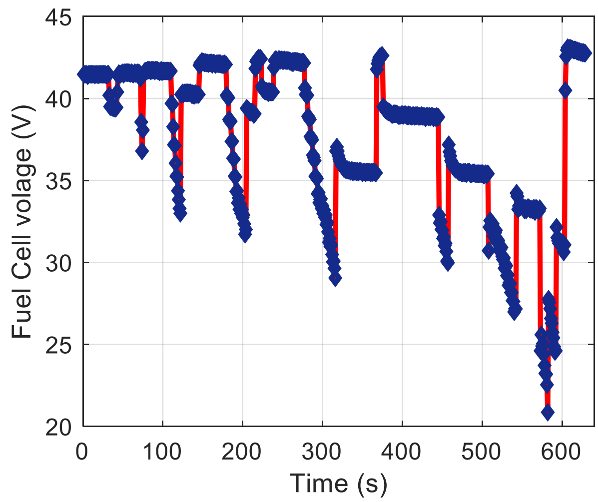

Fig.15. Stack Voltage under load variation

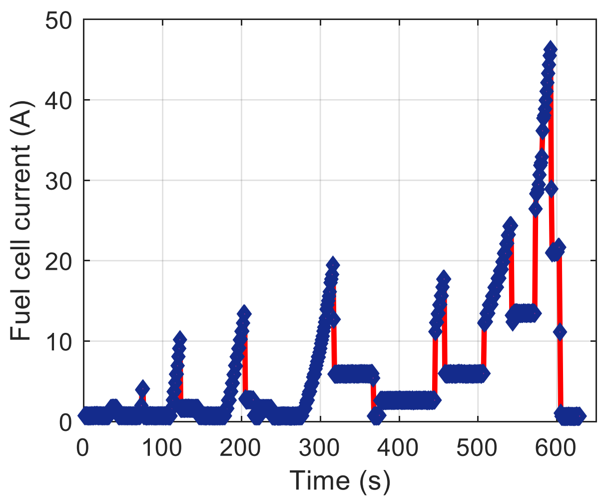

Fig.16. Stack current curve under load variation

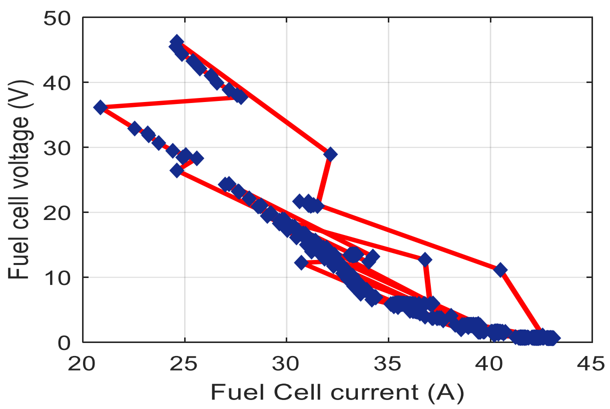

Fig.17. V–I experimental characteristics of FC system for dynamic profile

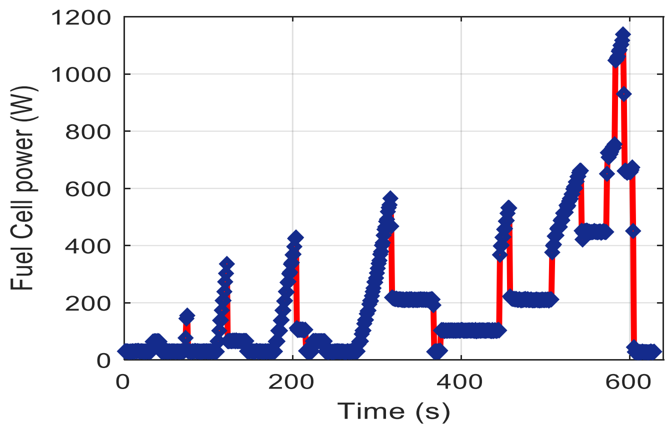

Fig.18. FC system power

As estimated, the hydrogen consumption reaches its maximum when the load current is maximum. Fig. 19 presents the variation of consumed hydrogen by the PEMFC. The peak of hydrogen consumption corresponds to a maximum power of 1180 W produced by the PEMFC at 600 second.

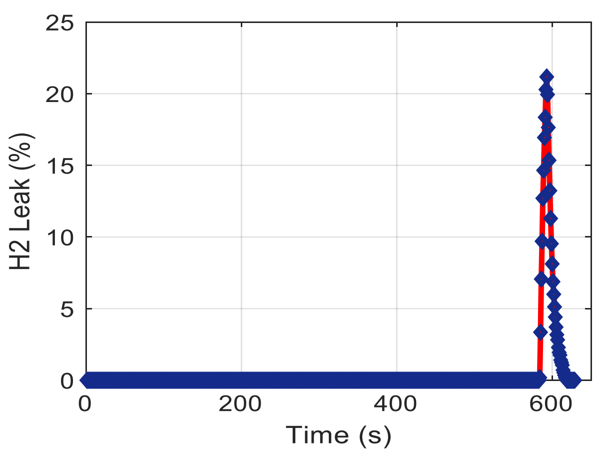

Fig.19. Hydrogen utilization

The variation of the measured temperature during this dynamic test is depicted in Fig.20. At the beginning of the test, the temperature is 27.5°C. From 0 to 300 second, the temperature increases smoothly to 28°C. The maximum produced current during this time is 20 A. The temperature increases with time to reach 40°C at 600 second. At this time, the current produced by the PEMFC is 46A. The maximum temperature is still in the normal range of working temperature. The main cause of the increase of the temperature is the working time added to the increase of the produced current.

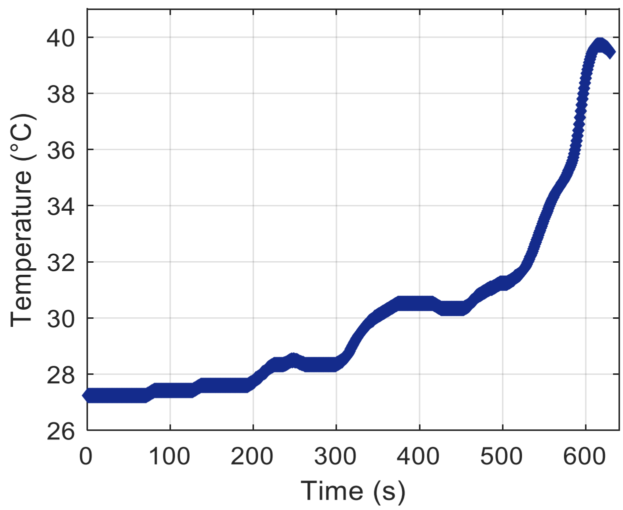

Fig.20. FC system temperature

The experimental results presented in this paper for the static and dynamic operation are in accordance with the obtained simulation results performed using Matlab Simulink software. Then, the approach used in simulation allowed to analyze the performance of the PEMFC electrical vehicle without an installed power converter

6. Conclusion

The work presented in this paper shows an experimental investigation on the performances of 1.26 kW PEMFC type NEXA. This PEMFC is used in many industrial systems, i.e. electrical vehicle. To determine the ability of this PEMFC to work when connected directly to the load, a test bed based on NEDC of electrical vehicle was used. Then, static and dynamic performances have been determined and discussed. The obtained static and dynamic experimental results are displayed using the software "Nexa Mon OEM". The results show the high efficiency of the PEMFC to work directly when connected to the load. Indeed, when the load current varies according to the NEDC, the PEMFC generates the required current. The power of the PEMFC depends to the produced current. The PEMFC temperature has increased but still in the normal range. The simulation and the experiment results show respectively such similarity to each other. This paper has showed that the PEMFC can produce the required power to the load in case of power converter fault or in case of any other technical problems. This advantage will make the PEMFC more interesting generator for hybrid and electrical vehicles. The hybrid fuel cell vehicle using the PEMFC is one of the alternatives being considered to replace the conventional vehicle due its higher performance at urban cycle.

References

[1] D. Fouquet and T. B. Johansson, “European renewable energy policy at crossroads-Focus on electricity support mechanisms”, Energy Policy, Vol. 36, No. 11, pp. 4079–4092, Nov. 2008.

[2] H. Doukas, K. D. Patlitzianas, A. G. Kagiannas, and J. Psarras, “Renewable energy sources and rationale use of energy development in the countries of GCC: Myth or reality”, Renew. Energy, Vol. 31, No. 6, pp. 755–770, May 2006.

[3] B. Zafar, “Design of a Renewable hybrid photovoltaic-Electrolyze-PEM/Fuel Cell System using Hydrogen Gas” International Journal of Smart Grid- ijSmartGrid, Vol.3, No.4, 2019.

[4] F. Slah, A. Mansour, M. Hajer, and B. Faouzi, “Analysis, modeling and implementation of an interleaved boost DC-DC converter for fuel cell used in electric vehicle”, Int. J. Hydrog. Energy, Vol. 42, No. 48, pp. 28852–28864, Nov. 2017.

[5] S. Farhani, A. Djerdir, and F. Bacha, “Study and Experimentation of a PEM Fuel Cell for Electric Vehicle,” International Conference on Signal, Control and Communication (SCC), pp. 320–324, 16-18 December 2019.

[6] S. Mekhilef, R. Saidur, and A. Safari, “Comparative study of different fuel cell technologies”, Renew. Sustain. Energy Rev., Vol. 16, No. 1, pp. 981- 989, Jan. 2012.

[7]B. Madaci, R. Chenni, E. Kurt, and K. E. Hemsas, “Design and control of a stand-alone hybrid power system”, Int. J. Hydrog. Energy, Vol. 41, No. 29, pp. 12485-12496, Aug. 2016.

[8] S. Gherairi, “Zero-Emission Hybrid Electric System: Estimated Speed to Prioritize Energy Demand for Transport Applications” International Journal of Smart Grid - ijSmartGrid, Vol.3, No.4, 2019.

[9] M. Becherif and D. Hissel, “MPPT of a PEMFC based on air supply control of the moto-compressor group”, Int. J. Hydrog. Energy, Vol. 35, No. 22, pp. 12521-12530, Nov. 2010.

[10] P. T. Bankupalli, S. Ghosh, L. Kumar, S. Samanta, and S. Jain, “Operational Adaptability of PEM Fuel Cell for Optimal Voltage Regulation With Maximum Power Extraction”, IEEE Trans. Energy Convers., Vol. 35, No. 1, pp. 203-212, Mar. 2020.

[11] N. Karami, R. Outbib, and N. Moubayed, “Fuel flow control of a PEM Fuel Cell with MPPT”, in 2012 IEEE International Symposium on Intelligent Control, Dubrovnik, Croatia, pp. 289–294, Oct. 2012.

[12] P. Thounthong, S. Raël, and B. Davat, “Energy management of fuel cell/battery/supercapacitor hybrid power source for vehicle applications”, J. Power Sources, Vol. 193, No. 1, pp. 376–385, Aug. 2009

[13] A. Kirubakaran, S. Jain, and R. K. Nema, “The PEM Fuel Cell System with DC/DC Boost Converter: Design, Modeling and Simulation”, Vol. 1, No. 3, p. 6, 2009.

[14] Z. You, L. Wang, Y. Han, and F. Zare, “System Design and Energy Management for a Fuel Cell/Battery Hybrid Forklift”, Energies, Vol. 11, No. 12, p. 3440, Dec. 2018.

[15] S. Farhani, A. N’Diaye, A. Djerdir, and F. Bacha, “Design and practical study of three phase interleaved boost converter for fuel cell electric vehicle”, J. Power Sources, Vol. 479, p. 228815, Dec. 2020.

[16] K.-C. Tseng, C.-C. Huang, and W.-Y. Shih, “A High Step-Up Converter With a Voltage Multiplier Module for a Photovoltaic System”, IEEE Trans. Power Electron., Vol. 28, No. 6, pp. 3047–3057, Jun. 2013.

[17] S. Somkun, C. Sirisamphanwong, and S. Sukchai, “A DSP-based interleaved boost DC–DC converter for fuel cell applications”, Int. J. Hydrog. Energy, Vol. 40, No. 19, pp. 6391–6404, May 2015.

[18] Z. Zhang, R. Pittini, M. A. E. Andersen, and O. C. Thomsena, “A Review and Design of Power Electronics Converters for Fuel Cell Hybrid System Applications”, Energy Procedia, Vol. 20, pp. 301–310, Jan. 2012.

[19] M. V. Naik and P. Samuel, “Analysis of ripple current, power losses and high efficiency of DC–DC converters for fuel cell power generating systems”, Renew. Sustain. Energy Rev., Vol. 59, pp. 1080–1088, Jun. 2016.

[20] S. Farhani, E. M. Barhoumi, and F. Bacha, “Design and hardware investigation of a new configuration of an

isolated DC-DC converter for fuel cell vehicle", Ain Shams Eng. J., Volume 12, Issue 1, pp. 591-598, March 2021

[21] E. Barhoumi, I. Ben Belgacem, A. Khiareddine, M. Zghaibeh, and I. Tlili, "A Neural Network-Based Four Phases Interleaved Boost Converter for Fuel Cell System Applications", Energies, vol. 11, no. 12, p. 3423, Dec. 2018.

[22] E. M. Barhoumi, P. C. Okonkwo, I. B. Belgacem, and M. Zghaibeh, "MPPT Control of an Interleaved Boost Converter for a Polymer Electrolyte Membrane Fuel Cell Applications", International Conference on Electrical and Information Technologies (ICEIT), pp. 1–5, Mar. 2020.

[23] X. Hu, X. Zhang, and X. Tang, "Model predictive control of hybrid electric vehicles for fuel economy, emission reductions, and inter-vehicle safety in car-following scenarios", Energy, vol. 196, pp. 117101, 2020.

[24] A. Sahbani, K. Cherif, K. Ben Saad, "Multiphase Interleaved Bidirectional DC-DC Converter for Electric Vehicles and Smart Grid Applications" International Journal of Smart Grid- ijSmartGrid, Vol.4, No.2, 2020.

[25] J. Han, J.-F. Charpentier, and T. Tang, "An Energy Management System of a Fuel Cell/Battery Hybrid Boat", Energies, Vol. 7, No. 5, pp. 2799–2820, Apr. 2014.

[26] J. Snoussi, S. Ben Elghali, M. Benbouzid, and M. Mimouni, "Auto-Adaptive Filtering-Based Energy Management Strategy for Fuel Cell Hybrid Electric Vehicles", Energies, Vol. 11, No. 8, p. 2118, Aug. 2018..

[27] P. Thounthong, S. Raël, and B. Davat, "Control strategy of fuel cell/supercapacitors hybrid power sources for electric vehicle", J. Power Sources, Vol. 158, No. 1, pp. 806–814, Jul. 2006.

[28] M. R. Banaei and S. G. Sani, "Analysis and Implementation of a New SEPIC-Based Single-Switch Buck–Boost DC–DC Converter With Continuous Input Current", IEEE Trans. Power Electron., Vol. 33, No. 12, pp. 10317–10325, Dec. 2018.

[29] S. Farhani and F. Bacha, "Modeling and control of a dc-dc resonant converter interfacing fuel cell in electric vehicle", 9th International Renewable Energy Congress (IREC), pp. 1–6, Mar. 2018.

[30] F. Slah, A. Mansour, M. Hajer, and B. Faouzi, "Analysis, modeling and implementation of an interleaved boost DC-DC converter for fuel cell used in electric vehicle", Int. J. Hydrog. Energy, Vol. 42, No. 48, pp. 28852–28864, Nov. 2017.

[31] E. M. Barhoumi, S. Farhani, and F. Bacha, "High efficiency power electronic converter for fuel cell system application", Ain Shams Eng. J., Available online 19 February 2021. https://doi.org/10.1016/j.asej.2021.01.010

[32] J. Zhao, Q. Jian, L. Luo, B. Huang, S. Cao, and Z. Huang, "Dynamic behavior study on voltage and temperature of proton exchange membrane fuel cells", Appl. Therm. Eng., Vol. 145, pp. 343–351, Dec. 2018.