Journal of Engineering and Applied Sciences 12 (Special Issue 7): 8003-8011, 2017
ISSN: 1816-949X

An Interleaved High Step up Cockloft Walton Voltage Multiplier for Fuel Cell Source Application

[1]A. Ganesan and [2]M. Kumaresan
[1]Department of EEE, M.G.R Educational and Research Institute University, 95 Chennai, India
[2]Department of ECE, Dr. M.G.R. Educational and Research Institute, 95 Chennai, India

Abstract: Increasing the need of renewable power source an adequate power conversion or generation of power circuit is need in present era. Due to environmental friendly and long time of voltage delivery aspects fuel cell source in preferred as suitable power supply. Even fuel cell is suffered in high current generation whilst interfacing with power converter and also need of high step up operation due to present demand and cost of source generation. This study is proposed an interleaved Cockcroft Walton voltage multiplier for high step up application. This converter is interfaced for reducing current level across fuel cell source and improving load voltage capability for medium to high voltage application. Photon Exchange Membrane Fuel (PEMFC) is proposed based on high efficient cell over other types of cell. Proposed Cockcroft Walton voltage multiplier is matched with fuel cell power generation for high step up ratio over classical transformer less approach of converter. The simulation and hardware scheme was implemented to verify about proposed circuit configuration and boosting capability using MATLAB/Simulink circuit environment.

Key words: Interleaved Cockcroft Walton voltage multiplier, Photon Exchange Membrane Fuel (PEMFC), Duty cycle (D), high step up, transformer less, high voltage application

INTRODUCTION

Increasing energy consumption and energy demand of word, a renewable power generation and source are considered as great important in today environmental development. Likewise, Photon Exchange Membrane Fuel Cell (PEMFC) is preferred in basis of high efficient and long time of delivering power across load or distribution (Jain *et al*., 2012; Ali and Salman, 2006; Harfman *et al*., 2008; Thounthong *et al*., 2007). Because other renewable power generation of Photovoltaic system (PV) wind power source are having drawbacks such as it reseach on due to environmental conditions (Singh and Kumar, 2016; Farhangi and Farhangi, 2006; Hirose and Matsuo, 2012; Paladhi and Ashok, 2015; Shuang *et al*., 2011). Whereas fuel cell converter system is used widely in electric vehicle, industrial drive and grid interface as alternative power source. Fuel cell is preferred in distribution application in especially in peak load (Gao, 2005). The generally renewable generation is required high step up of voltage regeneration due to effectiveness of their power generation, cost of initial generation and demand of present environment. So, a suitable power converter is required for improving performance of renewable or fuel cell performance (Lu *et al*., 2003; Bryant and Kazimierczuk, 2007; Da Silva *et al*., 2001; Jovanovic and Jang, 1999). Classical converter scheme is suffered from large amount of conduction ripple, losses and stress across source as well as load. In classical converter schemes are separated by transformer based power converter and transformer less power converter for improving source generation and step up performance (Anand *et al*., 2014; Torrico *et al*., 2008).

Transformer fed power converter is required extra active power circuit for improving high power generation and also suffering from winding oriented power losses across transformer element and low efficiency. So, transformer-less converter scheme is suitable for medium to high voltage power generation due to less number of components and neglecting winding oriented losses. The proposed fuel cell source even it having merits of long time power generation, unique in environmental variation, it draws a high current across fuel cell interfacing with power converter and also high stress across elements. An interleaved converter is suitable choice over above mentioned classical converter schemes because it draws a less current stress across fuel cell source and also applicable for high step up power generation (Coutellier *et al*., 2008). In order to improving step up ratio of conversion process given transformer-less interleaved DC-DC converter is not enough to obtained high step up voltage conversion and high power extraction. This study is introduces an interleaved based Cocroft Walton voltage multiplier for improving ratio of boosting across

Corresponding Author: A. Ganesan, Department of EEE, M.G.R Educational and Research Institute University, 95 Chennai, India

load and control of fuel cell current across input side. The simulation and hardware performance was analyses using MATLAB/Simulink Software and DSPIC controller, respectively.

MATERIALS AND METHODS

Proposed converter configuration: The fuel cell based interleaved Cockcroft Walton voltage multiplier is presented for improved high step-up ratio which is presented in Fig. 1. Four active power switches (S_1, S_2, S_A, S_B) are presented with boost type and interleaved circuit of inductors L_1, L_2. An introducing of interleaved circuit using diodes and active switches (D_A, D_B, S_A, S_B) fed with inductors (L_1, L_2). Interleaved inductors are controlled by given active switches and diodes. Aim to introducing of interleaved circuit to provide controlled fuel cell current across input and also regulates voltage over reciprocal elements. Capacitors (C_1-C_{14}) and diode (D_1-D_{14}) are called as voltage multiplier circuit applied for seven stages. Switch $S_1(S_A)$ and Switch $S_2(S_b)$ are working as reciprocal manner to each other. Two different alternative frequencies f_{Sa}, f_{Sb} are used for S_1, S_A, respectively and its switching pattern is given in Fig. 2.

The variable frequency of converter scheme is used to minimizes passive elements range and size, the frequency used for S_1 and S_2 is much higher than the switch S_A and S_B. The magnitude of voltage is controlled by varying duty cycle of switches S_1 and S_2 whereas ripple across converter circuit is controlled by Switch S_A and S_B.

Fuel cell power system: The proposed equivalent electrical circuit of PEM fuel cell is shown in Fig. 3. The output voltage of single cell can be expressed as:

$$V_{Fuel} = E_{Nernst} - V_{act} - V_{ohmic} - V_{conc} \tag{1}$$

The reversible voltage of fuel cell (E_{Nernst}) is obtained in an open circuit thermodynamic balance. There are several factors responsible for the voltage drop in a fuel cell and it's all denoted as polarization. The various voltage losses namely, activation losses (V_{act}) due to activation of anode and cathode, ohmic losses (V_{ohmic}) related with the conduction of the protons through the solid electrolyte and electrons by the internal electronic resistances, concentration losses (V_{conc}) due to the mass transportation. The first term represent the no load voltage when a certain load current is required. At that time sum of all other terms gives the reduction of useful voltage achievable at the cell terminal. The polarization curves for PEM fuel cell is shown in Fig. 4. The N number of cell connected in series and forming the stack voltage can be expressed as:

$$V_{stack} = N \times V_{Fuel} \tag{2}$$

The behavior of proposed PEM fuel cell under different condition such as hydrogen flow, air flow and operating temperature (343-383k) is shown in Fig. 5.

The V-I characteristic of fuel cell shows the different regions and the corresponding polarization effects that associated with a voltage drop in every region. It can be expressed the following equation such as:

$$\begin{aligned} E_{Nernst} &= 1.229 - 8.5\times10^{-4}(T-298.15)+ \\ & 4.318\times10^{-5}\,T\left[\ln\left(P_{H_2}+\frac{1}{2}\ln P_{O_2}\right)\right] \end{aligned} \tag{3}$$

$$V_{Act} = \xi_1+\xi_2 T+\xi_3 T\ln(CO_2)+\xi_4 T\ln(I) \tag{4}$$

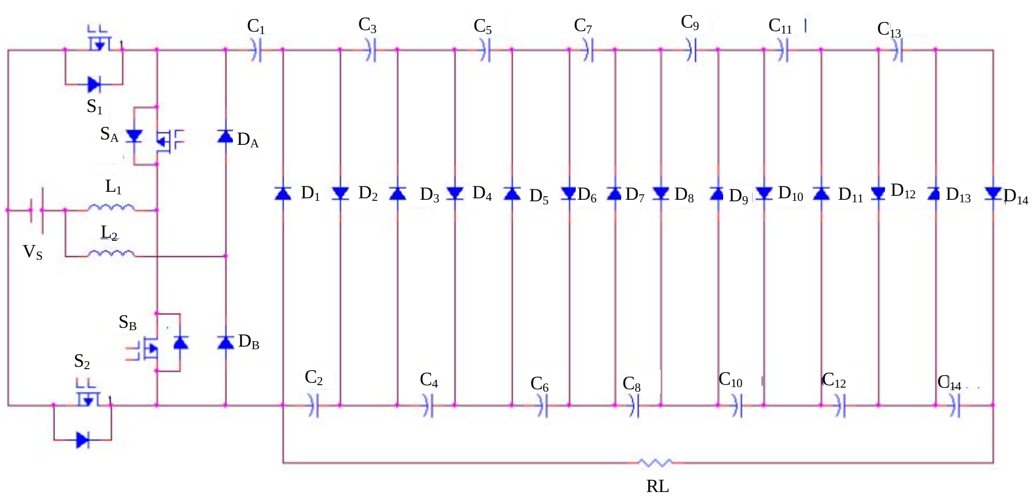

Fig. 1: Proposed interleaved cockcroft walton voltage multiplier

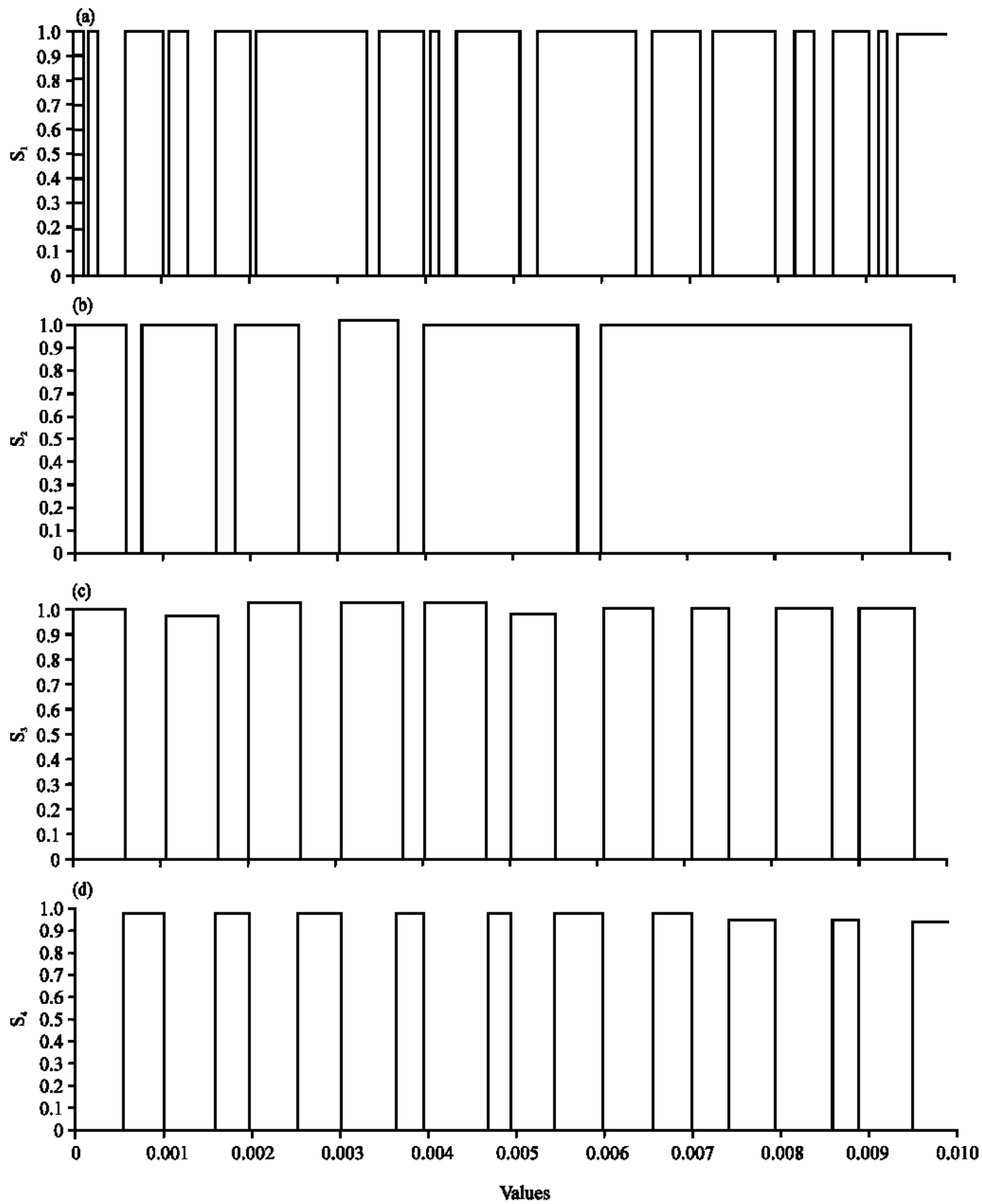

Fig. 2: a, d) Switching pulse pattern for proposed interleaved Cockcroft Walton voltage multiplier

$$CO_2 = \frac{PO_2}{5.08\times 10^6 \exp\left(-498/T\right)} \quad (5)$$

$$V_{ohmic} = I \text{ (Remembrance)}$$

Here, remembrance = r_m^1/A:

$$r_m = \frac{181.6\left[1+0.03\left(\frac{I}{A}\right)+0.062\left(\frac{T}{303}\right)^2\left(\frac{I}{A}\right)^{2.5}\right]}{\left[\lambda-0.634-3\left(\frac{I}{A}\right)\right]\exp\left[4.18\left(\frac{T-303}{T}\right)\right]} \quad (6)$$

$$V_{con} = \xi_6 e^{(\xi_7 I)} \quad (7)$$

The static and proposed dynamic model of fuel cell is shown in Fig. 6. The double layer capacitance charging can be obtained by Eq. 8 as follows:

$$\frac{dV_{act}}{dt} = \frac{1}{C_d} - \frac{V_{act}}{R_{act}C_d} \quad (8)$$

$$R_{act} = \frac{V_{act}}{I} \text{kWcm}^2 \quad (9)$$

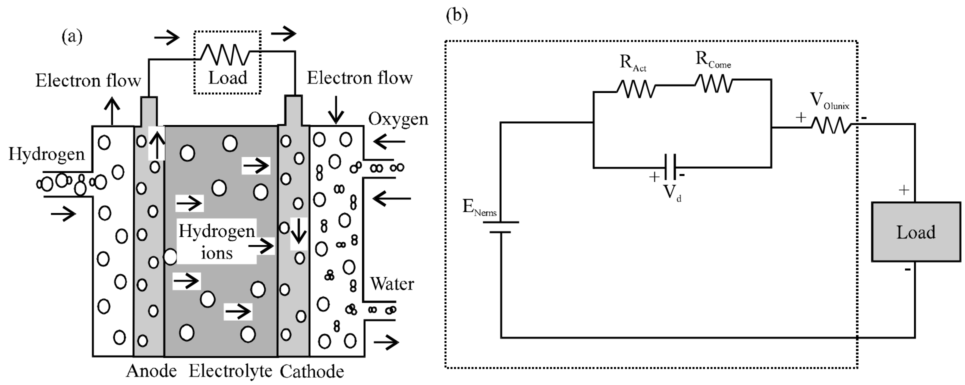

Fig. 3: a) Schematic diagram and b) Electrical circuit of PEM fuel cell

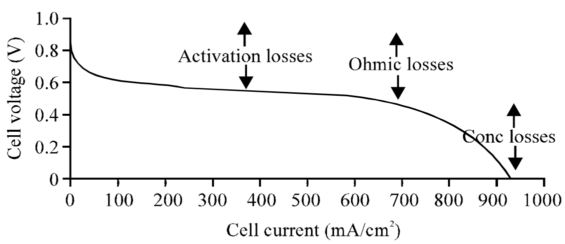

Fig. 4: V-I characteristic of single PEM fuel cell

This dynamic model of PEM fuel cell to depict by the transients voltage, cell temperature, hydrogen/oxygen input and output flow rates and cathode/anode channel temperatures and pressures under sudden change in load current. The operating condition of fuel cell held is reduced at the higher values of input variables and voltage losses.

Modes of operation details: Proposed interleaved Cockcroft Walton voltage multiplier is operated in different mode using switches operation which is given in Fig. 2. The operation modes is explain in given Fig. 7a-d.

Mode 1: During this mode switch S_A,S_1 is in on whereas switch S_B, S_2 is in off state which is shown in Fig.7a. Even and add number of capacitor voltage is capable of deliver to across load. Interleaved inductor L_1, L_2 is undergone control of fuel cell current and regulating boosted voltage by active switches S_A, D_A and D_B.

Mode 2: During this mode of conduction, S_A and S_B is in on whereas switch S_B, S_1 is in off state. Both interleaved inductor is in conduction and also multiplier circuit of capacitors (C_1-C_{14}) using diodes (D_1-D_{14}) is delivering power across load. Voltage level of capacitor is drawn by Eq. 10:

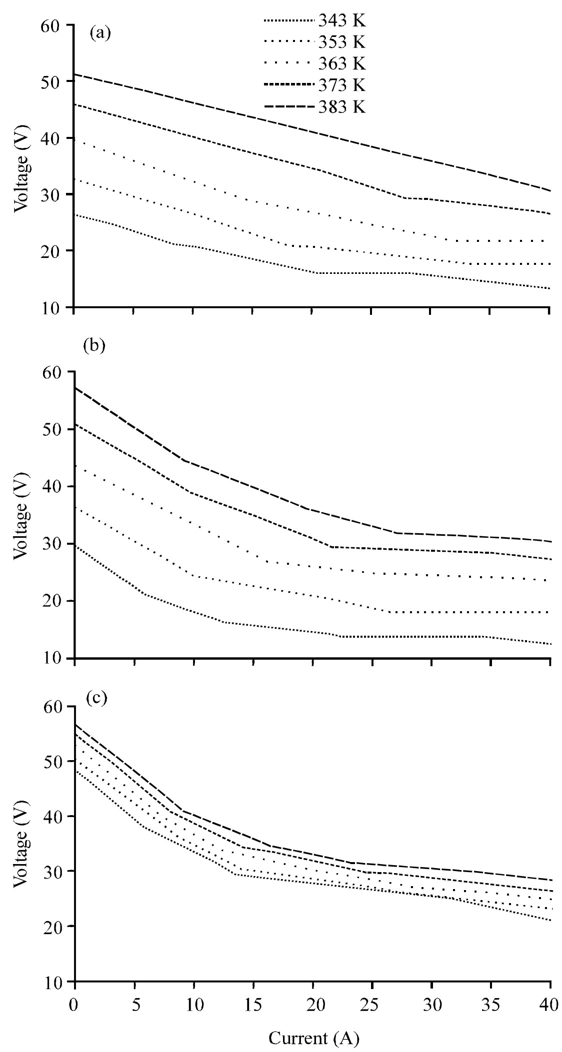

Fig. 5: Performance of PEM fuel cell under different condition: a) PH_2 flow; b) PO_2 flow and c) Temperature

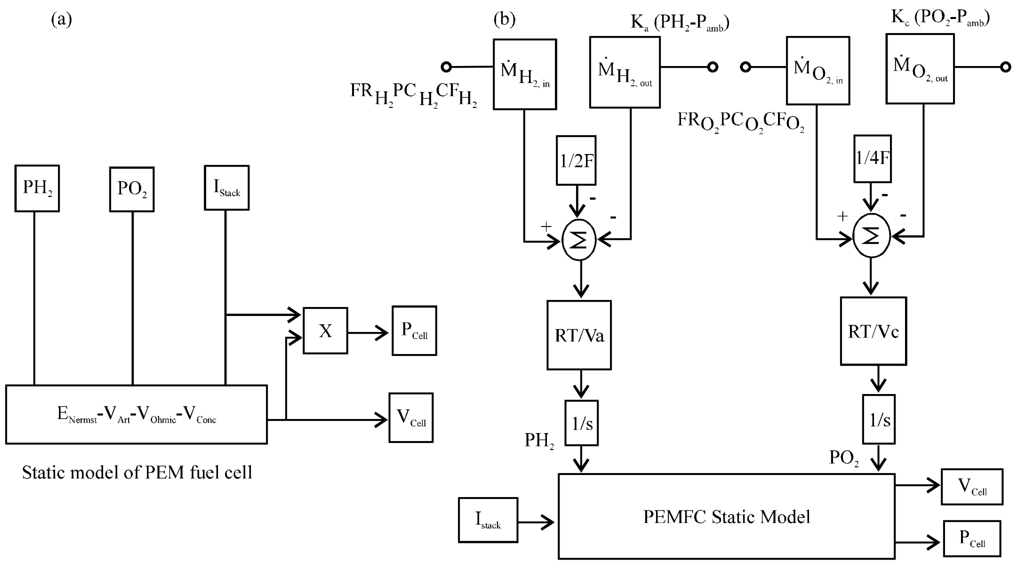

Fig. 6: a) Static model and b) proposed dynamic model of PEM fuel cell

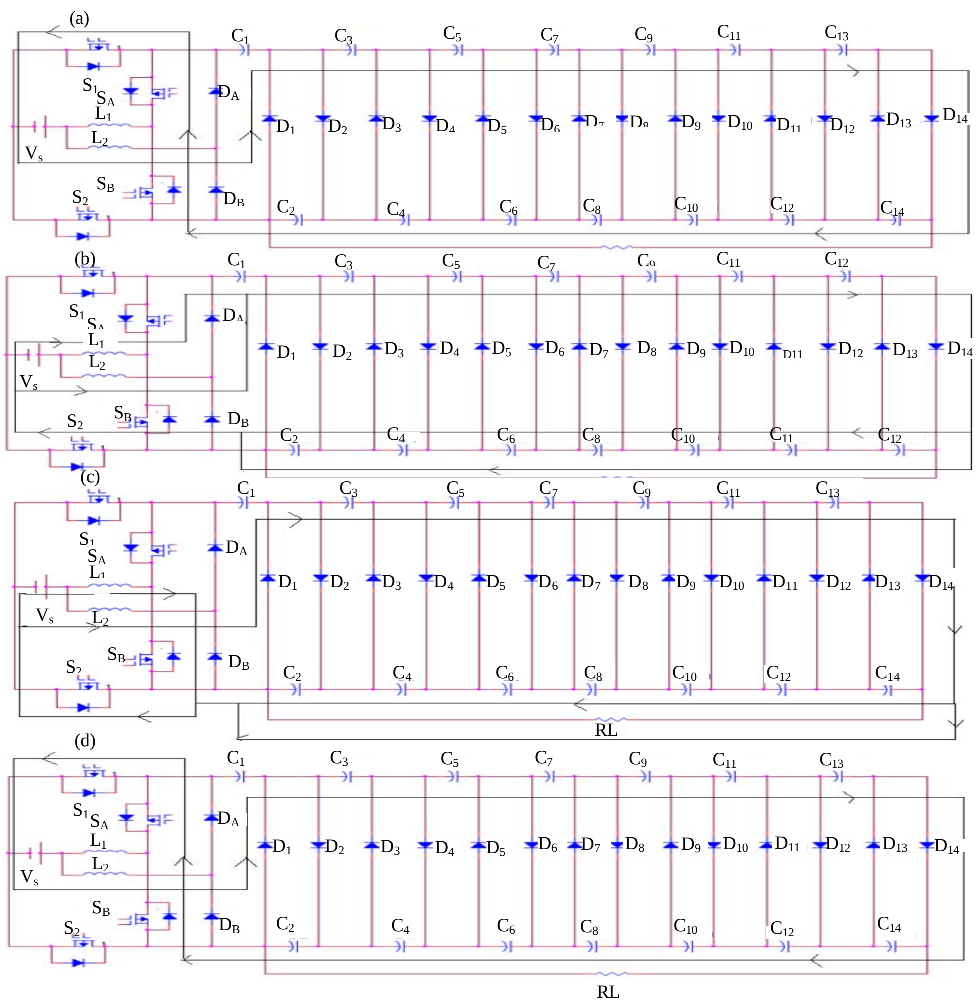

Fig. 7: Mode of operation of proposed converter: a) Mode 1; b) Mode 2; c) Mode 3 and d) Mode 4

$$V_0 = n V_c \quad (10)$$

Mode 3: Switch S_B, S_2 is in conduction in this mode of conduction whilst switch S_A, S_1 are off state. Power flow direction is changed across diode and passive elements. The interleaved circuit of diode D_A is used to regulate power across load terminals and also limiting fuel cell power in input side of interface.

Mode 4: During this conduction period switch S_B and S_2 is in on state whilst switch S_A, S_1 are in off state. Interleaving inductor circuit and reciprocal of switch and diode circuit is used to control of power flow regulation and voltage step up to load which is shown in Fig. 7d.

The proposed PEMFC based interleaved Cockcroft Walton voltage multiplier circuit is used to implement for improving high step up and low current control. The corresponding modes of operation is analyses using given switching pattern and circuit implementation using parameters given in Table 1 implementation of simulation and hardware circuit and performance are given in Chapter V.

Table 1: Parameters of proposed circuit

Name	Range
Output power (P_0)	2.7 kW
Output voltage (V_0)	600
Input DC voltage (V_i)	35
Modulation frequency (f_{sa})	1 kHz
Alternative frequency (f_{sb})	60 kHz
Resistive load (R_L)	133 Ω
Number of stage (n)	7
Interleaved inductors (L_1, L_2)	1.5 mH
Capacitors (C_1-C_{14})	460µ F

RESULTS AND DISCUSSION

Simulation implementation: The simulation implementation of proposed interleaved Cockcroft Walton voltage multiplier circuit is implemented using fuel cell source for improving dynamic performance of fuel cell power by controlling fuel cell current across interfacing point. Interleaved circuit is used to improving boost ratio of converter circuit also provide controlled power across reciprocal operation of switching circuit which is presented in proposed Cockroft Walton voltage multiplier circuit. PEMFC type cell is uses for supplying long time and dynamic power across presented circuit elements. Performance of converter by their operation was implemented using MATLAB/Simulink Software from Fig. 8 and corresponding input power and load power performances is presented in Fig. 9 and 10, respectively. Photon Exchange Membrane Fuel Cell (PEMFC) circuit applied as source for given circuit configuration is shown in Fig. 11.

Hardware implementation: Proposed circuit and control configuration is implemented in hardware platform to verifying about simulation implementation results in the form of boosting ratio of circuit and control configuration. ATMEGA328P-PU controller is implemented for controlling and verifying performance of proposed circuit configuration. The implementation circuit which is shown in Fig.11 and corresponding input and load performance is given in Fig. 12-14, respectively. About 12 V power supply capacity of battery power is used for power supply purpose.

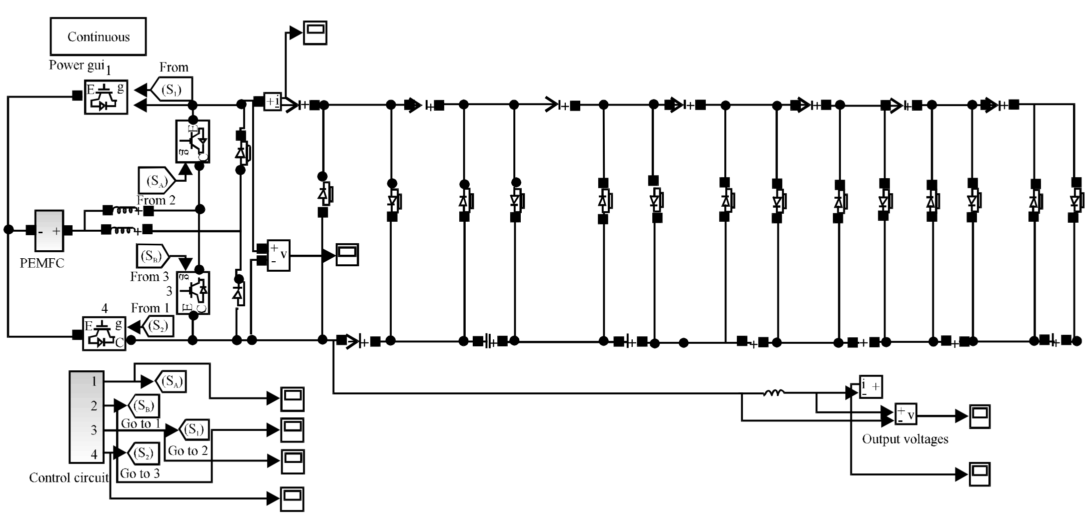

Fig. 8: Proposed circuit implementation

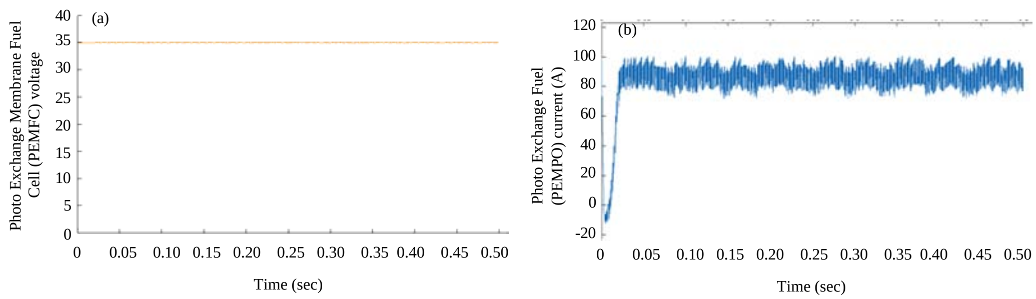

Fig. 9: Fuel cell power performance: a) Supply voltage and b) Supply current

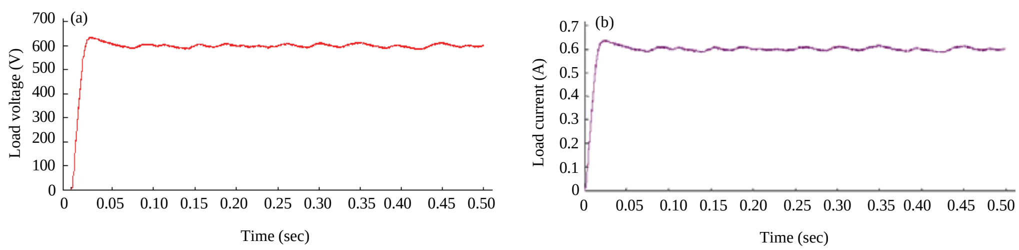

Fig. 10: Load power performance: a) Load voltage and b) Load current

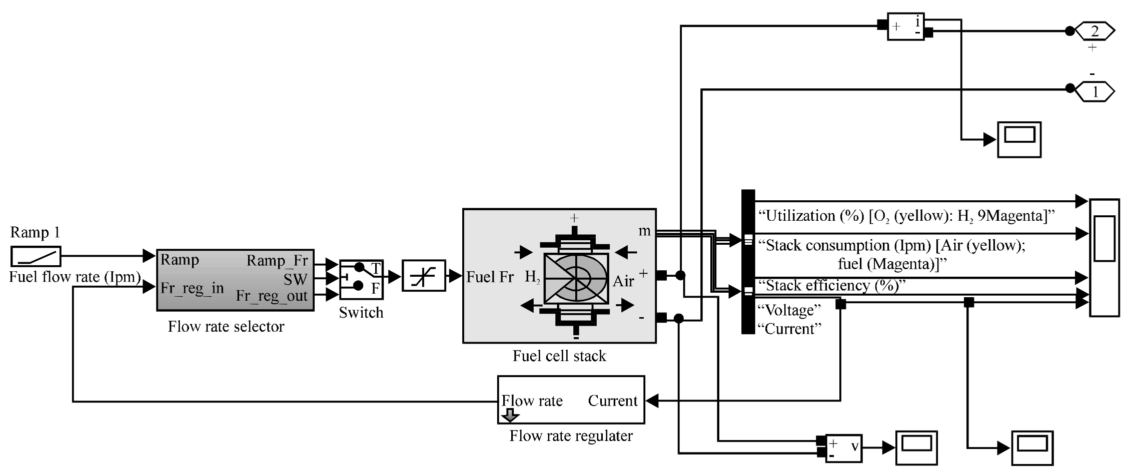

Fig. 11: Proposed fuel cell circuit configuration

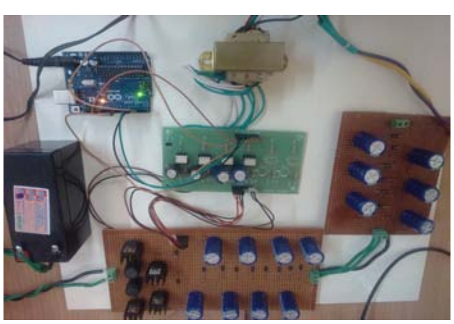

Fig. 12: Proposed circuit configuration of hardware implementation

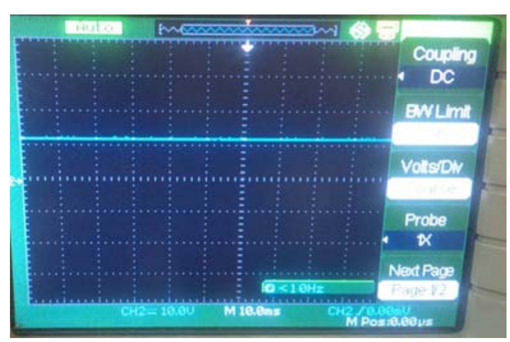

Fig. 13: Input put voltage performance of fuel cell

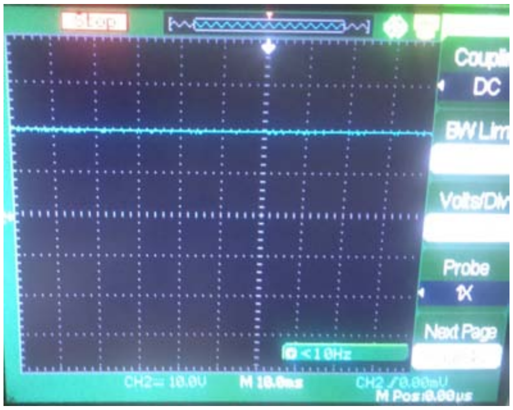

Fig. 14: Load voltage performance of fuel cell

CONCLUSION

The proposed interleaved Cockcroft Walton voltage multiplier is suitable choice for proposed fuel cell power source for improving voltage step up ratio and reducing current rating across source generation. An interleaved circuit used here for both step up and control of fuel cell current whilst interfacing with proposed circuitry. Seven-stage of voltage multiplier circuit was implemented for improving transformer less voltage conversion over classical interleaved power circuit. Ratio of voltage boost of proposed converter is achieved up to 1:17 in transformer-less circuit of operation in seven-stage of multiplier circuit. Number of stage, we can able to extend which is depends on application. The simulation and hardware implementation was analyzed about the performance of proposed topology using MATLAB/Simulink Software and ATMEGA328P-PU controller, respectively. The obtained results of hardware results are proved and matched with simulation results in voltage boosting capability.

REFERENCES

Ali, D.M. and S.K. Salman, 2006. Investigation into modelling of a fuel cell stack system. Proceedings of the 41st International Conference on Universities Power Engineering (UPEC'06) Vol. 1, September 6-8, 2006, IEEE, Newcastle-upon-Tyne, UK., ISBN:978-186135-342-9, pp: 137-141.

Anand, S., S.K. Gundlapalli and B.G. Fernandes, 2014. Transformer-less grid feeding current source inverter for solar photovoltaic system. IEEE. Trans. Ind. Electron., 61: 5334-5344.

Bryant, B. and M.K. Kazimierczuk, 2007. Voltage-loop power-stage transfer functions with MOSFET delay for boost PWM converter operating in CCM. IEEE. Trans. Ind. Electron., 54: 347-353.

Coutellier, D., V.G. Agelidis and S. Choi, 2008. Experimental verification of floating-output interleaved-input DC-DC high-gain transformer-less converter topologies. Proceedings of the 2008 IEEE Conference on Power Electronics Specialists (PESC'08), June 15-19, 2008, IEEE, Rhodes, Greece, ISBN:978-1-4244-1667-7, pp: 562-568.

Farhangi, B. and S. Farhangi, 2006. Application of Z-source converter in photovoltaic grid-connected transformer-less inverter. Electr. Power Qual. Utilisation J., 12: 41-45.

Gao, W., 2005. Performance comparison of a fuel cell-battery hybrid power-train and a fuel cell-ultracapacitor hybrid power train. IEEE. Trans. Veh. Technol., 54: 846-855.

Harfman, T.M., L. Palma, M. Chellappan and P. Enjeti, 2008. Design considerations for fuel cell powered UPS. Proceedings of the 23rd Annual IEEE Conference on Applied Power Electronics and Exposition (APEC'08), February 24-28, 2008, IEEE, Austin, Texas, ISBN:978-1-4244-1873-2, pp: 1984-1990.

Hirose, T. and H. Matsuo, 2012. Standalone hybrid wind-solar power generation system applying dump power control without dump load. IEEE. Trans. Ind. Electron., 59: 988-997.

Jain, S., J. Jiang, X. Huang and S. Stevandic, 2012. Modeling of fuel-cell-based power supply system for grid interface. IEEE. Trans. Ind. Appl., 48: 1142-1153.

Jovanovic, M.M. and Y. Jang, 1999. A new, soft-switched boost converter with isolated active snubber. IEEE. Trans. Ind. Appl., 35: 496-502.

Lu, D.D.C., D.W. Cheng and Y.S. Lee, 2003. A single-switch continuous-conduction-mode boost converter with reduced reverse-recovery and switching losses. IEEE. Trans. Ind. Electron., 50: 767-776.

Paladhi, S. and S. Ashok, 2015. Solid state transformer application in wind based DG system. Proceedings of the 2015 IEEE International Conference on Signal Processing, Informatics, Communication and Energy Systems (SPICES'15), February 19-21, 2015, IEEE, Kozhikode, India, ISBN:978-1-4799-1824-9, pp: 1-5.

Shuang, G., D. Lei, T. Chengwei and L. Xiaozhong, 2011. Novel converter of wind power generation system of non-grid-connection for radio base station. Proceedings of the 2011 International Conference on Electric Information and Control Engineering (ICEICE'11), April 15-17, 2011, IEEE, Wuhan, China, ISBN:978-1-4244-8036-4, pp: 2396-2400.

Singh, B. and R. Kumar, 2016. Solar photovoltaic array fed water pump driven by brushless DC motor using Landsman converter. IET. Renewable Power Generation, 10: 474-484.

Thounthong, P., S. Rael and B. Davat, 2007. Control strategy of fuel cell and supercapacitors association for a distributed generation system. IEEE. Trans. Ind. Electron., 54: 3225-3233.

Torrico, B.R.P., L.D. Bezerra, G.V.T. Bascope, D.D.S. Oliveira and C.G. Branco *et al*., 2008. High frequency isolation on-line UPS system for low power applications. Proceedings of the 3rd Annual IEEE Conference on Applied Power Electronics and Exposition (APEC'08), February 24-28, 2008, IEEE, Austin, Texas, ISBN:978-1-4244-1873-2, pp: 1296-1302.