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Experimental Study of Design and Implementation Classical Controller into Fuel cell/Battery Hybrid System

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Abstract. *In this study of power management, the hybrid system consists of a 1.2kW Nexa PEM fuel cell, three 12V batteries, DC/DC converters to power Unmanned Aerial Vehicles (UAV). The control strategy is control the power between the FC and the battery by using PID controller is based on the following principle: The PEMFC is the main power supply for the electric engine driving the propeller and has to be operated at optimal efficiency. In the case that the FC cannot completely supply the power demands, the battery will provide short burst power demands as required. Simultaneously the FC should keep the battery sufficient charged at all times. The maximum NexaPEM fuel cell efficiency is about 50% at part load and drop to 38% at full power. All the goals above were achieved through control of the voltage and current of the step-down bidirectional DC6350F-S converter in batteries side.*

Keywords: *control, power management, hybrid system, fuel cell*

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I. INTRODUCTION

For achieving the power density of batteries with the energy density of FCs the two electrical sources can be used together as a hybrid power source. Such a hybrid system could supply up to 100% of the power from the FC alone before having to draw power from the batteries. The issue of increased system mass and volume has been largely resolved through the use of commercially power control circuits such as DC converters. Successful application of these has led to FC/battery hybrid power source with only a 13% increase in mass compared to the FC alone [1]. The batteries can be recharged by the FC subject to safety limits on both the FC power and battery charging current. Brodd has reported that lithium-ion cells batteries have their high energy output to weight ratio are already playing a significant role in limiting the weight of hybrid systems [2].

Lee et. al., tested the performance of a hybrid system consisting of FCs and a battery [3]. As predictable they found that during low power demands the FC can charge the battery, which in turn assisted the FC to meet the power demands at high loads and maintaining FC operating at high efficiency. They also made a number of more detailed observations one of which stated that as the humidification of the air supply increased, so did the FC stack power and that when there was a sudden increase in the load there was a short delay in the battery's response. There are many strategies exist for the control of hybrid power system. Jiang et. al., researched flexible strategies for multi-objective control of a power converter that could be applied to two different hybrid configurations of battery and FC without any change [4]. The simulation results showed that the multi-objective control strategy is able to select the regulation mode correctly. The FC current, battery current and battery voltage were regulated appropriately and results validated by experimental work.

In this research work, controlling the power between the FC and the battery by using classic PID controller is based on the following principle: The PEMFC is the main power supply for the electric load and has to be operated at optimal efficiency. In the case that the FC cannot completely supply the power demands, the battery will provide short burst power demands as required. Simultaneously the FC should keep the battery sufficient charged at all times.

II. EXPERIMENTAL SET-UP

2.1 Nexa fuel cell system

The Nexa power module is a small, low maintenance and fully integrated system that produces unregulated DC power. It contains a Ballard fuel cell stack, as well as all the auxiliary equipments necessary for fuel cell operation. Auxiliary subsystems include oxidant air supply, hydrogen delivery and cooling air supply. Also it has sensors monitor system performance. The control board and microprocessor fully automate operation. The Nexa system incorporates operational safety systems for indoor operation.

Hydrogen is the fuel used in the system; it is flammable substance, colourless and odourless. It is highly combustible in the presence of oxygen and burns without colour flame. For this reason the Nexa FC system had to be installed in well-ventilated lab area equipped with hydrogen alarm sensors, extractor fan for air circulation in the lab and for safety during FC operation. Fig. 1 shows Nexa power module FC system set-up in the lab.

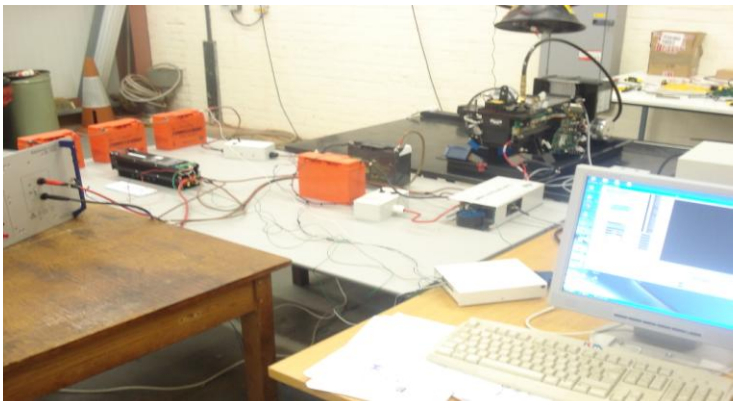

Fig. 1: Fuel cell/battery hybrid system set-up

The Nexa fuel cell output voltage level can vary from 43V at no load to about 26V at the full load. The operating temperature in the stack is around 65 ^{0}C at the full load. The stack is consisting of 46 cells, each with a 110 cm^2 membrane. The system is auto-humidified and air-cooled by a small fan. Regarding the hydrogen feeding of the Nexa fuel cell, the fuel is 99.99% hydrogen with no humidification, and the hydrogen pressure to the stack is normally maintained at around 1.8 bar. The maximum Nexa system efficiency is about 50% at part load and drop to 38% at full power (Fig. 2). A PC was used for the acquisition of the measured values, and in order to simulate a variable power demand, the energy produced was delivered to an electronic load.

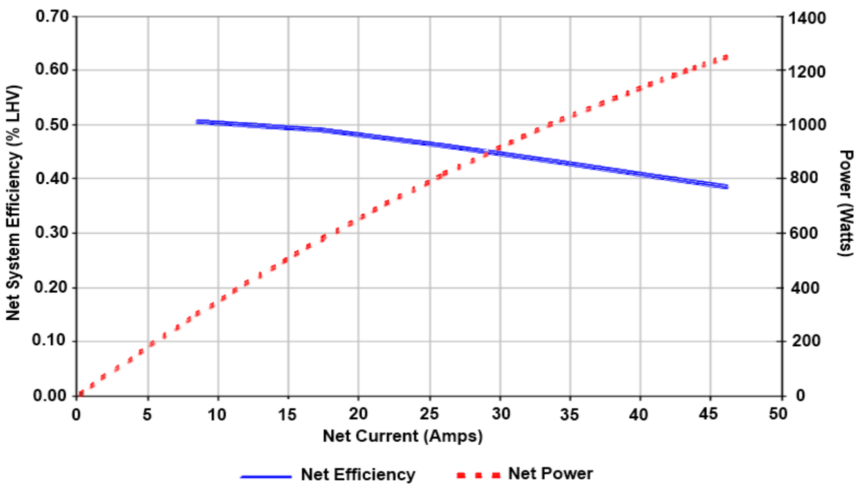

Fig. 2: Nexa FC power module efficiency

2.2 Fuel cell/battery hybrid system set-up description

FC hybrid system consists of a 1.2kW Nexa PEMFC, three 12V lead acid batteries, a unidirectional step-down DC/DC converter connected to the Nexa FC, a bidirectional DC/DC converter connected to the batteries and programmable electronic load. The bus voltage between the two converters is 27V. The schematic diagram of hybrid system is shown in Fig. 3. This architecture enables us to achieve both the high-energy density from the fuel cell and the high-power density from the batteries [5-7] to satisfy desired power for different phases of flight. In the experiment, power demand was implemented via the programmable electronic load. The PCI-6259 data acquisition (DAQ) was used to communicate between MATLAB and the hardware for sending and receiving data. The external connection, the NI SCB-68 connector block was used for interfacing

I/O signals and to plug in data acquisition device via 68-pin connector. The SCB-68 rack can only accept voltage levels up to 10V so a voltage divider was used to step down voltages above 10V and the readings were then scaled back in the software. The current flowing through the various devices was sensed using numerous AMP25 Linear-to-60A Hall sensors.

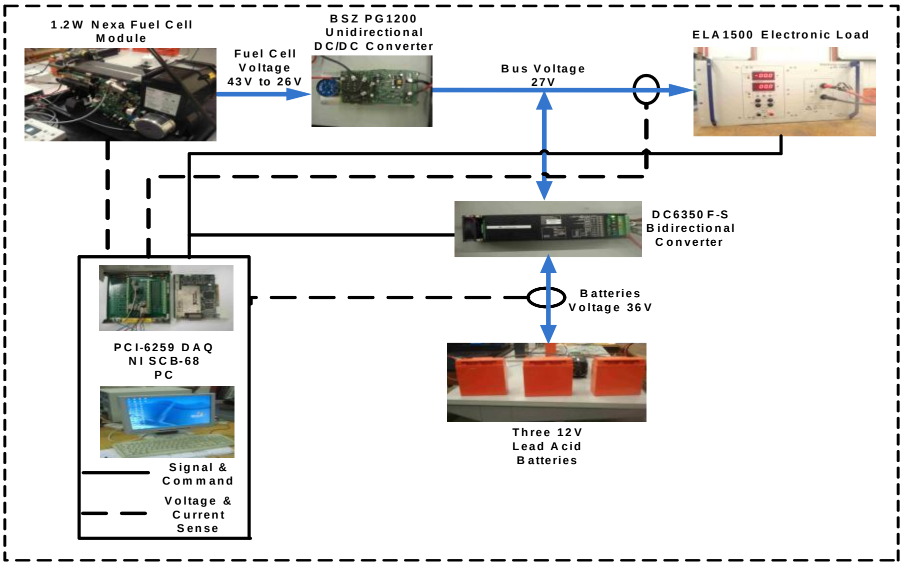

Fig. 3: The schematic diagram of fuel cell/battery hybrid system

III. PID CONTROLLER HARDWARE-IN-THE-LOOP IMPLEMENTATION & RESULTS

The optimal operating region of the Nexa FC is in the range between 8A to 29A. During hardware-in-the-loop testing a differential component was found to be necessary to maintain performance. Therefore, a PID controller was designed and implemented in hardware-in-the-loop to control the battery current in FC/battery hybrid system which was described in Section 2.2, controller schematic diagram is illustrated in Fig. 4. For safety considerations, a saturation block is located between the controller and DC converter. The controller parameters were tuned manually and they are: KP = 0.003, KI = 0.0001 and KD = 0.001. The load current was step changed at t = 615 seconds, t = 731 seconds and t = 861 seconds between 5A and 35A as shown in Fig. 5. With each step change it can be seen that the current drawn from the FC followed the load current, while the battery current showed a significant delay. In fact the batteries took about 10 seconds to supply around 10A. This was due to the controller's integral component which introduced a lag into the closed loop system, but could not be removed as it was necessary for minimising steady-state error.

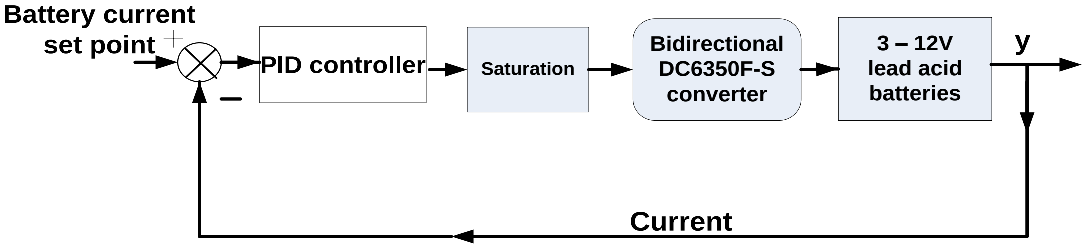

Fig. 4: Schematic diagram of the PID controller

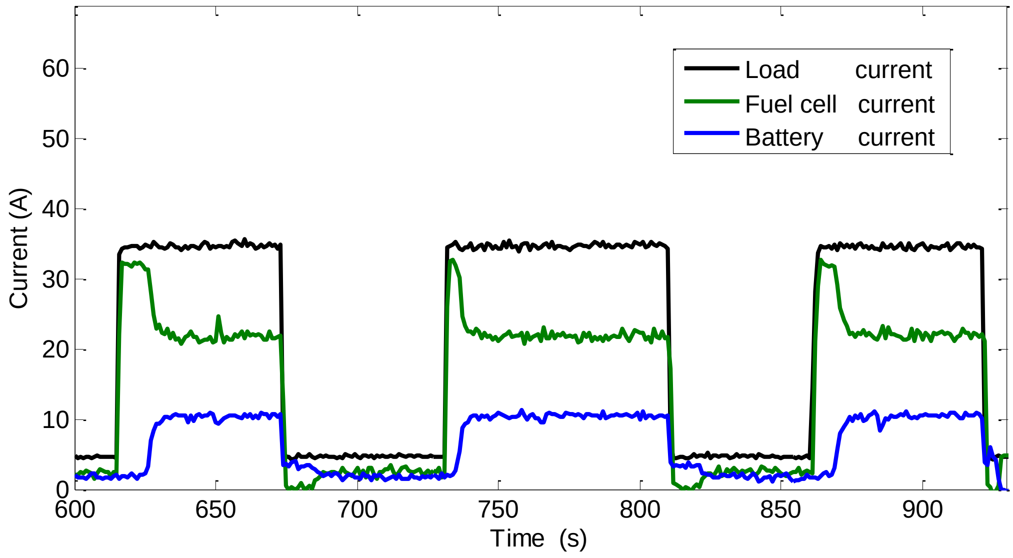

Fig. 5: Load, fuel cell and battery step current with PID controller

To improve the PID controller response, a basis was added to the control loop between the controller and bidirectional DC converter as shown in Fig. 6. The test was then repeated with the same controller parameters: KP = 0.003, KI = 0.0001 and KD = 0.001. Fig. 7 shows the load current was varied at t = 824 seconds, t = 945 seconds and t = 1076 seconds from 5A to 35A. With each step change it can be seen that the current drawn from the FC followed the load current with small overshoot, while the battery current showed a very small delay compare with controller without basis. The batteries current response takes about 2 seconds to supply around 10A.

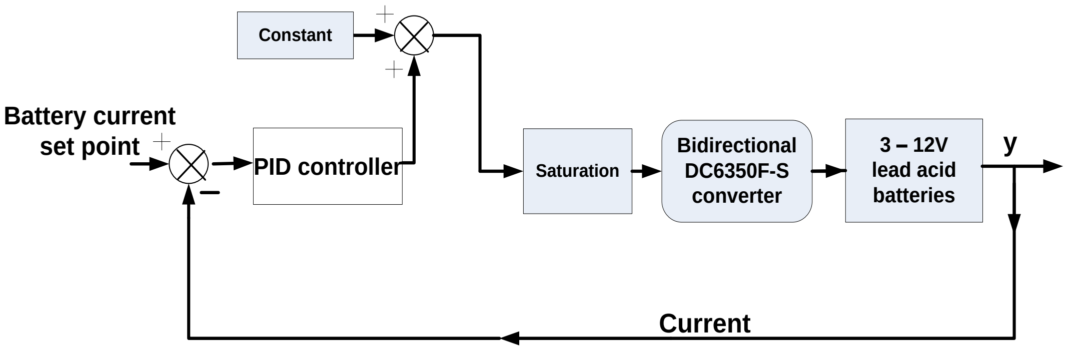

Fig. 6: Schematic diagram of the PID controller with basis

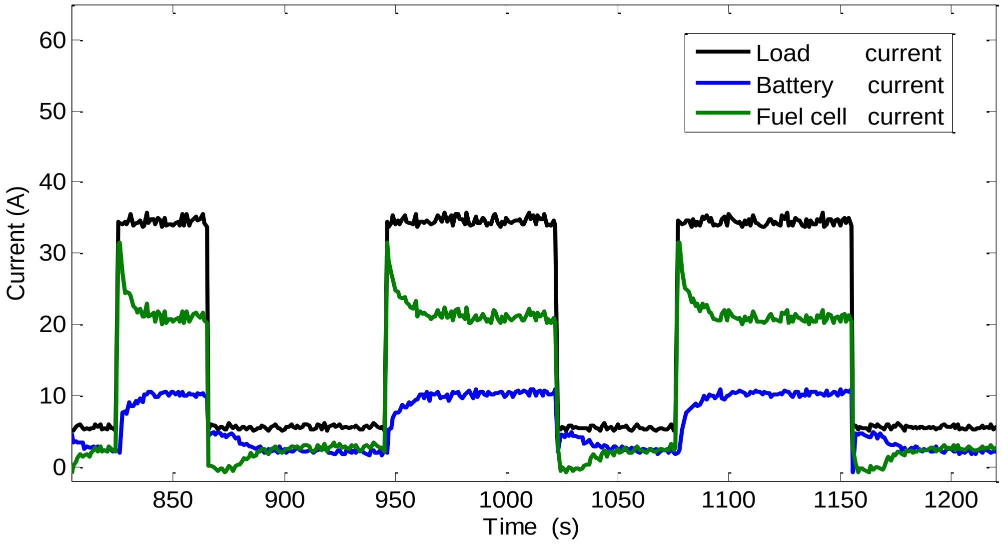

Fig. 7: Load, fuel cell and battery step current with PID controller with basis

IV. CONCLUSION

The power management between the FC and the battery in the hybrid system has been investigated in this paper. The strategy was to develop a classical PID controller to control the system behavior when the system was subjected to test cycles designed for load variation. The PID response was satisfactory by adding a basis for initial condition; however, a more advanced controller was needed to provide faster response time. Based on this study, we recommend a feed-forward fuzzy logic controller for future work, since the feed-forward output is not affected by the system feedback, it will not cause the control system to oscillate. Also, improved the system response and stability.

V. FUTURE INVESTIGATIONS

It is known that FC is used to store electrical energy in integration with PV solar fields [8] To supply a small load such as radio transmitting stations for mobile phones or large loads [9-13] instead of Diesel generators which considered the main sources of air pollutions [14]. For Libya, the drivers for that are that the national grid is not so robust, where many problems such as voltage dip/sag/ instability and power instability occur frequently, and to reduce the air emissions from electrical energy generation sector of Libya, because this sector is the main source of pollution in the country [15-18]. In additional to the country has significant potential of solar and wind energies [19-23]. However, its use in Libya is not yet confirmed. There are many articles in the field of solar electricity generation and storage methods such as PHS [24]. Therefore, the research is continuing to figure out the economic and technical feasibility due to the use of this technology in storage at the strategic level in Libya.

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