Journal of Petroleum Technology and Alternative Fuels Vol. 2(7), pp. 103-110, July 2011
Available online at http://www.academicjournals.org/JPTAF

Full Length Research Paper

Power transfer analysis of a hybrid fuel cell/battery as portable power source generator

Joevis J. Claveria* and Akhtar Kalam

School of Engineering, Science and Health, Victoria University of Technology, Victoria, Australia.

Accepted 9 May, 2011

The configuration of hybrid power system (HPS) are widely used and accepted in providing a stable and higher power capability sources in generating energy for human needs. Hybrid configuration is composed of at least two generating sources combined to produce larger supply of energy. The advantages of using hybrid configuration are distinctively beneficial. It reduces the stress on each source and decreases the internal power loss of the system. It also smoothes the hybrid source terminal voltage of the system due to load demands and create quality energy when conventional source is incapable. Moreover, in portable application, it is quicker to replenish the fuel for a fuel cell than for a battery which requires recharge. This paper presents an analysis of hybrid system consisting of- a fuel cell and battery as portable power source. The fuel cell used in this experiment is a Heliocentris TM "Constructor", a 50 W proton exchange membrane (PEM) fuel cell, a rechargeable lead acid battery pack, DC – DC converter and a variable resistive load. The experimental results show the characteristics of the hybrid configuration under different load conditions.

Key words: Hybrid power system (HPS), proton exchange membrane fuel cell (PEMFC), DC-DC converter, microcontroller, pulse width modulation (PWM), lead acid battery.

INTRODUCTION

According to the International Energy Outlook (2010), the use of renewable energy is the fastest growing source of electricity generation. The estimated total generation from renewable resources increases by 3.0% annually and the renewable share of world electricity generation grows from 18% in 2007 to 23% in 2035 (U.S. Energy Information Administration, 2010). The increase in the use of renewable resources is remarkable and accepted globally; promoting the green revolution of power energy. The boost in generating capacity using alternative generating sources like wind, hydropower, solar, bio-fuels and fuel cells are most likely to be used in supplying additional energy to the grid, power back up application and in stand-alone portable power generation.

The introduction of utilizing renewable energy resources improves the energy production, fuel economy and operating performances of a system. It shows significant environmental benefits in terms of operation and purpose. Hence, distributed generation of energy has an excellent effect in combining different alternative sources of energy in power industry to step-up the use of renewable energy.

A rewarding improvement in the generation area is the hybrid power systems. Hybrid power system (HPS) is a process of combining at least two sources providing energy in a system. Both could work at the same time or alternately generate energy in a system. Initially, HPS were designed for powering remotely located telecommunication stations by integrating one or two renewable energy sources with storage devices such as batteries (Maskey et al., 2010). The significance of this became popular for remote area power generation applications and a reasonable solution to cover up the energy demands of both stand-alone and grid connected consumers (Dagdougui et al., 2010). Hybrid systems are more likely to yield energy once it is needed. A concrete

*Corresponding author. E-mail: joevis.claveria@live.vu.edu.au.

illustration of this configuration is the fusion of a micro hydropower generator and batteries in remote location. The downfall of this arrangement arises due to insufficient amount of water to supply the micro hydropower plant during summer time. On this occasion, batteries work alone to sufficiently provide enough energy to a residential home.

Another type is the combination of wind power and batteries. The irregular blowing of wind is another concern on this design. Furthermore, the photovoltaic (PV) cell and batteries are also used. The inadequacy of sunlight, weather conditions and the intensity of sunlight that the PV absorbs are the drawback of this configuration. However, the backup batteries are continuously and perfectly providing energy to the load.

Generally, batteries play a very important role in a hybrid power system. They are often used as an energy storage unit for the DC power produced from different charging sources (that is, PV modules, wind generator, micro-hydro generator and fuel cell). Aside from this, they are also a good back-up power source of energy when primary source cannot deliver the intended supply to the load (Batteries, 2009).

A novel hybrid configuration is fuel cell and batteries. The significant aspect as presented in this paper is the production of energy from the fuel cell is continuous as long as there is uninterrupted supply of hydrogen (H_2) to the fuel cell. The use of a fuel cell in stand-alone generation is promising due to the characteristics of the fuel cell. It has: high efficiency conversion; high power density; low emission; operates quietly; simple in construction (Larminie and Dicks, 2000).

Hybrid fuel cell/battery power sources have potentially widespread uses in applications wherein the power demand is impulsive rather than constant. Such systems could provide much needed capability of high current pulses and extend the operation time of comparable in size and weight battery system. This is especially true for the military applications (Gao et al., 2004; Cygan et al., 1998).

This arrangement defies the downside of other hybrid configurations. It is not affected by weather, wind condition and circumstances of sunlight hours. Aside from this, the high efficiency of the fuel cell makes this design on top of these configurations.

Hybridization is the key in the fast growing source of electricity generation in the world, especially with the renewable energy resources that were involved in the production. It offers several advantages over a single source generation system. One of the advantages of using a hybrid power system is a continuous supply of power to the load when other source fails.

The improvement of this system is significant to economic, social, technological and environmental challenges point of view. As a result, this paper is arranged as follows. Subsequently, the components used are enumerated and the hybrid design of the fuel cell and battery is shown, after which the systems configuration and its set-up are analyzed. This is followed by verifying the viability of the experimental results and measurements of the experiment, before presenting the conclusion. The result of the study shows the capability of a hybrid fuel cell and battery to act as stand-alone portable power generator. This will provide other researchers to study and design a hybrid source using other alternative energy resources.

HYBRID CONFIGURATION

Lead acid battery

A deep-cycle battery has the ability to work for a long period of time. Lead acid is a type of a deep-cycle battery that is designed to regularly charge and discharge almost 80% of their capacity hundreds of times. It was designed to absorb and give up electricity by a reversible electrochemical reaction. Lead acid battery is a complex, non-linear device exhibiting memory effect in hybrid power systems. On the other hand, automotive starting, lighting and ignition batteries are of shallow-type and are not recommended for use for renewable systems since they only discharge small amount of their capacity (Gao et al., 2004; Saiju and Heier, 2008).

When compared with other types of deep cycle batteries, the rating of lead acid battery is average on efficiency conversion. In this research, further experiments will be done using other types of deep-cycle batteries.

Microcontroller board

A microcontroller unit (MCU or µC) works like a small computer on a single integrated circuit consisting internally of a relatively simple processor, clock, timers, input/output (I/O) ports and memory. The microcontroller board controls most of the parameters in the system, including the generation of pulse width modulation (PWM) for the electronic gate switch and the battery charge/discharge state.

DC – DC converter

The heart of the energy conversion between a generator and a load is a converter. In this paper, the experiments were conducted at Victoria University's Power laboratory that uses a DC-DC boost converter. This converter implies that the output voltage is higher than the input

Table 1. Technical data of fuel cell stack.

Denomination	Specification
Rated output power	40 W
Maximum output power	Approximately 50 W
Open circuit voltage	Approximately 9 V
Voltage at rated power	5 V
Maximum current	10 A
Current at rated power	8 A

voltage. Moreover, the addition of embedded electronic converters in renewable power system is now used for higher efficiency result. They are more efficient when compared with the conventional converters.

Resistive load

The load used in this experiment was a variable resistive load. It is linear and simpler to investigate its characteristics.

Constructor fuel cell

The constructor (Heliocentris Constructor Instruction Manual, 2008) is a 50 W, proton exchange membrane (PEM) fuel cell. Basically, a PEM fuel cell is a type of fuel cell that uses a polymer mebrane that separates the hydrogen and oxygen ions to produce electricity. The PEM fuel cell operates between 50 to 100°C. New applications are growing in the field of portable power generation, where fuel cells are compared with primary and rechargeable batteries in portable electronics.

Table 1 illustrates the working speciifications of the Constructor fuel cell stack used in the experiement.

SET UP AND SYSTEMS CONFIGURATION

In Figure 1, the set-up and systems configuration of the experiment is technically detailed. The fuel cell is directly connected to an input filter, followed by the converter, the battery, the output filter and the load.

The purpose of this hybrid configuration set-up is to analyze the power transfer of the fuel cell and battery to the load and to study the response of the system when an increase of load occurs. Table 2 shows the components needed for the experiment. They are critically analysed to provide closer value to what is expected.

EXPERIMENTAL RESULTS AND MEASUREMENTS

The results achieved from this experiment are limited to the resistive variable load only. Due to the low specification of the components used, errors are considerably present on this experiment.

Fuel cell configuration

Figure 2 represents the fuel cell and load configuration. This arrangement specifies the allowable maximum load or the maximum power point of the fuel cell alone. It was completed by directly connecting the fuel cell and adjusting the load gradually to its maximum value. The output load voltage, current and effective power of the fuel cell is varying or unregulated.

It was found out that the measured open voltage of the fuel cell is 8.73 V_{dc}. The variable load was connected and gradually varies from 2 to 40 Ω, which shows the maximum and minimum voltage of 7.43 and 4.72 V_{dc}, respectively. The maximum voltage of 7.43 V_{dc} happened at 40 Ω load and the minimum voltage of 4.72 V_{dc} occurred at 2 Ω load. Furthermore, the maximum and minimum currents are 4.27 and 0.22 A_{dc}, respectively.

The result in this configuration shows the minimum and maximum power capabilities of the fuel cell alone. It was also noted that the measured voltage and current of the fuel cell takes some time to respond when load was gradually changed. By means of the power formula:

$$P_{fc\ (max)} = I_{(max)}^2 \ x \ R_{Load} \quad (1)$$

Where, $P_{fc\ (max)}$ – maximum power of fuel cell; $I_{(max)}$– maximum current of fuel cell; R_L – load resistance.

The maximum current on this experiment is 4.27 A_{dc} when the load is 2 Ω. Therefore, the maximum power of the fuel cell in this configuration is 36.465 Watts.

Battery configuration

In Figure 3, the specification of the Lead acid battery used in this experiment is a 12 V, 0.8 Ah rechargeable battery. Generally, the formula used in calculating the energy of battery is:

$$P_{bat} = E_{bat} \ x \ (Ampere/hour)_{bat} \quad (2)$$

The computed value of the battery in this experiment is *9.6 W/h*. This value is assumed using the Ideal battery characteristic which means that the battery has no

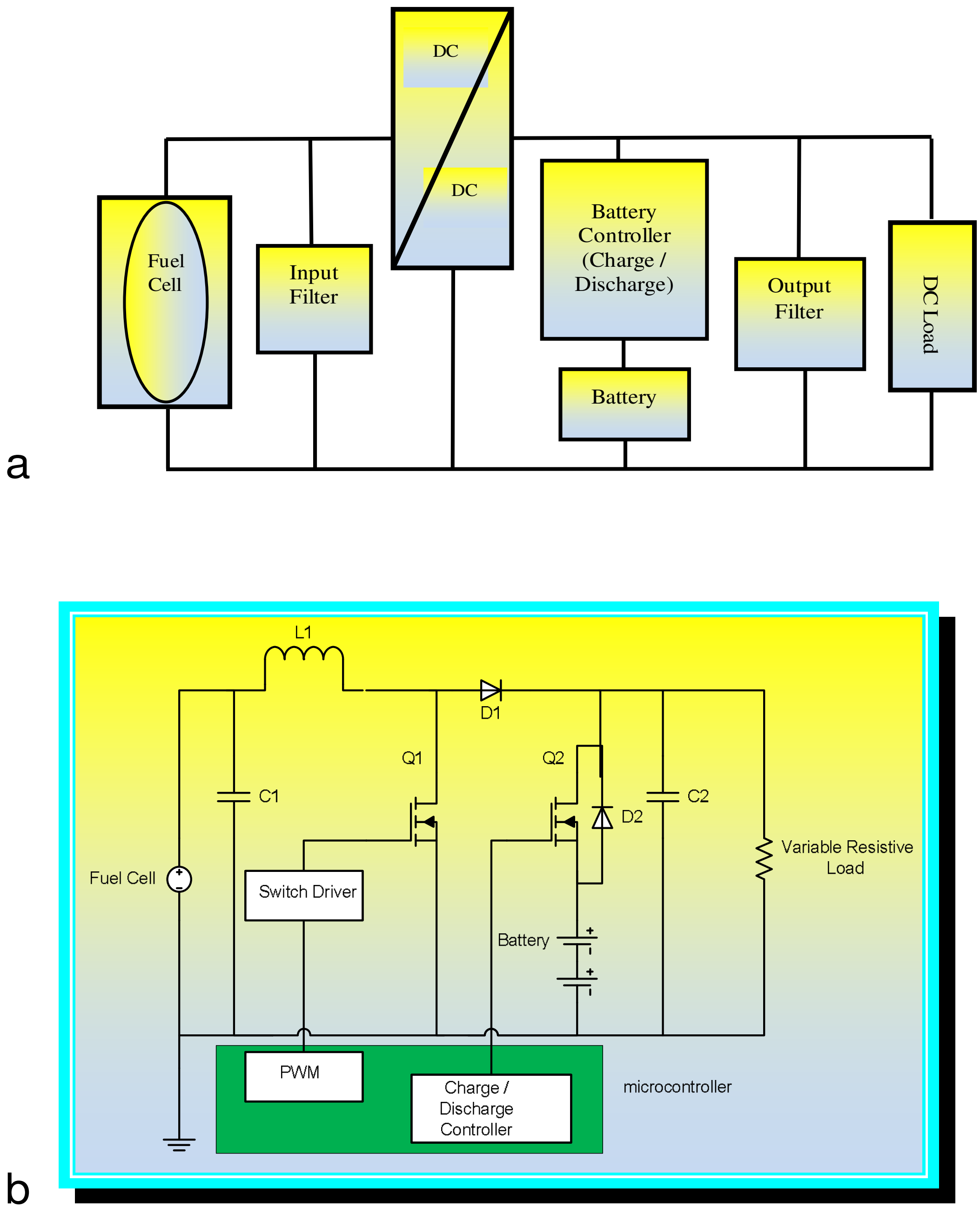

Figure 1. (a) Block diagram; (b) circuit diagram of hybrid fuel cell/battery configuration.

Table 2. Specifications of hybrid power source.

Power Source	Specification
Fuel cell (Constructor)	50 W, PEM fuel cell, 10 cells in series
Battery pack	12 V 0.8 Ah rechargeable, lead acid battery
DC-DC converter	Input voltage 4-8 Vdc, output 12 Vdc (boost)
Microcontroller	PWM generator, Battery controller
Resistive load	Variable load 0-40Ω

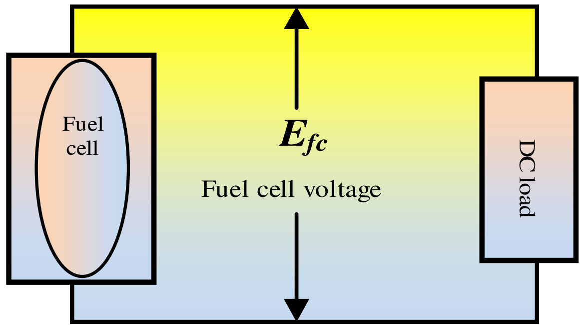

Figure 2. Fuel cell and load.

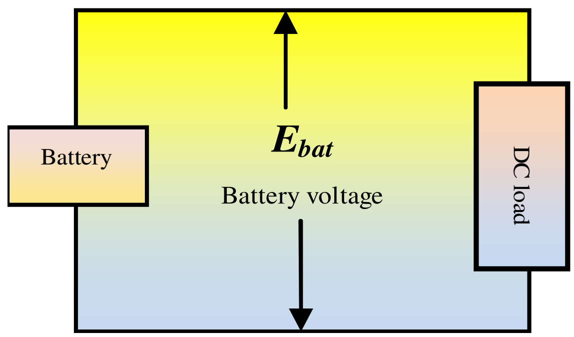

Figure 3. Battery and load.

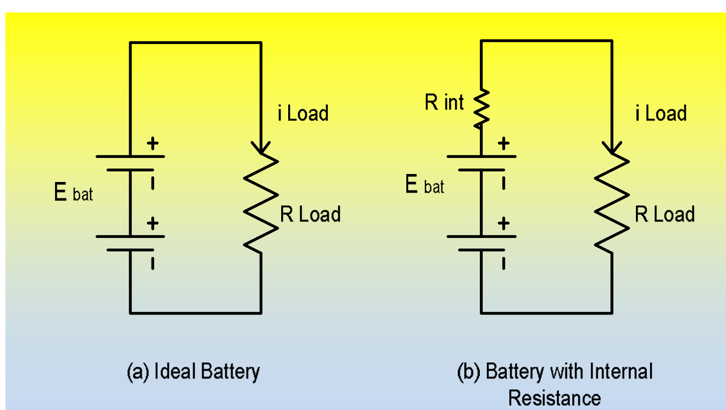

Figure 4. (a) Ideal battery; (b) battery with internal resistance.

internal resistance. The voltage across the battery is exactly the same voltage across the load. This is commonly used in theoretical analysis and computer circuit simulation of battery.

On the other hand, the battery with internal resistance is the actual analysis of an equivalent battery. It has an internal resistance and builds up a voltage drop in a circuit. Therefore, the actual energy that the battery will supply in the system will be less than *9.6 W/h* due to the voltage drop from the internal resistance of the battery.

The following formula illustrates the difference of the ideal battery and the actual battery in Figure 4:

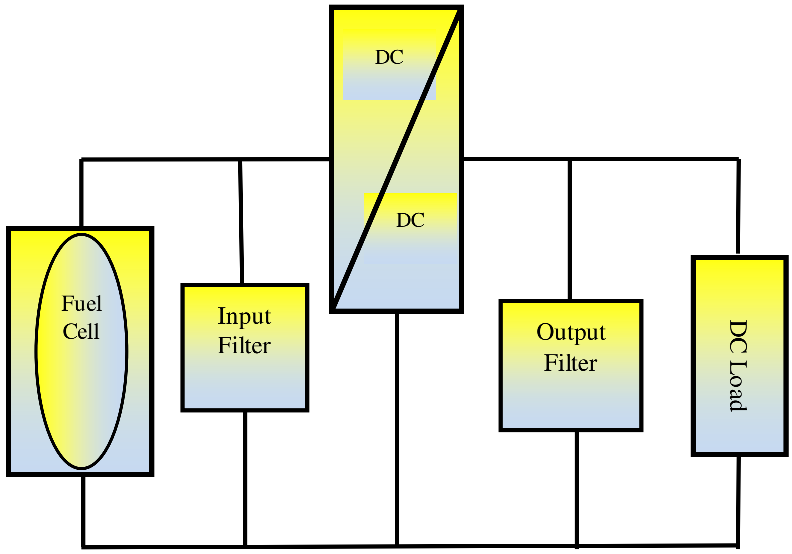

Figure 5. Fuel cell, DC-DC converter and load configuration.

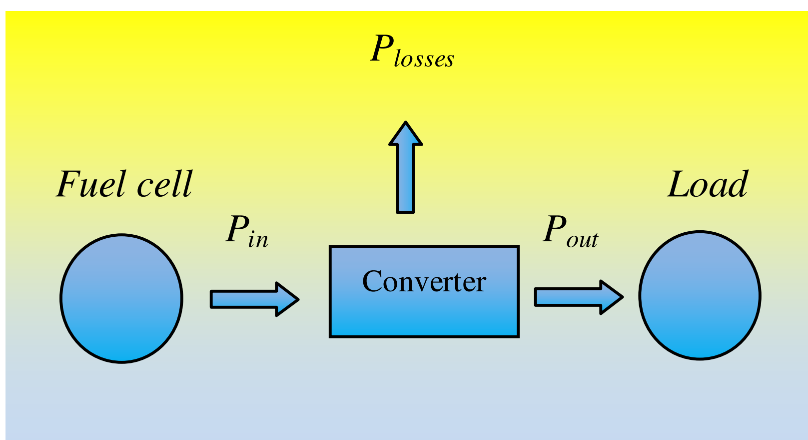

Figure 6. Energy conversion of Figure 5.

$$E_{bat} = i_L\ (R_L) \quad (3)$$

$$E_{bat} = i_L\ (R_{int} + R_L) \quad (4)$$

Fuel cell, DC-DC converter and load configuration

Another type of configuration tested was the fuel cell, DC-DC converter and load arrangement. The experiment was done by connecting the entire component following Figure 5. The load is gradually adjusted from zero to 40 Ω and the value of currents and voltages are recorded.

The output power of the fuel cell serves as the input power to the converter. The boost converter performs the energy conversion process by converting the power of the fuel cell at low voltage to a higher designated usable voltage.

In the process of energy conversion, the three important aspects to consider are the input power, output power and power losses in the system. The converter converts energy and dissipates power, while the conversion process takes place. Figure 6 illustrates the energy conversion of the system fuel cell, converter and load. Power losses in the system are vital. Generally, the

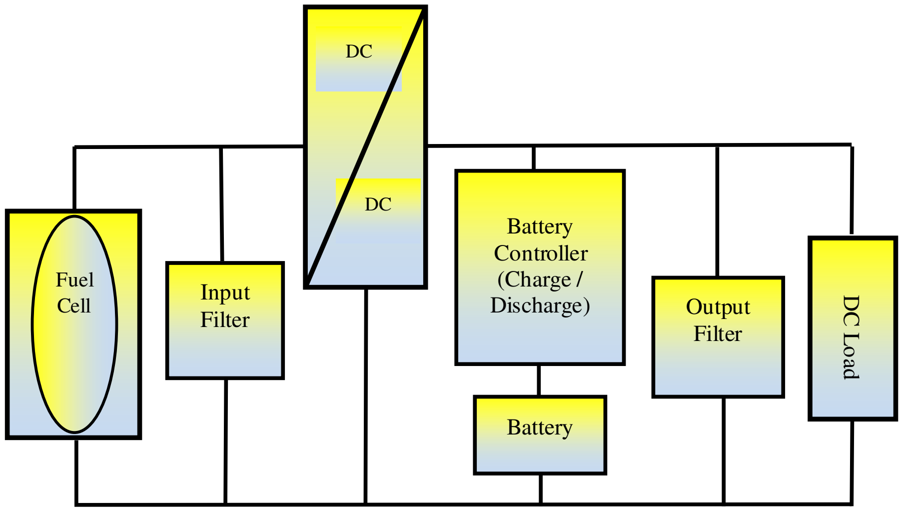

Figure 7. Fuel cell, DC-DC converter, battery and load configuration.

conduction and switching losses of silicon devices are accountable on power losses in a converter. In conduction losses, all silicon devices have resistance associated with it and this causes power loss. Similarly, the switching losses are linked to semiconductor components, like transistors, that continuously switch and dissipate power when in operation. Aside from these, heat is also a factor.

The formula representing Figure 6 in terms of power conversion is:

$$P_{in} = P_{out} + P_{losses} \quad (5)$$

$$P_{out} = P_{in} - P_{losses} \quad (6)$$

Where P_{in} – actual power of the fuel cell; P_{out} – output power of the converter; P_{losses} –power losses in the syste .

Fuel cell, DC-DC converter, battery and load configuration

Figure 7 demonstrates the hybrid configuration of the fuel cell/battery as portable power source in a system. Figure 8 illustrates the equivalent block diagram of the fuel cell and battery in terms of power conversion. The power formula of Figure 8 in terms of power conversion is:

$$P_t = P_{out} + P_{bat} \quad (7)$$

Where: $P_{out} = P_{in} - P_{losses}$

Therefore:

$$P_t = P_{in} - P_{losses} + P_{bat} \quad (8)$$

Where P_t – total power of the hybrid; P_{in} – actual power of the fuel cell; P_{out} – output power of the converter; P_{bat} – output power of the battery; P_{losses} – power losses in the system .

The actual maximum power generated from the fuel cell is 36.465 watts which is the input power to the converter, P_{in}. The conversion process takes place on the converter and produces the usable power to a higher voltage. The output power of the converter was measured to be 23.835 W from the fuel cell, DC-DC converter and load configuration. This is the maximum allowable power produced by the converter when the battery is not yet coupled.

In order to obtain the efficiency of the converter in the system, the formula for efficiency is used:

$$\% \ efficiency = \frac{P_{out}}{P_{in}} \ x \ 100\% \quad (9)$$

The percent efficiency of the converter is 65.36%. Higher efficiency of the converter may be achieved by critically analyzing the selection of electronic components to be used in improving the power density and thermal performance of a converter (Moxey, 2008).

The experimentation of the hybrid configuration was done by gradually changing the load demand from zero to 40 Ω. It was found out that the maximum total power of the hybrid system is 26.542 W.

The power of the battery delivered to the load can be calculated using formula (7):

$$P_{bat} = P_t - P_{out}$$

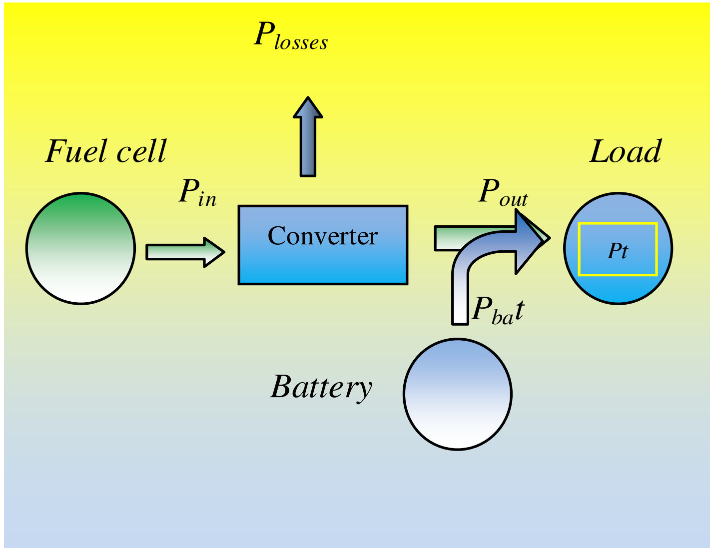

Figure 8. Energy conversion of Figure 7.

The maximum power delivered by the battery to the load is 2.707 W for a period of time. The battery operates to provide power both during load transients and during peak loads of the system. The percent increased of power to the system can be calculated using the formula:

$$\% \ increased = \frac{P_t - P_{out}}{P_{out}} x \ 100 \qquad (10)$$

The percent increased by the battery to the system is 11.36%.

Conclusion

The analysis on a hybrid fuel cell/battery is significant compared with other configurations which are used as portable power source generator. It defies the downside of other types of hybrid power resources. It was also evaluated on the experiment that the fuel cell is slow in responding on instantaneous varying load demands. Thus, the addition of battery to the system helps the fuel cell to handle the load where it draws the power from the battery until the fuel cell supports the increased of load demand. The battery provides additional power of 2.707 W for a period of time and a power increased of 11.36% in the system.

The converter is responsible for the energy conversion of the fuel cell and converts the power to a higher voltage application. The size of the converter and its components are essential for energy conversion process. This means fewer components involve, means less power losses in energy conversion stage. Moreover, the addition of microcontrollers and high efficient power converters are considered new and must be incorporated in further researches on hybrid power systems.

REFERENCES

U.S. Energy Information Administration (2010). International Energy Outlook 2010, U.S. Depatment of Energy.

Maskey RK, Mult HC, Nestmann F (2010). Hydro based renewable hybrid power system for rural electrification: A concept paper, [Online] Viewed 2010, 5 November. Available: http://www.mtnforum.org/apmn/hybridconcept.htm.

Dagdougui H, Minciardi R, Ouammi A, Robba M, Sacile R (2010). Modelling and control of a hybrid renewable energy system to supply demand of a green-building, International Environmental Modelling and Software Society *(iEMSs)*, Ontario, Canada, pp. 1-8.

Batteries (2009). Kyocera Solar Electric Products Catalog,pp. 44-49.

Larminie J, Dicks A (2000). Fuel Cell Systems Explained, John Wiley and Sons Ltd., England, pp. 21-24.

Gao L. Jiang Z, Dougal RA (2004). Performance of Power converters in Hybrid Fuel Cell/ Battery Power sources. 35th IEEE Power Electronics Specialists Conference. Columbia, SC., 3: 2018-2022.

Cygan PJ, Atwater TB, Jarvis LP (1998). Hybrid power sources for military applications. 13th Annual Battery Conference on Applications and Advances, pp. 85-90.

Saiju R, Heier S (2008). Performance Analysis of Lead Acid Battery Model for Hybrid Power System. Transmission and Distribution Conference and Exposition. Chicago, IL, pp. 1-6.

Heliocentris Constructor Instruction Manual (2008), Version 0.0, March 2008.

Moxey G (2008). DC/DC converter efficiency revisited, [Online] Viewed 2010, 10 December. Available: http://www2.electronicproducts.com/Dc_dc_converter_efficiency_revisited-article-FAJH_Energy_Jul2008-html.aspx.