Simple MPPT Technique for DC-DC Converter in Fuel Cell System

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Abstract – *This paper presents the simulation of fuel cell mathematic model interfaced with DC-DC boost converters. The drawbacks of the fuel cell stack are that it lacks maximum power to generate the suitable application and high input current ripple. So, the maximum power point tracking (MPPT) technique of voltage constant controller is implemented to the system to extract the maximum power from the fuel cell. The MPPT technique forces the fuel cell to meet the maximum power that the fuel cell can generate. This MPPT method increases the efficiency of power delivered from the fuel cell. The benefits of the converter chosen are the interleaving technique used in converter reduced the current ripple that could damages the fuel cell stack. The converters chosen is the conventional dc boost converter and interleaved boost converter that will be simulated along with the MPPT algorithm in MATLAB/Simulink environment. The interleaved boost converter has also chosen for its advantages of reduction of passive component's size, as well as reduced the current ripple. It is proved that the MPPT method of constant voltage gives a stable and linear performances in designing a high efficient fuel cell system.*

Keywords: *fuel cell, MPPT, interleaved converter*

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I. Introduction

Clean energy in conversion technology is an alternative to replace fossils fuels in transportation industry. As the fossil fuels decreases in supplies, green or renewables energy is chosen for its primary energy sources. However, significant renewable energy such as wind and solar are very dependent to nature or weather. A modern technology on fuel cell is brought to overcome the limitations. Fuel cells are used to convert the hydrogen energy to produce electricity. This could supply the grid or distribution network for many applications. For that reason, fuel cell is recommended for its low operating temperature, high power density and fast start up. There are many variety fuel cell types according to their electrolytes. Commonly used is the proton exchange membrane fuel cells (PEMFC) for the following reasons: (1) lower operating temperature; (2) lower operating pressure for better safety; (3) higher conversion ratio [1-4].

Fig. 1 shows the fuel cell reaction at the anode and the cathode electrode. At the anode electrolyte, the electrons are free by the ionisation of hydrogen gas and generated the H^+ ions, can be written as

$$2H_2 \rightarrow 4H^+ + 4e^-. \quad (1)$$

At the cathode electrode, by the reaction of oxygen and electrons from the electrode and H^+ ions from the electrolyte, water is formed [5-7], given by

$$O_2 + 4H^+ + 4e^- \rightarrow 2H_2O \quad (2)$$

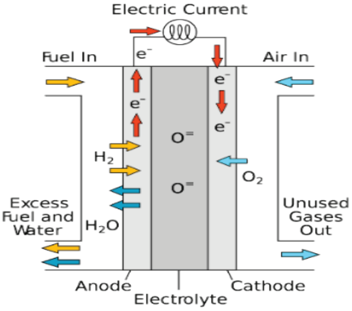

Fig. 1. Fuel cell chemicals reactions

Fuel cell calls for huge amount for an investment, therefore the ability to extract the maximal power from the fuel cell stack must be considered for an optimum performance of the system. Connecting the fuel cell with an external load, the output power depends on the internal electro-chemical reaction and the external load impedances. Fuel cell operating point is located at the fuel cell's I-P curve that intersect with load line. The operating point is called maximum power point (MPP), at which the fuel cell produces its maximum power as illustrated in Fig. 2. The MPP is varies with different model or type of fuel cell [8-12].

Previous researcher had studied on the decisive factor for the MPP determination such as the external load. By adding a variable load to the external load, they found that changing the external load could increase the effectiveness to alter the power delivery [10]. Up till recent, several studies on MPPT for fuel cell has been reported, but massive report on photovoltaic application is recorded. The methods including the famous perturbation and observe (P&O), conductance incremental method, the parasitic capacitance method and many more. Among them, P&O is the most commonly used but due to the limitations that its exhibits erratic instable behaviour under rapidly changing conditions, the algorithm is unsuitable for the job to track the frequent MPP in certain condition of fuel cell [14]. So, a simple algorithm is chosen to satisfy the system needs which is the constant voltage technique. Constant voltage often combined with other MPPT technique due to its simplicity [15, 16].

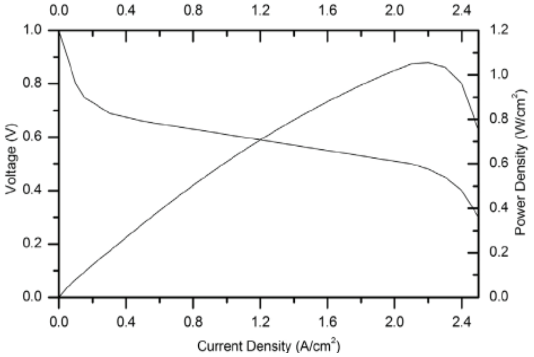

Fig. 2. Typical fuel cell polarization and power curves [12]

Other than to satisfy the conditions to extract the maximum power from the fuel cell stack, the fuel cell itself produces low voltage but high current energy sources. Thus, to make up the low voltage from the fuel cell to fed to high voltage application, DC-DC boost converter is needed. The DC-DC boost converter also could help in increasing the fuel cell life span as it could reduce the current ripple that sometimes feed back to the fuel cell and lead to fuel cell membrane damages. A conventional DC-DC boost converter (CBC) has reached its limitation [17]. Many studies have shown the extensive usage of DC-DC boost converter with different topology to satisfy each system requirement. This DC-DC boost converter has shown its capability to work in continuous conduction mode (CCM) and lead in increasing the fuel cell efficiency [18]. A high current ripple could cause problems such as excess fuel consumption, shortening its lifetime, and noises in overload situation [19].

Interleaved DC-DC boost converter (IBC) is a suitable solver for the limitations of the conventional DC-DC boost converter. By using interleaved boost converter, a high step up and ripple reduction system can be used for better output voltage and output current. The switching losses for the topology is reduced and has faster transient response [18-21]. The IBC has been considered as a satisfactory solution for its merits. Extensive studies have been carried out on the interleaved technique. In [22], a study had been done to obtain the optimal parameter values of the input inductors and output capacitors. Some of the studies also included the design considerations for the leg number, output load, switching frequency and dynamic response [23].

In this paper, the fuel cell mathematic model is used and combined with MPPT technique to control duty cycle for the interleaved boost converter. A detailed modelling of the converter topology will be discussed along with the MPPT technique. This paper are organized as follows: A dynamic model of the fuel cell, the MPPT technique and converter details are presented in Section II. In Section III, the simulation results are shown and discussed. The conclusions are presented in Section IV.

II. Methodology

Block diagram of the fuel cell MPPT system is shown in Fig. 3. This system includes the fuel cell model, a DC-DC converter, MPPT controller and load. A boost converter is chosen for its simplicity and high efficiency as well as step up the load voltage. The fuel cell act as the dc source for the converter, as well as the input for MPPT. The MPPT functioning to control the duty cycle of the converter, so that the maximum output power from the fuel cell can be obtained.

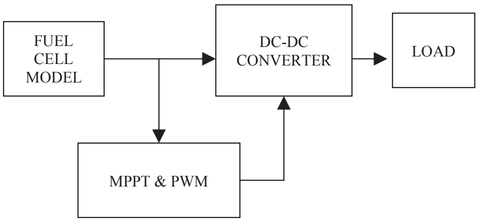

Fig. 3. Block diagram of MPPT system for PEMFC

A. Fuel Cell Polarization Curve

To investigate a PEMFC system, as mentioned in previous chapter, a comprehensive model of the PEMFC model is built. According to the literature, the PEMFC can be modelled based on mathematical equations on chemical reactions. The PEMFC model that has been developed is based on Horizon H-500 fuel cell stack with specifications is shown in Table I.

The static and dynamic model of the PEMFC is developed for power generation application. The mathematical model is based on the electro-chemical equations of the parameters in PEMFC. The model is simulated in MATLAB/Simulink and used to analyze the V-I and P-I curves of fuel cell. It is influenced by the temperature, oxygen partial pressure, hydrogen partial pressure and water membrane content [10]. When current is drawn from a fuel cell, the cell voltage V_{cell} decreases from its equilibrium thermodynamic potential, E_{nerst}. This voltage drop consists of activation loss n_{act}, ohmic loss n_{ohmic}, and concentration loss n_{con}.

TABLE I
PARAMETERS OF FUEL CELL BASED ON HORIZON H-500

Items	Values
Type of fuel cell	PEM
Number of cells	36
Rated Power	500W
Performance	21.6V @ 24A
Reactants	Hydrogen and Air
External temperature	5 to 30ºC
Max stack temperature	65ºC

The produced voltage of a single cell is depicted by the Nernst equation, given by

$$E_{cell} = E_0 + \frac{RT}{2F} \ln \frac{P_{H_2} P_{O_2}^{1/2}}{P_{H_2O}}, \qquad (3)$$

where E_0 is the standard potential of the hydrogen or oxygen reaction which is about 1.23V, R is the universal gas constant, F is the Faraday's constant, T is the temperature, and P_{H2} is the partial pressure of hydrogen at anode, P_{H2O} and P_{O2} are partial pressure of water and oxygen, respectively, at the cathode. E_{cell} is the open circuit voltage of the cell and it is higher than the cell output voltage of the cell effected by losses which are activation losses, ohmic losses, and concentration losses.

The output voltage of fuel cell stack can be calculated by

$$V_{FC} = N_{cell}\, E_{cell} = E - V_{act} - V_{ohmic} - V_{conc}, \qquad (4)$$

where E is open circuit voltage, V_{act} is activation losses voltage, V_{ohmic} is ohmic losses voltage, V_{conc} is concentration losses voltage and N_{cell} is number of cell. A relationship between voltage and current is given by

$$V_{FC} = E - ATln\left(\frac{I_{FC}}{I_o}\right) - BTln\left(\frac{I_L - I_{FC}}{I_L}\right) - I_{FC}R_{int}, \qquad (5)$$

where V_{FC} is the output voltage of the fuel cell, I_{FC} is the output current of the fuel cell, I_o is the exchange current, I_L is the limiting current, R_{int} is the internal resistance, A and B is the activation coefficient and concentration coefficient, respectively.

There are three losses occur in fuel cell operation which are activation losses, ohmic losses, and concentration losses. Activation losses occur due to the resistance at the surface of the electrode. Ohmic losses occur during transferring process of electron and proton in reaction and concentration losses defined as mass transport losses and resistance by the surface of the electrode. The activation loss, n_{act}, is given by

$$n_{act} = -0.9514 + 3.12 \times 10^{-3} T_{cell} \\ -1.87 \times 10^{-4} T_{cell} lni + 7.4 \times 10^{-5} T_{cell} \ln C_{O_2}, \qquad (6)$$

where C_{O_2} is the concentration of oxygen, given as

$$C_{O_2} = \frac{P_{O_2}}{5.08 \times 10^6 (-\frac{498}{T_{cell}})}. \qquad (7)$$

The concentration loss, n_{con} and ohmic loss, n_{ohmic} can be computed as

$$n_{conc} = B \ln(1 - \frac{i}{i_{lim}}) \quad , \qquad (8)$$

$$n_{ohmic} = -i \times R_{int}, \qquad (9)$$

where

$$R_{int} = 1.605 \times 10^{-2} - 3.5 \times 10^{-5} T_{cell} + \\ 8 \times 10^{-5} T_{cell} \times i. \qquad (10)$$

B. Implementation Constant Voltage Technique in The Fuel Cell System

Since the power available from the fuel cell is limited, it is necessary to adjust the operating point to settle on or trace the maximum power points, MPP. Changing the operating parameters can shift the working point but regulating the external load impedance is a more effective way to locate the MPP.

PEMFC cannot be used directly as an energy supply. The fuel cell has DC output that mostly dependent on the current which imposes a high output voltage variation. The voltage range sometimes is not acceptable for most of DC electrical device. That is why, an alternative solution of using MPPT to provide a better performance which generate a stable and linear output of fuel cell system and can be fed to various application.

The power generated is varies in the fuel cell system and MPPT is one of the control strategy which has fast response in overcoming the problems. However, the maximum power point (MPP) also varies with temperature and membrane water content condition. The MPPT at all operating conditions is a challenging problem. The various operating condition could affect the stack current and fuel flow, thus lead to changes in fuel consumption and the extraction of maximal power of the fuel cell. There are many MPPT methods available in the literature, but the constant voltage (CV) algorithm is the simplest MPPT control method. The CV method does not require any input. However, the measurement of the voltage V_{FC} is necessary to set up the duty cycle of the DC-DC converter later. The constant voltage can be expressed in a linear relation below;

$$V_{mpp} = K_v \, . V_{oc} \qquad (11)$$

where K_v is the constant voltage factor and V_{oc} is fuel cell voltage when I_{fc} is zero.

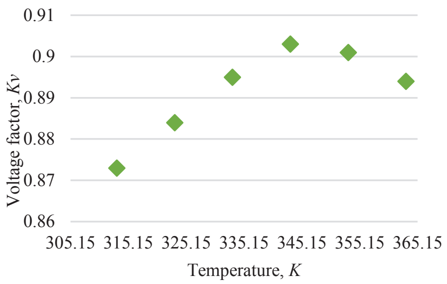

Fig. 4. Voltage factor versus various temperature

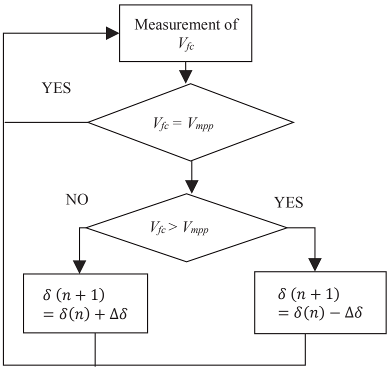

Fig. 5. Flowchart of the Constant Voltage algorithm

Based on Fig. 4, K_v has been brought using different temperature to find out which voltage factor is suitable to be used. Fig. 5 shows the flowchart of the constant voltage algorithm in finding the duty cycle for the converter. The MPPT controller uses the FC voltage to find MPP and then generates control instructions for the converter. The converter forces the fuel cell to work at current which defined by the MPPT controller.

The duty cycle for the interleaved boost converter can be calculated as

$$\delta\,(n+1) = \delta(n) + \Delta\delta \tag{12}$$

$$\delta\,(n+1) = \delta(n) - \Delta\delta \tag{13}$$

where $\Delta\delta$ is the constant value that is equal to 0.01, $\delta(n)$ is the duty cycle for the current time voltage that is compared between V_{mpp} and V_{ref}. Fig. 6 shows the Simulink diagram of the MPPT of constant voltage.

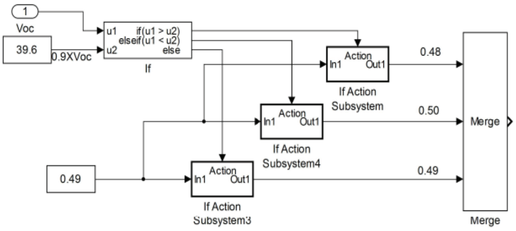

Fig. 6. Simulation diagram of MPPT in Simulink

C. *Conventional Boost Converter (CBC)*

Boost converter is a converter that has output voltage higher than its input voltage. It is switching converter that operates by periodically opening and closing an electronic switch. Boost converter consist of DC voltage source, inductor, diode, IGBT for switching, capacitor and resistor.

When the switch, *S* is on, the diode become reverse biased and the inductor current increased. When the switch is off, the diode become forward biased and the inductor current decreased and the energy that is stored in the inductor is being released to the output circuit. The circuit for conventional DC-DC boost converter is shown in Fig. 7 and Fig. 8.

The conventional boost converter (CBC) can be operated in two modes; continuous current mode (CCM) and discontinuous current mode (DCM). These modes can be determined through the value of inductor current. The circuit in Fig. 7 show the conventional boost converter when the switch is closed in on state. Table II shows the parameters value for the conventional boost converter components.

TABLE II
PARAMETERS OF THE CONVENTIONAL BOOST CONVERTER

Parameters	Value
Switching frequency	10k Hz
Input voltage	Vfc
Inductance	1mH
Capacitance	220uF

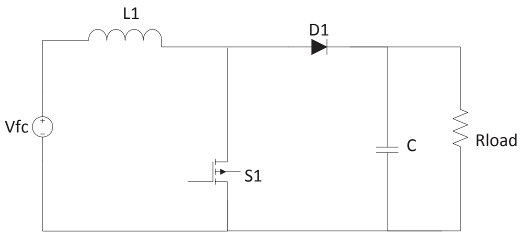

Fig. 7. Circuit diagram of conventional boost converter in on-state (switch closed)

When the switch is closed, the diode is reversed biased. There no current flow through the load causing the output stage isolated from the input. The voltage inductor is the voltage input for the circuit, given by

$$V_L = V_{in} \tag{14}$$
$$L\frac{di_L}{dt} = V_{in} \tag{15}$$
$$\Delta iL_{(closed)} = \frac{dtV_{in}}{L} \tag{16}$$

where V_L is the voltage across the inductor L and i_L is the current through the inductor L. When the switch S is opened, the diode is in forward biased. The current flows towards the load and input. This will cause the output voltage to be greater than the input voltage. Fig. 8 shows the circuit diagram of the conventional boost converter when the switch opens in off-state.

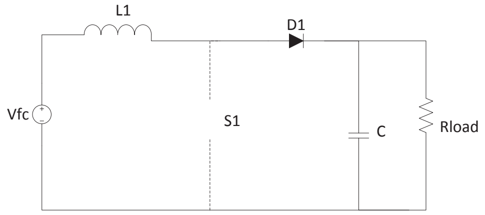

Fig. 8. Circuit diagram of conventional boost converter in off-state (switch opened)

In a steady state operation, D is the duty cycle, T is the total time for one cycle, V_{in} is the input voltage and V_o is the output voltage of the converter, i_L is the current through the inductor.

$$V_L = V_{in} - V_o \tag{17}$$
$$L\frac{di_L}{dt} = V_{in} - V_o \tag{18}$$
$$\Delta iL_{(opened)} = \frac{(V_{in}-V_o)(1-D)T}{L} \tag{19}$$

Moreover, (20) – (27) can be used to calculate and design the converter.

$$\Delta iL_{(closed)} + \Delta iL_{(opened)} = 0 \tag{20}$$
$$\frac{(V_{in}-V_o)(1-D)T}{L} + \frac{dtV_{in}}{L} = 0 \tag{21}$$
$$\frac{V_o}{V_{in}} = \frac{1}{(1-D)} \tag{22}$$
$$V_o = \frac{V_{in}}{(1-D)} \tag{23}$$
$$\text{Input power} = \text{output power} \tag{24}$$

$$V_{in}I_{in} = \frac{{V_O}^2}{R} \tag{25}$$
$$V_{in}I_L = \frac{(\frac{Vin}{1-D})^2}{R} \tag{26}$$
$$I_L = \frac{Vin}{(1-D)^2 R} \tag{27}$$

Thus, the output voltage can be concluded to be always higher than the input voltage.

D. *Interleaved Boost Converter (IBC)*

Interleaving technique is an interconnection of a multiple switching cells that will increase the effective pulse frequency by synchronizing several smaller sources and operating them with relative phase shift. An interleaving technique saves energy and improves power conversion efficiency.

Interleaved boost converter (IBC) is constructed to achieve the requirement of small volume, light weight and reliable properties. The principle of IBC is as follow; each phase consists of buck/boost converter, which is composed by a bridge of power switches and storage energy inductor.

The methods or step in designing the converter required a proper value of inductor, capacitor and power semiconductor device, so the switching losses could be reduced. The switches are controlled by phase shifted switching function known as interleaving operation. The interleaved boost converter can be operated in two modes, which is continuous current mode (CCM) and discontinuous current mode (DCM). It is assumed that the value of the resistance in the inductors is negligible and the filter capacitor is high enough that the voltage ripple across them are insignificant compared to their dc voltage. It is also assumed that all semiconductor components are in ideal state. Table III shows the parameters for the interleaved boost converter.

TABLE III
PARAMETERS FOR INTERLEAVED BOOST CONVERTER

Parameters	Value
Switching frequency	20k Hz
Input voltage	Vfc
Inductance	1mH
Capacitance	220uF

Fig. 9 to Fig. 12 shows the circuit diagram for every conditions or modes of operation for the interleaved boost converter.

Condition 1: D_1 is in a reverse biased state and D_2 is in a forward biased state. The voltage input supplies the energy to the L_1 producing in increasing current of the L_1. Meanwhile, inductor current 2 decreases because of L_2 supply energy to the load. Fig. 9 shows the circuit diagram of interleaved boost converter in condition 1.

Condition 2: Both D_1 and D_2 are reverse biased. This condition makes both inductor 1 and 2 charges the energy from voltage input resulted in increased current. Fig. 10 shows the circuit diagram of interleaved boost converter in condition 2.

Condition 3: D_2 is in reverse biased condition while D_1 is in forward biased condition. Inductor 1 discharges and supply energy to the load producing the decreasing of inductor current 1. The increasing of current 2 happen because voltage input supplies energy to the inductor 2.

Fig. 11 shows the circuit diagram of interleaved boost converter in condition 3.

Condition 4: Both D_1 and D_2 are forward biased. This condition makes both inductor 1 and 2 discharges and the energy was supply to the load makes the decreasing of current 1 and 2. Fig. 12 shows the circuit diagram of interleaved boost converter in condition 4.

The value of suitable inductor, *L,* and capacitor, *C*, for accurate performances is given by

$$L = \frac{V_{in}DT}{\Delta Iin} \tag{28}$$

$$C = \frac{V_{out}DT}{R\Delta V_{in}} \tag{29}$$

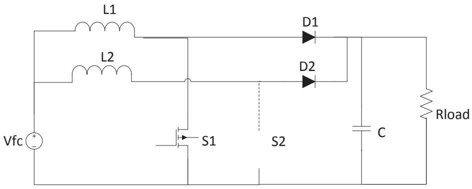

Fig. 9. Circuit diagram for condition 1

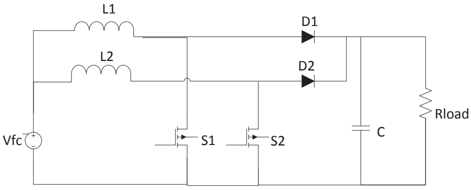

Fig. 10. Circuit diagram for condition 2

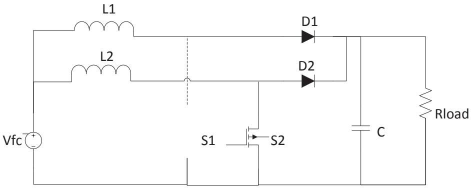

Fig. 11. Circuit diagram for condition 3

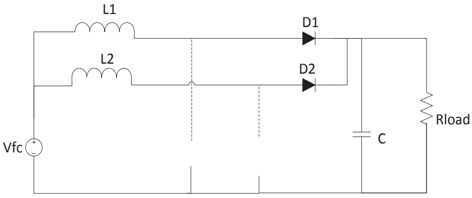

Fig. 12. Circuit diagram for condition 4

III. Simulation Results and Discussion

A. Fuel cell polarization

The fuel cell mathematical model is built in MATLAB/Simulink environment. The polarization curve is obtained by simulation based on the voltage versus time, whereas the power curve from the power versus current density. Both graphs are shown in Fig. 13 and Fig. 14.

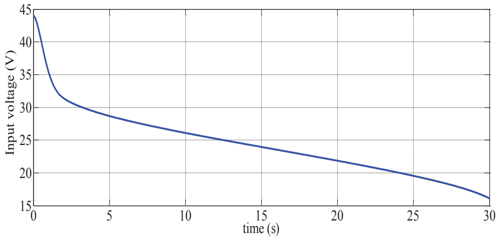

Fig. 13. Fuel cell voltage versus time

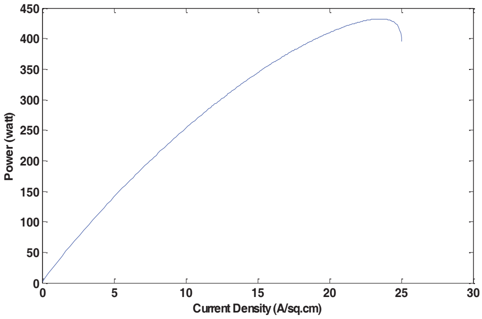

Fig. 14. Graph of output power against current density

B. FC with Conventional Boost Converter

Fig. 15 shows the simulation diagram of the conventional boost converter in MATLAB/Simulink that is connected directly to the fuel cell model without MPPT algorithm. The output of the fuel cell is non-linear and not stable. This indicates that the performance of the boost converter as the converter output voltage is degrading along time as shown in Fig. 13.

i. Conventional Boost Converter without MPPT

The Simulink circuit diagram for the conventional boost converter is connected directly to the output voltage fuel cell math model, as also shown in Fig. 15. The switching pulse for the converter is generated by the pulse generator in Simulink software.

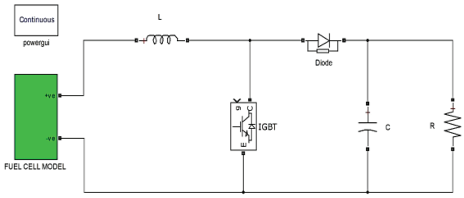

Fig. 15. Conventional boost converter without MPPT

Input current after the circuit diagram is simulated is around 2.5A. This input current produces high current ripple. This current ripple is the one that should be reduced to avoid fuel cell damages or extend its lifespan. The ripple is as high to 2A at the early stage of the simulation. Fig. 17 shows the ripple (zoomed in) when the input current almost become steady. The ripple reduced to 1A until end of the simulation at 30s.

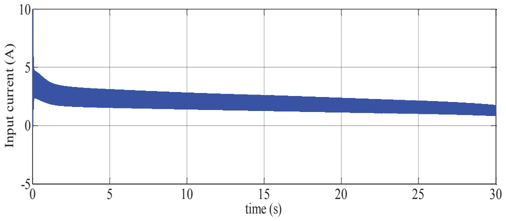

Fig. 16. Input current CBC without MPPT

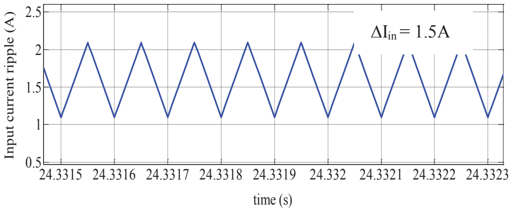

Fig. 17. Input current ripple CBC without MPPT (zoomed in)

Output current is also affected from the non-linear input of the fuel cell. The graph in Fig. 18 shows the declining output current value of the CBC that run without MPPT. It declines from 1.75A to 0.6A. This condition could lead to bad performances of the converter as this could fed or connected to some other DC applications. As for the output voltage of the converter, the value is doubled as its do its function to step up the FC voltage but the performances also not linear and unsteady. This non-linear voltage also could not be fed to inverter or load for further applications as it could affect the efficiency of the overall system.

ii. *Conventional Boost Converter with MPPT Controller*

In this subsection, the conventional boost converter is supplied by the voltage from the fuel cell. The switching pulse is generated from the MPPT and pulse width modulation (PWM). In the PWM block, the reference value is compared to the output from the MPPT. Fig. 20 shows the schematic in Simulink for the conventional boost converter and MPPT controller subsystem block. Fig. 21 presents the graph comparing the value of V_{fc} and V_{mpp} thus resulting in the changes of duty cycles. When the V_{fc} is lower than the V_{mpp}, the duty cycle is set to 0.45 but when opposite, the duty cycle is set to 0.5. Based on this information and Fig. 5, the ideal duty cycle for this converter is 0.5.

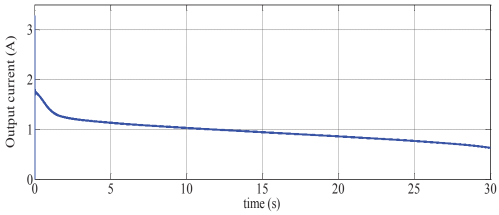

Fig. 18. Output current CBC without MPPT

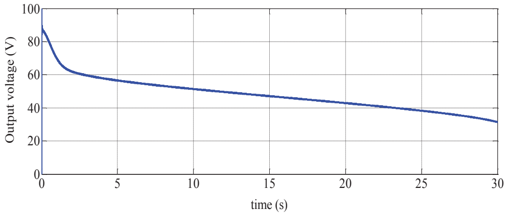

Fig. 19. Output voltage CBC without MPPT

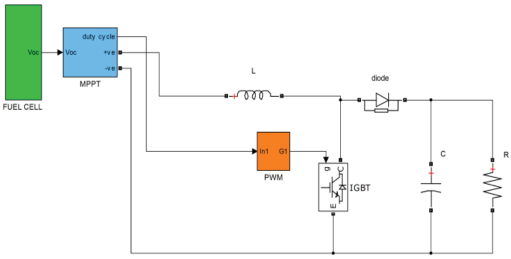

Fig. 20. Conventional boost converter with MPPT

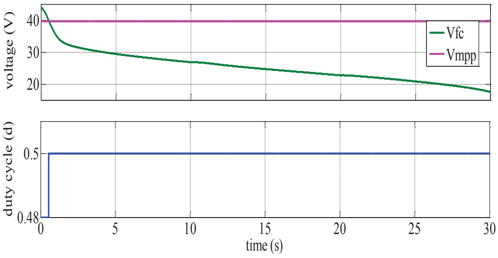

Fig. 21. Duty cycle in MPPT

The Fig. 22 below shows the results for the input current of the CBC with MPPT controller. The current seems to be has less ripple compared with CBC without MPPT controller. This could help extending the fuel cell lifespan and gives out better performances. The current is steady and stable on average of 3.5A. Even though it steady, but without the interleaved technique, the current still produced high current ripple. Fig. 23 shows the ripple produced around 2A.

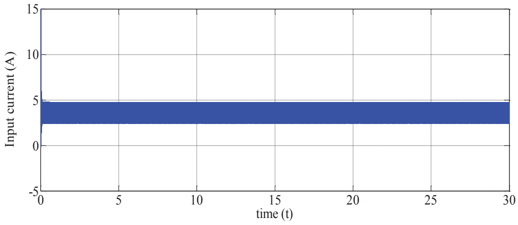

Fig. 22. Input current CBC with MPPT controller

For the output current and output voltage in the Fig. 24 and Fig. 25 of the CBC with the MPPT controller, both produces better results compared to without MPPT controller which gives out value of 1.75 A and 88V respectively. The output results are doubled from the input value.

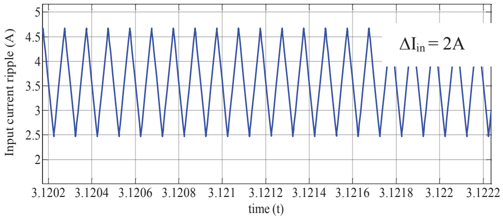

Fig. 23. Input current ripple of CBC with MPPT (zoomed in)

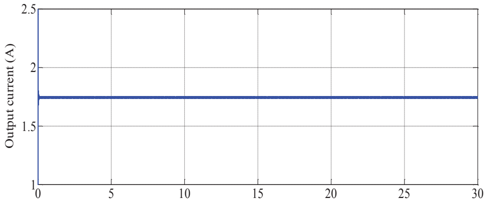

Fig. 24. Output current CBC with MPPT controller

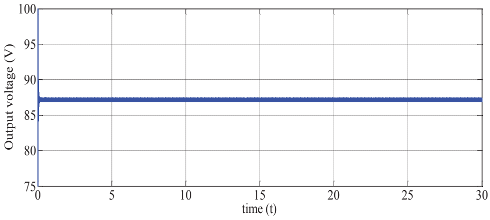

Fig. 25. Output voltage CBC with MPPT controller

C. FC with Interleaved Boost Converter

i. Interleaved Boost Converter without MPPT controller

The complete block diagram of fuel cell control system with IBC in MATLAB/Simulink is shown in Fig. 26. The IBC is controlled with MPPT to provide the switching pulse and suitable duty cycle for optimum performance of the fuel cell system.

With MPPT in the system, the output is more stable from the beginning operation. The MPPT provides an efficient and smooth process for the fuel cell to operate with.

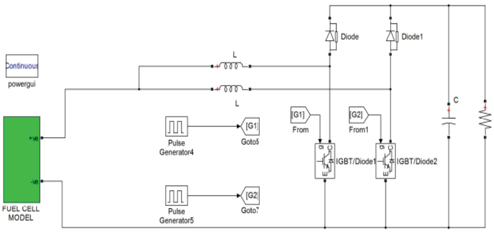

Fig. 26. Diagram of Interleaved boost converter without MPPT

The input current of this converter gives out a high ripple which is similar with the input current of CBC without MPPT controller which is around 2.4A. The ripple produces are around 1.5A and that is a high value for the fuel cell to handle. Fig. 28 shows the input current ripple for the interleaved boost converter. The output current of the IBC produced is decreased from 0.8A to 0.35A as shown in Fig. 29. This unstable current could not give out satisfactory results for the fuel cell system.

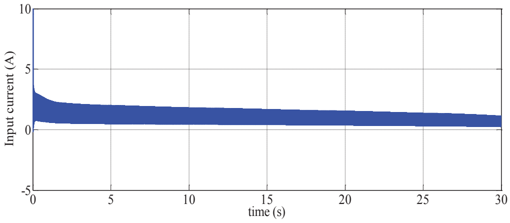

Fig. 27. Input current IBC without MPPT controller

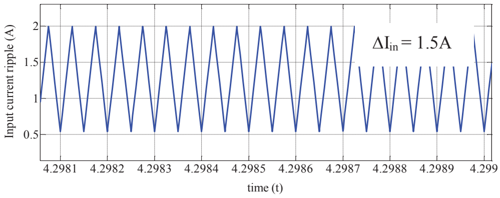

Fig. 28. Input current ripple IBC without MPPT controller (zoomed in)

The output voltage is also not linear and do not have steady performances as it followed the voltage output from the fuel cell. The voltage varies from 84V to 32V as in Fig. 30. The output does not suitable to be fed for high voltage application.

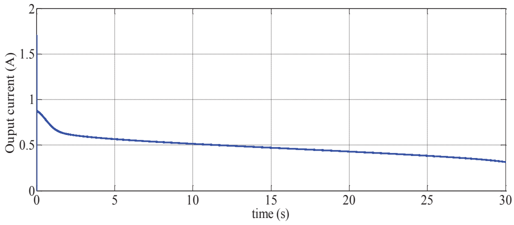

Fig. 29. Output current IBC without MPPT controller

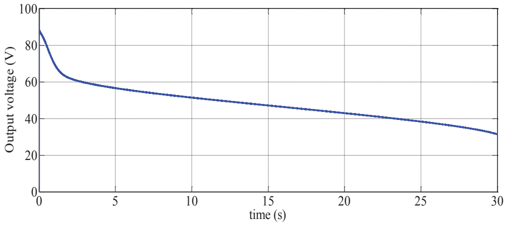

Fig. 30. Output voltage from IBC without MPPT controller

ii. Interleaved Boost Converter with MPPT controller

Fig. 31 shows the fuel cell output is fed to the MPPT algorithm for the duty cycle value generation. The PEMFC could be properly simulated as it uses an MPPT controller to extract the maximum power from the fuel cell stack. The MPPT helps in getting the proper value of duty cycle for every power generated from the fuel cell. Thus, helping the interleaved boost converter to obtain a better result in input current, output current and steady output voltage. The IBC helps in reducing the ripples in the input current that is crucial in fuel cell system performances. Fig. 32 shows the current ripple produced is less than 0.1A, which is better than the conventional converter system which do not perform interleaved technique. From Fig. 33, the current ripple waveform lies between 3.6652A to 3.6648A.

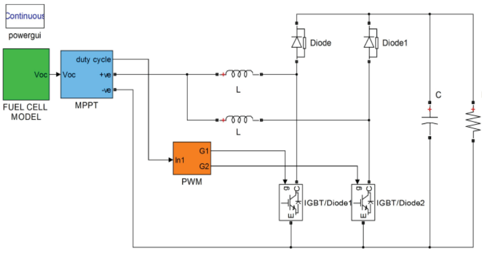

Fig. 31. Interleaved boost converter with MPPT controller

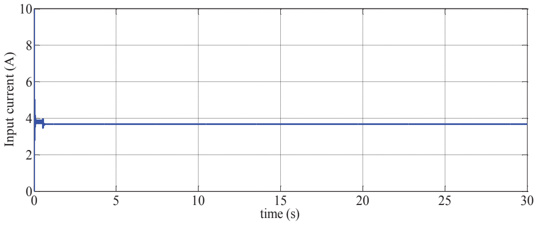

Fig. 32. Input current IBC with MPPT controller

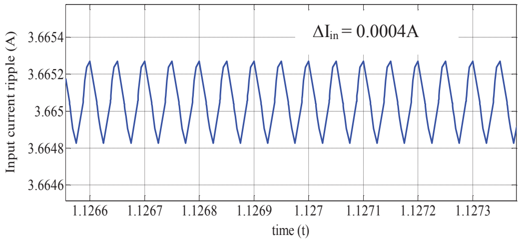

Fig. 33. Input current ripple IBC with MPPT controller (zoomed in)

The output current of the IBC with the MPPT controller is giving the output current of 1.75A which is higher and stable compared to IBC without an MPPT controller. Fig. 34 shows the output current of the IBC with MPPT controller. Fig. 35 indicates the output voltage is almost linear and give out a steady DC voltage. The output voltage could be proper to be injected to inverter for AC application or directly to the suitable DC applications. The output voltage doubled the value from 44V to linear 88V.

The efficiency of the system can be improved by the reduction of the current ripple and steady performances of the output voltage. The efficiency of the fuel cell can be computed as,

$$\eta_e = (0.675 V_{cell}) \times 100\% \qquad (30)$$

$$\eta = \frac{P_{out}}{P_{in}} \qquad (31)$$

The specification for the Horizon-500 is 40% at 21.6V. The efficiency of the fuel cell model has satisfied the requirement for an optimization of the parameter used in the model.

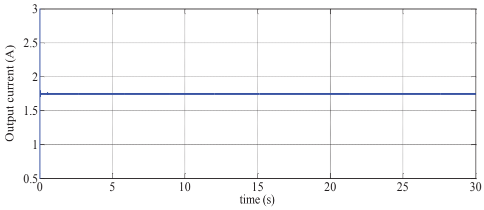

Fig. 34. Output current IBC with MPPT controller

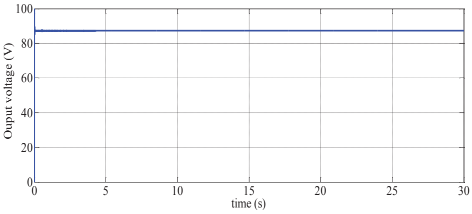

Fig. 35. Output voltage IBC with MPPT controller

TABLE IV
COMPARISON PERFORMANCES FOR BOTH CBC AND IBC

Converters	Conditions	Percentage efficiency of power conversion, %	Input current ripple, *A*	Input current, *A*	Output current, *A*
Conventional boost converter (CBC)	Without MPPT	29.7	1.5	2	1
	With MPPT	26.75	2	3.5	1.74
Interleaved boost converter (IBC)	Without MPPT	29.7	1.5	2.4	0.4
	With MPPT	26.75	0.0004	3.66	1.8

Table IV shows the comparison in both converter for each condition of with or without MPPT controller. Based on the Table IV, even though the CBC produced a bit higher percentage than the IBC, but IBC has better performances in reducing the current ripple and stable output voltage which is the crucial point in extending the lifespan of the fuel cell.

IV. Conclusion

This paper recommending the interleaved boost converter combined with constant voltage technique of maximum power point tracking for optimum fuel cell power extraction. The interleaved boost converter helps in increasing the fuel cell life span as its reduced the input current ripple that could damage the fuel cell stack. This simulation focusing on the reduction of the current ripple, and maximum power extraction of the fuel cell for higher reliability compared with fuel cell combined with DC-DC converter without using the MPPT. The analysis for both converters is done and can be seen that the converter along with interleaved technique reduces the current ripple and helps in fuel cell extension lifespan. The MPPT controller also gives out better results for the fuel cell combined converter and lead to steady power conversion.

Acknowledgements

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