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AN IMPROVED MULTIDEVICE INTERLEAVED BOOST CONVERTER WITH NOVEL MULTIPLEX CONTROLLER FOR FUEL CELL

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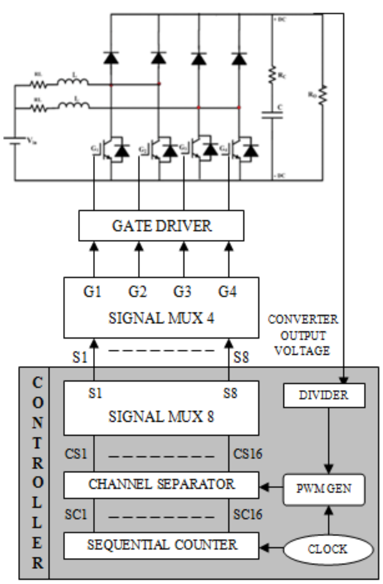
Graphical abstract



Abstract

Mass commercialization of fuel cells (FC) and its usage in transportation requires that the FC technology to be competitive with regard to performance and cost, while meeting efficiency and emissions targets. Therefore, fuel cell output current ripple that may shorten FC lifespan, worsen FC efficiency and reduce the FC output capacity need to be addressed. In this paper, an improved multi-device interleaved boost converter (MDIBC) with novel multiplex controller topology is designed to further reduce the input current and output voltage ripples, without increasing the number of MDIBC switching devices. The Matlab/Simulink behaviour model of the improved MDIBC with novel multiplex controller and conventional MDIBC circuit are developed in the simulation studies. The proposed improved MDIBC design is then compared with the conventional MDIBC and its performance is verified.

Keywords: Multidevice Interleaved Boost Converter, Novel Multiplex Controller, Input Current Ripple, Output Voltage Ripple, Ripple Frequency, Ripple Factor

Abstrak

Pengkomersilan massa sel fuel (SF) dan penggunaannya dalam pengangkutan memerlukan teknologi SF untuk berdaya saing dengan mengambil kira prestasi dan kos, di samping mencapai kecekapan dan sasaran pelepasan. Oleh itu, riak arus keluaran SFl yang boleh memendekkan jangka hayat sel fuel, memburukkan kecekapan SF dan mengurangkan kapasiti keluaran SF perlu ditangani. Dalam kajian ini, penukar galak berselang-seli peranti berbilang (PGBPB) yang lebih baik dengan topologi pengawal multipleks yang baru direka untuk mengurangkan riak arus masukan, riak voltan keluaran, tanpa meningkatkan tambahan peranti pensuisan PGBPB. Model tingkah laku Matlab/Simulink daripada PGBPB yang lebih baik dengan pengawal multipleks yang baru dan litar PGBPB sedia ada telah dibangunkan dalam kajian simulasi. Reka bentuk PGBPB yang lebih baik yang dicadangkan kemudianya dibandingkan dengan PGBPB sedia ada dan prestasinya disahkan.

Kata kunci: Penukar Galak Berselang-seli Peranti Berbilang, Pengawal Multipleks yang baru, Riak Arus Masukan, Riak Voltan Keluaran, Frekuensi Riak, Faktor Riak

1.0 INTRODUCTION

Fuel cell (FC), is one of the emerging technology that, at the right cost point, can be the most promising power supplies, able to shape the future of the global energy landscape. Cost reduction through technological innovation is bringing fuel cells closer to mass commercialization because of its high efficiency, high stability, low energy consumption and environment friendly characteristic. FC has better energy storage capability than other power cells, thus enhancing a range of automobile operations and other applications. FC is also a reliable and sustainable clean energy source that has the potential to reduce world dependence on non-renewable hydrocarbon resources.

Among the various FC technologies available the polymer electrolyte membrane fuel cell (PEMFC) has been found as prime candidate because of its, compact and lightweight, with high power density at low operating temperatures in comparison with other types of FC systems [1]-[3] .

In FC hybrid electric vehicle applications, the power supply system is composed of a FC engine, boost DC-DC converter, energy storage element, and bi-directional DC-DC converter [4]-[7], as shown in Figure 1. In this system, a high power DC-DC converter is required to adjust the output voltage, current and power of the FC engine to meet the vehicle requirement [5].

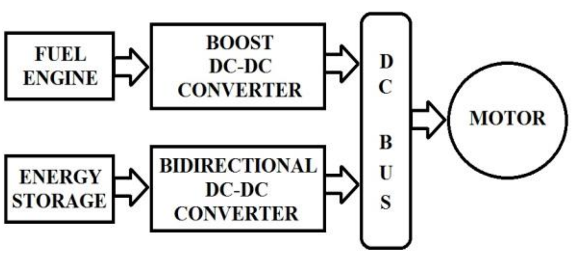


Figure 1 Power supply system of fuel cell electric vehicle

In such applications, maintaining high efficiency using conventional boost converter is challenging. For high power applications such as in an electric vehicle, the low input voltage causes large input current to flow. The FC large current ripple affects the FC capacity, also the fuel consumption and its lifespan [8]. Given the low duty cycle operation, the rms ripple current through the boost diode and output capacitor becomes very high. This condition enormously increases the losses, thus rendering the conventional boost converter inefficient. Hence, the challenge of designing the type of boost converter for high power applications should be considered in handling high current at the input and high voltage at the output [9].

An interleaved boost DC-DC converter is a suitable candidate for current sharing and for increasing the voltage for high power applications [9]-[14]. Thus, the multidevice interleaved boost converter (MDIBC) is proposed as a reference for improvement, in reducing the input current ripple, the output voltage ripple and the size of passive components. Compared with other topologies, such as the boost converter (BC), multidevice boost converter (MDBC) and interleaved boost converter (IBC), MDIBC has better performance. In addition, low electromagnetic interference and low stress in MDIBC switches can be obtained.

Since the design of high-power DC-DC converters and their controllers has an important role controlling power regulation, therefore, the goal of this study is to further improve the conventional MDIBC with an improved design version.

The next step in the process is to interface the improved MDIBC with PEMFC. Finally, we create an improved close-loop MDIBC that is controlled by a novel multiplex controller to compare and verify its dynamic performance.

2.0 METHODOLOGY

Normally, the output voltage of PEMFC fluctuates with the load, and the variation range is very wide. Therefore, PEMFC is unsuitable to power the load directly. A DC-DC converter is necessary to boost the PEMFC voltage and to convert the fluctuating PEMFC output voltage to a constant one. The amount of power flow between the input and the output converter can be controlled by adjusting the duty cycle. The adjustment is performed to controlling the output voltage and the output current and by maintaining constant power using a pulse width modulation (PWM) controller.

2.1 Conventional Boost Converter

DC-DC boost converters are essentially step-up power converters that receive a low voltage input and then provide a high voltage output. A block diagram of an ideal dc-dc boost converter is shown in Figure 2.

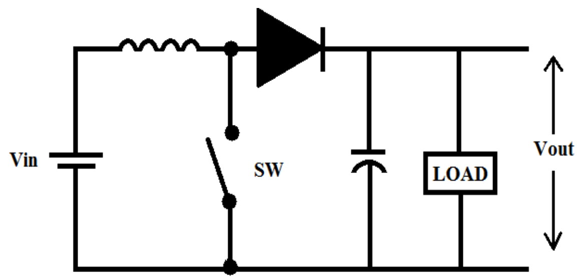


Figure 2 Conventional boost converter

The input and output voltage relationship is controlled by the switch (SW) duty cycle, D, according to the following equation:

$$Vout = \frac{1}{1 - D} Vin \quad (1)$$

An ideal boost converter has no energy losses, thus the output and input powers are equal. In practice, losses occur in the switch and passive elements, but efficiency that is more than 90% is still possible by careful selection of system components and operating parameters.

2.2 Conventional Multidevice Interleaved Boost Converter

A schematic design illustrated in Figure 3 shows the structure of the conventional multidevice interleave boost converter [15].

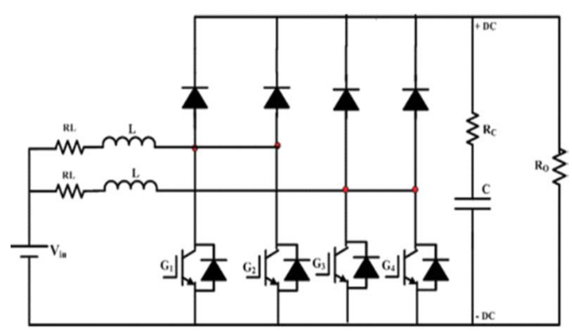


Figure 3 Conventional MDIBC reference [15]

The conventional MDIBC consists of two-phase interleaved, with two insulated gate bipolar transistors (IGBTs) and two diodes connected in parallel at each phase. Output voltage ripple and frequency of inductor current ripple should be increased to enable reduction of inductor and capacitor size and input/output EMI filter. Figure 4 shows the sequence of the IGBT gate signals.

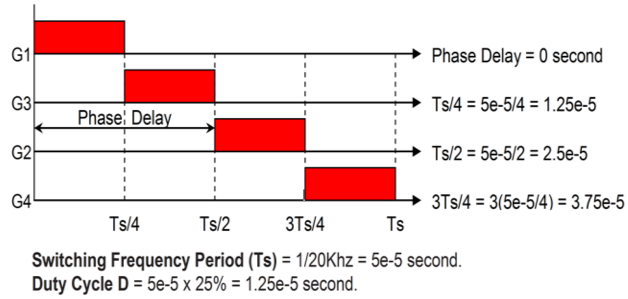


Figure 4 Sequences of the gate signals to provide double ripple frequency and to achieve the interleaved control

The control strategy implemented is phase shift interleaved control of which it provides doubles ripple frequency in the inductor current. This produces high bandwidth which contributes to fast dynamic response and size reduction of passive components.

Switching sequences at each phase may overlap depending on the duty ratio as shown in Figure 5. The duty ratio should be more than half for the output voltage to exceed the input voltage.

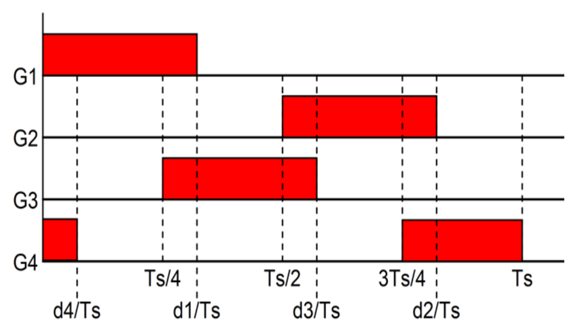


Figure 5 Overlap phase-shift interleaved control

2.3 Improved Multidevice Interleaved Boost Converter

From [16, 17, 18] Considering [16, 17, 18], it can be concluded that the high-frequency ripple will have a negligible effect on the performance, behavior and lifetime of a FC, except at very high ripple factors. Furthermore the fact that additional power losses increase with the increasing magnitude of the current ripple [19], making FC current ripple reduction becomes even more important factors when designing a converter. The proposed design of the improved MDIBC shown in Figure 6 aims to reduce the FC current ripple, extending the FC lifetime and increasing its performance.

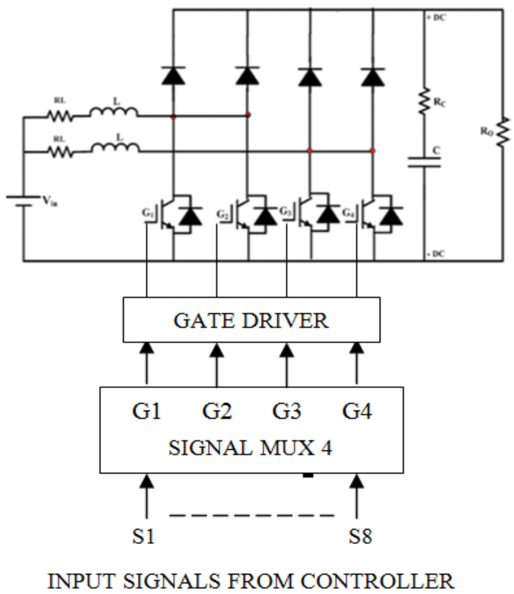


Figure 6 Proposed Topology of the Improved MDIBC

In order to improve the conventional MDIBC to obtain a further double ripple frequency and reduction of current ripple amplitude, the input signals are increased to 8 signals (S1 to S8) and will be independently switched to 4 output signals (G1 to G4) to drive the conventional MDIBC converter switches by using a signal multiplexer (SIGNAL MUX 4). The function of the multiplexer is to select and enable one channel at a time. The multiplexer digital circuits are design using high speed logic gates.

Typically to obtain a double ripple frequency and reduction of current ripple amplitude will require to increases the number of switching devices in the conventional MDIBC. Hence, the cost of the system will increase. By improving the conventional MDIBC using signal multiplexer the converter can offer a further double ripple frequency and reduction of ripple amplitude without increasing the number of switches. The sequence of the input signals to achieve the improved MDIBC switching function is shown in Figure 7.

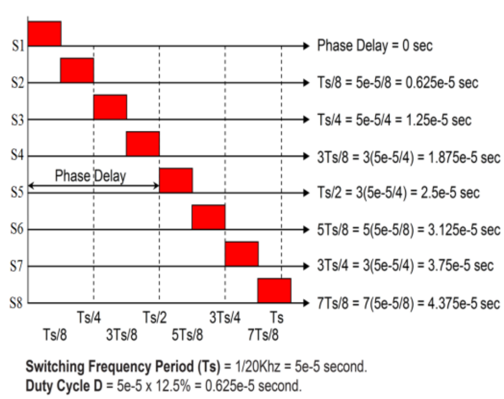


Figure 7 Sequence of the Improved MDIBC input signals

2.4 Novel Multiplex Controller

The design of a novel multiplex PWM controller is developed for the boost converter output voltage to perform in a closed-loop manner using voltage-mode feedback, as shown in Figure 8.

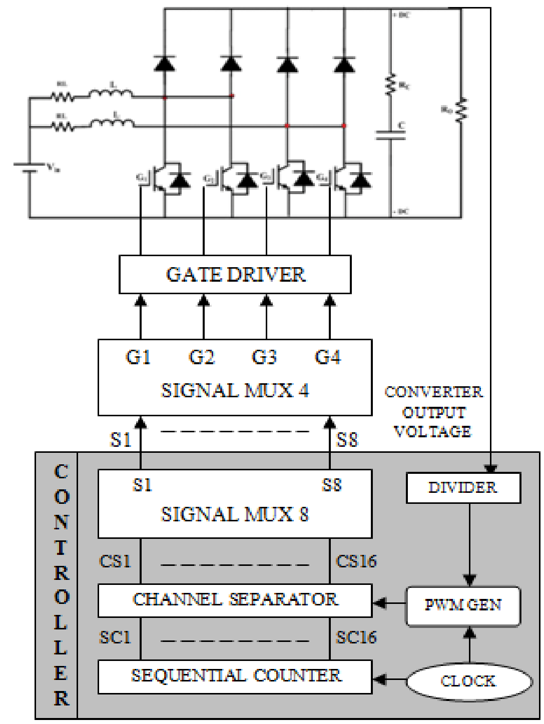


Figure 8 Block Diagram of Proposed Novel Multiplex Controller

The significant feature of this approach is to achieve a quadruple ripple frequency and further reducing the ripple amplitude without increasing the number of switches by using a novel multiplex controller topology to drive the Improved MDIBC.

In this control mode, the improved MDIBC output voltage is regulated and reverted to a PWM generator (PWM GEN) via a voltage divider. The converter output voltage is then compared with a constant-amplitude triangle or a saw tooth waveform as shown in Figure 9.

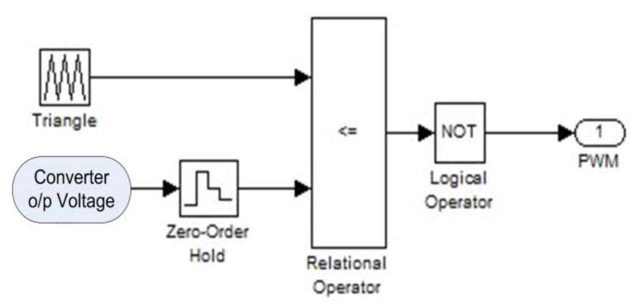


Figure 9 Simulink Model for PWM Generator

The relational operator subsequently produces a PWM signal that is fed to the channel separator. Given that the novel multiplex controller is required to increase the signals to sixteen (CS1 - CS16) for the multiplexer (SIGNAL MUX 8) to drive the improved close loop MDIBC, additional work is necessary to generate the signals from a single source. Splitting the single PWM signal is achieved by using channel separator and sequential counter before feeding to the signal multiplexer (SIGNAL MUX 8) so that only one channel can be enabled at a time to feed another signal multiplexer (SIGNAL MUX 4) of the improved MDIBC. This process is intended to maintain the operation of all phases in sequence, in which each phase is only active during a predetermined period to drive the gate.

The proposed method to generate PWM signal for the channel separator is conducted by comparing a level control dc value signal with a constant peak repetitive triangle or saw tooth signal, as illustrated in Figure 10.

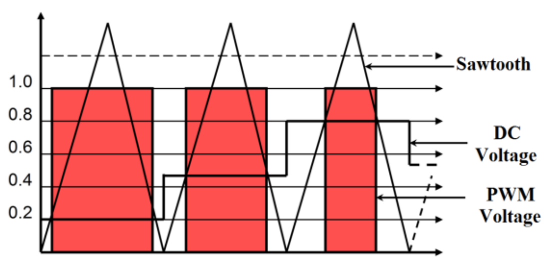


Figure 10 Creating a PWM Signal by comparing two waveforms

Here, as the DC voltage increases or decreases, the PWM duty cycle decreases or increases, respectively. The generated PWM voltage from the controller is then used to drive the converter switches to adjust the output voltage, current and power of the FC engine.

3.0 RESULTS AND DISCUSSION

The boost converter allows a desired level of output DC voltage to be obtained without having to increase the FC stack size. The design concern is the size, cost, and weight of the high-power inductor. To reduce the inductor size and weight, a small inductance value is preferred. Research has shown that conventional MDIBC has the capability to minimize component values. The advantages and disadvantages of several types of topologies of boost converters are described in [20] to [27], and based on their component count, the component values presented in [24] to [28] are summarized and compared in Table 1.

Table 1 Component Values of Various Topologies

Topology	L (μH)	R_L (mΩ)	C (μF)	R_C (mΩ)
Conventional Boost Converter (BC)	750	68	550	0.697
Multi-Device Boost Converter (MDBC)	375	34	275	1.394
Interleaved Boost Converter (IBC)	375	34	320	1.15
Multidevice Interleaved Boost Converter (MDIBC)	187.5	17	160	2.3

For performance comparison between the conventional MDIBC, the proposed improved MDIBC and the proposed improved MDIBC with a novel multiplex controller, similar model parameters are considered as listed in Table 2.

Table 2 Simulation Model Parameter

Parameter	Improved / Conventional MDIBC
Fuel Cell Rated Power	6kW
Output Voltage	115 Volts
Inductance	187.5 μH
Capacitance	160 μF
Switching Frequency	20 kHz

To simulate the conventional MDIBC, the proposed improved MDIBC and the proposed improved MDIBC with a novel multiplex controller, equivalent circuits are constructed in terms of block diagrams using icons in Simulink. These simulation models are used to evaluate the differences between ideal circuits and actual implementations. Using these models, we can also validate quickly whether or not the designs of the proposed controller meet the prescribed performance requirements.

A simulation model of the conventional close-loop MDIBC system was developed using Matlab/Simulink and is shown in Figure 11. While the proposed, improved close-loop MDIBC configuration to obtain a further double ripple frequency and reduction of ripple amplitude is shown in Figure 12. The proposed improved close-loop MDIBC with a novel multiplex controller to obtain a quadruple ripple frequency and further reduction of ripple amplitude is shown in Figure 13.

The experimentation for the improved close-loop MDIBC prototype will be conducted using the novel multiplex controller to drive the four IGBT switches of the boost converter as shown in Figure 8. This design will eliminate the need for software programming, which are a time consuming task when using other types of controllers such as digital signal processor (DSP), microcomputer and microcontroller.

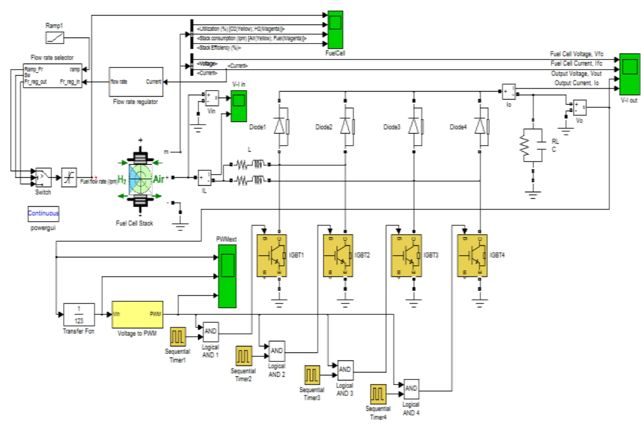


Figure 11 Simulation Model of the Conventional MDIBC

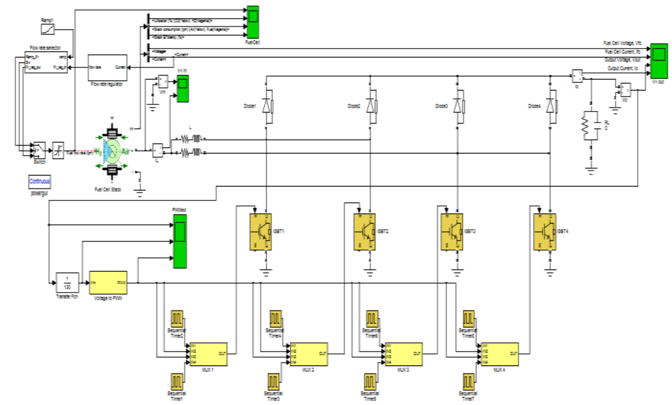


Figure 12 Simulation Model of the Improved MDIBC

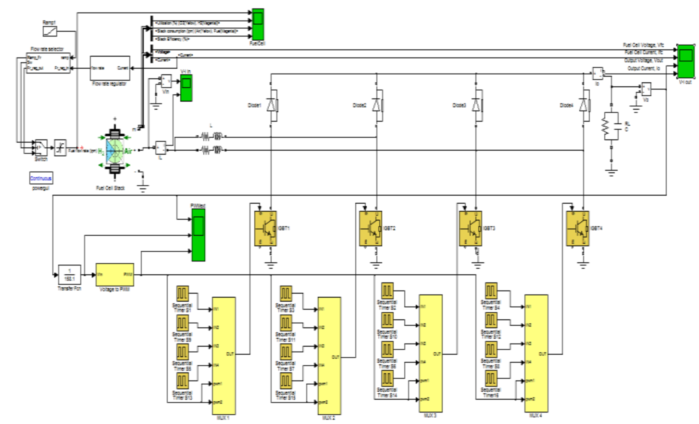


Figure 13 Simulation Model of the Improved MDIBC with Novel Multiplex Controller

3.1 Matlab Simulation Results

To illustrate the comparative results between the conventional close-loop MDIBC system and the proposed improved close-loop MDIBC systems, the two converters used a similar type of PEMFC. The rated power of the stack for the simulation is 6 kW and the nominal voltage is 45 V. The following parameters are deduced from the datasheet and the V-I curve shown in Figure 14.

Voltage at 0 and 1 A [Eoc, V1]
= [65 V, 63 V]
Nominal operating point [Inom, Vnom]
= [133.3 A, 45 V]
Maximum operating point [Iend,Vend]
= [225 A, 37 V]

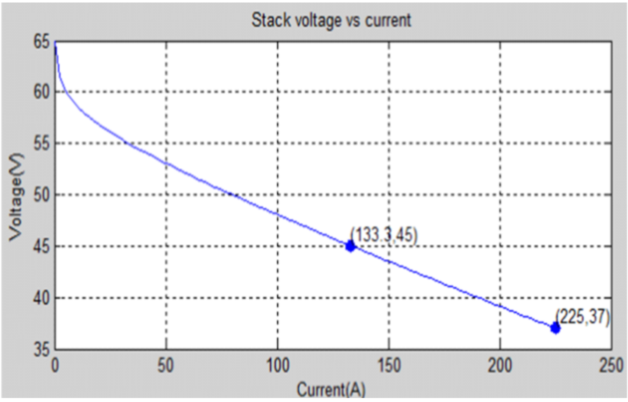
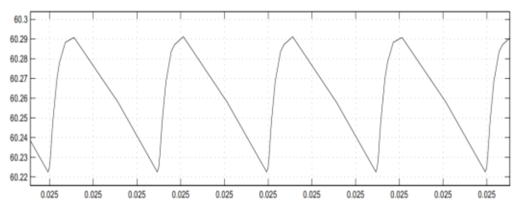


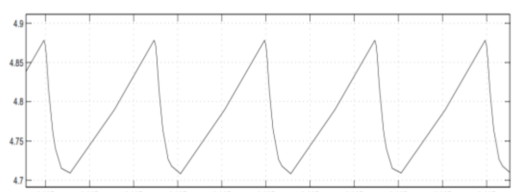
Figure 14 6kW PEMFC V-I curve

A comprehensive simulation was conducted to verify the performance of the close-loop MDIBC systems. The simulation waveforms of the conventional close-loop MDIBC input voltage ripple, input current ripple and output voltage ripple are shown in Figure 15 a), b) and c), respectively.

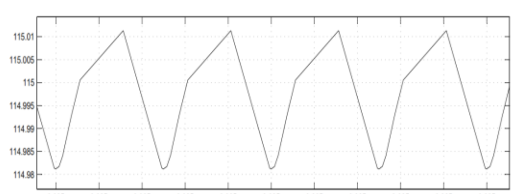
Similarly, the simulation results of the input and output voltage/current ripples, which are obtained by the improved close-loop MDIBC are shown in Figure 16, and the results of another version of the improved MDIBC using a novel multiplex controller are shown in Figure 17.



a) Fuel Cell Input Voltage Ripple
= 60.29V - 60.22V = 0.07Volt

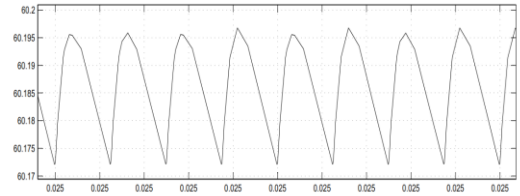


b) Fuel Cell Input Current Ripple
= 4.87A - 4.71A = 0.16Amp

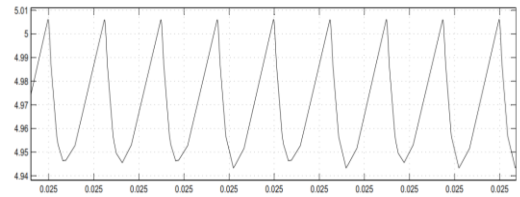


c) Converter Output Voltage Ripple
= 115.01V - 114.98V = 0.03Volt

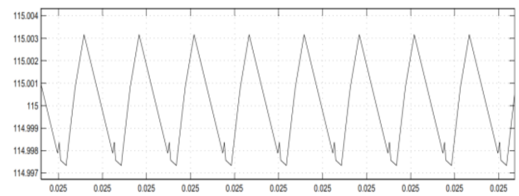
Figure 15 Conventional MDIBC voltage/current waveforms



a) Fuel Cell Input Voltage Ripple
= 60.195V - 60.173V = 0.022Volt

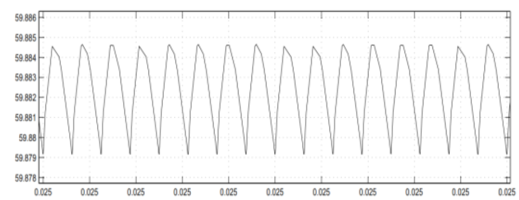


b) Fuel Cell Input Current Ripple
= 5.006.A - 4.944A = 0.062Amp

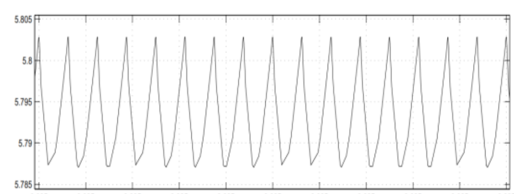


c) Converter Output Voltage Ripple
= 115.0032V - 114.9974V = 0.006Volt

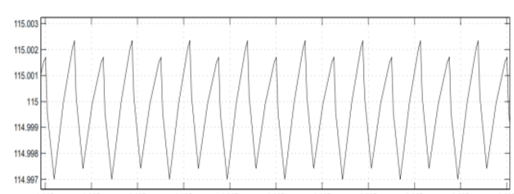
Figure 16 Improved MDIBC voltage/current waveforms



a) Fuel Cell Input Voltage Ripple
= 59.8845V - 59.8792V = 0.0053Volt



b) Fuel Cell Input Current Ripple
= 5.803A - 5.787A = 0.016Amp



c) Converter Output Voltage Ripple
= 115.0025V - 114.9975V = 0.005Volt

Figure 17 Improved MDIBC with a Novel Multiplex PWM Controller voltage/current waveforms

The figures indicate that the ripples of the input and output voltage/current of the improved close-loop MDIBC system are smaller than those of the conventional close-loop MDIBC system, and the ripples of the input and output voltage/current of the improved close-loop MDIBC system using a novel multiplex PWM controller, is further reduced compared to the improved closed-loop MDIBC, also the ripple frequency further increased. Hence, the smaller FC output current ripple not only improved the FC capacity but also the fuel consumption and lifespan [8]. Moreover, smaller FC output current ripple leads to higher efficiency and durability. Simulation results, as shown in Table 3, show that the proposed improved close-loop MDIBC systems is better than the conventional close-loop MDIBC system in achieving higher performance, improved efficiency and hence lowering the system cost.

3.2 Summary

The enhancements brought about by the improved close-loop MDIBC systems in comparison with the conventional MDIBC system are summarized as follows;

i. Input voltage, input current, input inductor current and output voltage ripples can be further reduced.
ii. Ripple frequencies of input and output waveforms can be further increased.
iii. FC current ripple factor of the system can be further reduced, by increasing the input signals to MDIBC switches.

Table 3 Conventional MDIBC vs. Improved MDIBC Systems

Topology	Input Voltage Ripple	Input Current Ripple	Output Voltage Ripple
Conventional MDIBC	0.07 Volt	0.16 Amp	0.03 Volt
Improved MDIBC	0.022 Volt	0.062 Amp	0.006 Volt
Improved MDIBC with Novel Multiplex Controller	0.0053 Volt	0.0016 Amp	0.005 Volt

For interfacing with a FC, the inductor current ripple value should be less than 5% of the maximum input current. This is important since the issues could cause irreversible damage to the PEMFC. A ripple factor of less than 4% for the FC output current will have a negligible effect on the conditions in the FC diffusion layer, thus not severely affecting the FC lifetime [21].

4.0 CONCLUSION

Comparison between the proposed improved close-loop MDIBC systems and conventional closed-loop MDIBC system has been presented. Results showed that the improved MDIBC systems reduced the input current and output voltage ripples, without increasing additional switching devices. It is indicated that the improved closed loop MDIBC systems ripple factor is less than 4%.

In the improved close-loop MDIBC system using a novel multiplex controller the frequencies of input and output waveforms can be increased, hence the passive components can be further reduced, thus reducing the total cost with improved performance. As a result, the efficiency and durability of the improved MDIBC systems are higher than the conventional MDIBC system. Therefore, the proposed improved MDIBC systems is suitable for high power FC systems and can be utilized to develop higher efficiency FC hybrid electric vehicles.

Acknowledgement

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References

[1] Ke, Jin, Xinbo, R., Mengxiong, Y., and Min, Xu. 2009. A Hybrid Fuel Cell Power System. *IEEE Trans Industrial Electronics*. 4: 1212-1222.
[2] Emadi, A., Lee, Y. J., and Rajashekara, K. 2008. Power Electronics And Motor Drives In Electric, Hybrid Electric, And Plug-In Hybrid Electric Vehicles. *IEEE Trans Industrial Electronics*. 6: 2237-2245.
[3] Ehsani, M., Gao, Y., and Emadi, A. 2005. *Modern Electric, Modern Hybrid, and Fuel Cell Vehicles*. New York: Taylor & Francis Group.
[4] Dwari, S. & Parsa, L. 2007. A Novel High Efficiency High Power Interleaved Coupled Inductor Boost DC-DC Converter for Hybrid and Fuel Cell Electric Vehicle. *Vehicle Power and Propulsion Conference. IEEE*. 399-404, 9-12.
[5] Haiping, X., Ermin, Q., Xin, G., and Li, K. *2005*. High Power Interleaved Boost Converter in Fuel Cell Hybrid Electric Vehicle. *Electric Machines and Drives, IEEE International Conference*. 1814-1819
[6] Samosir, A. S., Yatim, A. 2008. Dynamic Evolution Control Of Bidirectional DC-DC Converter For Interfacing Ultracapacitor Energy Storage To Fuel Cell. *Electric Vehicle system, Power Engineering Conference* 2008. AUPEC Australasian Universities. 1-6, 14-17.

[7] Samosir, A. S. & Yatim, A. H. M. 2010. Implementation of Dynamic Evolution Control of Bidirectional DC-DC Converter for Interfacing Ultracapacitor Energy Storage to Fuel Cell System. *Industrial Electronics, IEEE Transactions*. 57(10): 3468-3473.

[8] Liu, C. and Lai, J. 2007. Low Frequency Current Ripple Reduction Technique With Active Control In A Fuel Cell Power System With Inverter Load. *IEEE Transaction Industrial Electronics*. 4: 1429-1436.

[9] Jun, W., Jin, T. & Smedley, K. 2006. A New Interleaved Isolated Boost Converter For High Power Applications. *Applied Power Electronics Conference and Exposition, 2006. APEC '06. Twenty-First Annual IEEE*. 19-23.

[10] Giral, R., Martinez-Salamero, L., Leyva, R. & Maixe, J. 2000. Sliding-mode Control Of Interleaved Boost Converters. *Circuits and Systems I: Fundamental Theory and Applications, IEEE Transactions*. 47(9): 1330-1339.

[11] Van der Broeck, H. & Tezcan, I. 2006. 1 KW Dual Interleaved Boost Converter for Low Voltage Applications. *Power Electronics and Motion Control Conference*, 2006. *IPEMC 2006. CES/IEEE 5th International*. 3(1): 1-5, 14-16.

[12] Chen, C., Wang C., & Feng. H. 2009. Research Of An Interleaved Boost Converter With Four Interleaved Boost Convert Cells. *Microelectronics & Electronics, 2009. PrimeAsia. Asia Pacific Conference on Postgraduate Research*. 19-21.

[13] Rosas-Caro, J. C., Ramirez, J. M. & Garcia-Vite, P. M. 2008. Novel DC-DC Multilevel Boost Converter. *Power Electronics Specialists Conference, 2008*. PESC 2008. IEEE. 2146-2151, 15-19.

[14] Samosir, A. S. & Yatim, A. H. M. 2008. Implementation Of New Control Method Based On Dynamic Evolution Control With Linear Evolution Path For Boost Dc-Dc Converter. *Power and Energy Conference, PECon. IEEE 2nd International*. 213-218.

[15] Hegazy, O., Joeri, Van, Mierlo, J., & Philippe L. 2012. Analysis, Modeling and Implementation of a Multidevice Interleaved DC/DC Converter for Fuel Cell Hybrid Electric Vehicles. *IEEE Transaction Industrial Electronics.* 27: 11.

[16] Ehsani, M., Gao, Y., & Emadi, A. 2005. *Modern Electric, Modern Hybrid, and Fuel Cell Vehicles.* New York: Taylor & Francis Group.

[17] Yoon, C., Kim, J. & Choi, S. 2011. Multiphase DC–DC Converters Using A Boost-Half-Bridge Cell For High-Voltage And High-Power Applications. *IEEE Trans. Power Electron.* 26(2): 381-388.

[18] Hsieh, Y. C., Hsueh, T. C. & Yen, H. C. 2009. An Interleaved Boost Converter with Zero-Voltage Transition. *IEEE Trans. Power Electron.* 24(4): 973-978.

[19] Yang, X., Ying, X. & Chen, W. 2010. A Novel Interleaving Control Scheme for Boost Converters Operating In Critical Conduction Mode. *Journal Power Electronic.* 10(2): 132-137.

[20] Thounthong, P., & Pierfederici, S. 2010. A New Control Law Based on the Differential flatness Principle For Multiphase Interleaved DC–DC Converter. *IEEE Trans. Circuits System II, Exp. Briefs*. 57(11): 903-907.

[21] Yu, W., Qian, H., & Jason, L. 2010. Design of High-Efficiency Bidirectional DC–DC Converter and High-Precision Efficiency Measurement. *IEEE Transaction Power Electronics.* 25(3): 650-658.

[22] Kong, X. & Khambadkone, A. M. 2007. Analysis And Implementation Of A High Efficiency, Interleaved Current-Fed Full Bridge Converter For Fuel Cell System. *IEEE Transaction Power Electronics.* 22(2): 543-550.

[23] Kim, H., Yoon, C. & Choi, S. 2010. A Three-Phase Zero-Voltage And Zerocurrent Switching Dc–Dc Converter For Fuel Cell Applications. *IEEE Transaction Power Electronics.* 25(2): 391-398.

[24] Al Sakka, M., Van Mierlo, J., Gualous, H. & Lataire, P. 2009. Comparison Of 30 KWDC/DC Converter Topologies Interfaces For Fuel Cell In Hybrid Electric Vehicle. *Proc. 13th Eur. Conf. Power Electronics Application*. Spain. 8-10.

[25] Li, W. & He, X. 2011. Review Of Nonisolated High-Step-Up DC/DC Converters In Photovoltaic Grid-Connected Applications. *IEEE Trans. Ind. Electronic.* 58(4):1239-1250.

[26] Kabalo, M., Blunier, B., Bouquain, D. & Miraoui, A. 2010. State-Of-The-Art of DC–DC Converters for Fuel Cell Vehicles. *Proc. IEEE Vehicle Power and Propulsion Conference Lille, France.* 1-3, 1-6.

[27] Emadi, A., Williamson, S. S. & Khaligh, A. 2006. Power Electronics Intensive Solutions For Advanced Electric, Hybrid Electric, And Fuel Cell Vehicular Power Systems. *IEEE Trans. Power Electron.* 21(3): 567-577.

[28] Lee, Y. J. & Emadi, A. 2008. Phase Shift Switching Scheme for Dc/Dc Boost Converter with Switches In Parallel. *Proc. IEEE Vehicle Power Propulsion Conference* China. 3-5.