

High Step-Up Converter in renewable energy systems

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Abstract: High-efficiency dc–dc converters with high-voltage gain have been researched due to increasing demands. They are required as an interface system between the low voltages. This paper presents a high step-up converter for renewable energy source applications with three-winding coupled inductor. The proposed high step-up dc–dc converter is devised for boosting the voltage generated from fuel cell to a 400-V dc-bus voltage. Through the three-winding coupled inductor and voltage doubler circuit, the proposed converter achieve high step-up voltage gain without large duty cycle. The passive lossless clamped technology not only recycles leakage energy to improve efficiency but also alleviates large voltage spike to limit the voltage stress. Furthermore, the switch voltage stress and the diode peak current are also minimized. The switching loss is reduced due to soft switching. The circuit is simulated using MATLAB Simulink and implemented using embedded controller. Both Simulation and Hardware results are compared and verified.

Key words: Pi-filter, High step-up converter, PIC controller, DC-DC Converter

I. Introduction

Power electronics is the application of solid–state Electronic to the control and conversion of electric power. It also refers to a subject of research in electronic and electrical engineering which deals with the design, control, computation and integration of nonlinear, time-varying energy-processing electronic systems with fast dynamics[1-4].

The equivalent circuit of the proposed converter shown in Fig. 2 is composed of a coupled inductor T_r , a main power switch S , diodes $D1$, $D2$, $D3$, and $D4$, the switched capacitor C_b , and the output filter capacitors $C1$, $C2$, and $C3$. L_m is the magnetizing inductor and $Lk1$, $Lk2$, and $Lk3$ represent the leakage inductors. The turns ratio of coupled inductor $n2$ is equal to $N2/N1$, and $n3$ is equal to $N3/N1$, where $N1$, $N2$, and $N3$ are the winding turns of coupled inductor. The steady-state waveforms of the proposed converter operating in CCM are depicted. The each operating modes is discussed in detail.

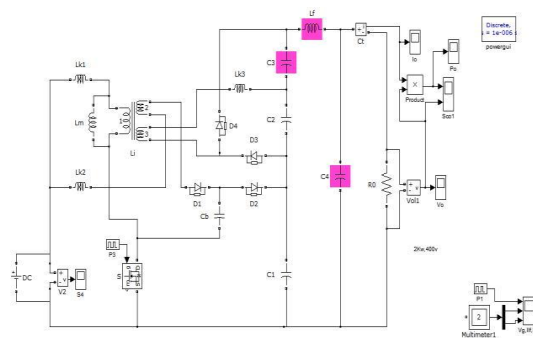


Fig. 2. Equivalent circuit of the proposed converter

3. Modes of operation

Mode I $[T0, T1]$

During this interval, by turning ON the switch S at t_0 , Diodes $D1$, $D2$, and $D4$ are in reverse biased. The current flow path is shown in Fig.3. The primary current i_{Lk1} through the leakage inductor increases linearly, and the stored energy in magnetizing inductance still transfers to the load and capacitor $C2$ via diode $D3$.

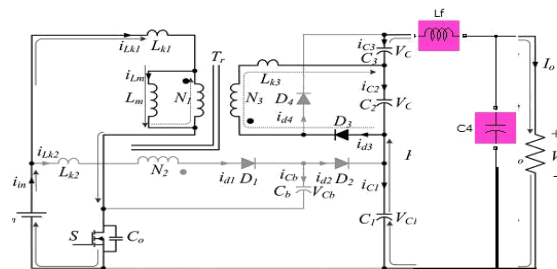


Fig.3 Mode 1

Mode II [T1, T2]

In this model, the switch S is still in the turn-on state which forward biased the diodes D1 and D4 and reverse biased the diodes D2 and D3. The flow of current is shown in Fig. 4. The DC source V_{in} still charges the magnetizing inductor L_m and leakage inductor L_{k1} , and increasing currents through these inductors linearly. Whereas some of the energy from DC source V_{in} transfer to the secondary side of the coupled inductor to charge the capacitor C3. LC series circuit is used to charge the switched capacitor C_b .

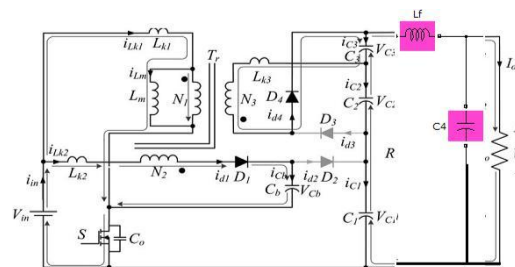


Fig.4 Mode II

Mode III [T2, T3]

During this interval, by turning OFF the switch S at t_2 , diodes D1 and D4 are still forward biased and diodes D2 and D3 are reverse biased. The current path is shown in Fig. 5. The magnetizing current and LC series current charge the parasitic capacitor C_o of the MOSFET.

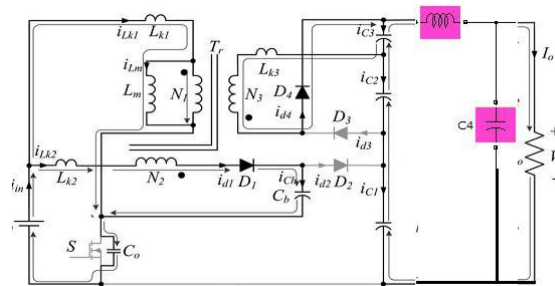


Fig.5 Mode III

Mode IV [T3, T4]

During this interval, the switch S is still in the off state which forward biased the Diode $D1$, $D2$ and $D4$ and reverse biased the diode $D3$. The current-flow path is shown in Fig. 6. The charging of the output capacitor $C3$ is done by the current I_{d4} and decreases linearly. The total voltage of $V_{in}+V_{Lm}+V_{Cb}$ is charging to clamped capacitor $C1$, and few of the energy is given to the load.

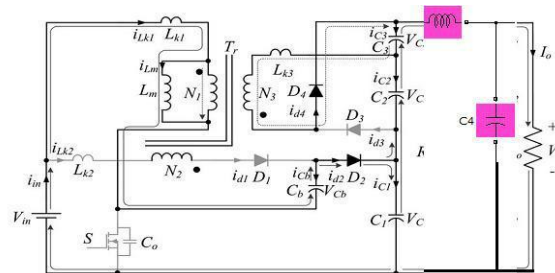


Fig.6 Mode IV

Mode V [T4, T5]

During this interval, switch S is still in the turn-off state which makes the diodes $D1$ and $D4$ are in OFF state. The diodes $D2$ and $D3$ get forward biased. The current-flow path is shown in Fig. 7. The energy of the primary side still charges the clamped capacitor $C1$ and supplies energy to the load. A part of the energy from DC source V_{in} is transferred to the secondary side of the coupled inductor which helps to charge the capacitor $C2$, and the current i_{d3} increases linearly

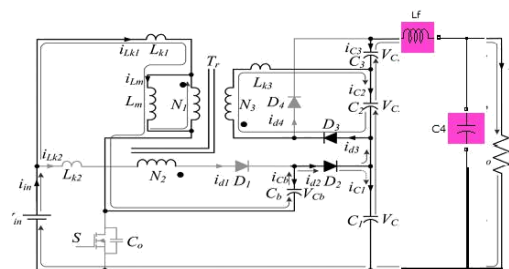


Fig.7 Mode V

Mode VI [T5, T6]

During this interval, switch S is still in the turn-off state making the diodes $D1$, $D2$, and $D4$ reverse biased and the diode $D3$ forward biased. The current-flow path is shown in Fig.8. The current i_{Lk1} is dropped till zero. The magnetizing inductor L_m continuously moves energy to the third leakage inductor L_{k3} and the capacitor $C2$. The energy in $C1$ and $C3$ are discharge to the load. The capacitor $C2$ is charge through current i_{d3} and supplies the load current.

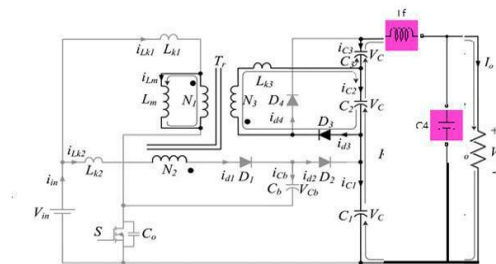


Fig.8 Mode VI

III.Simulation of High step up converter

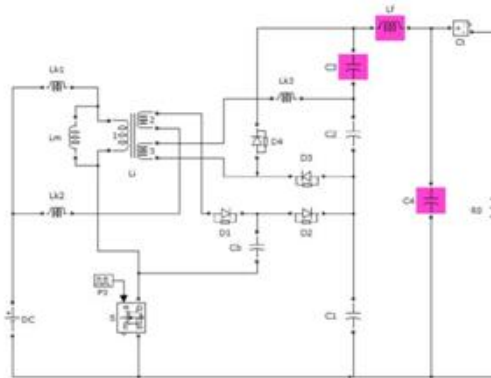


Fig.9 Circuit diagram of high step-up converter with PI-Filter

Fig .9 shows the simulated circuit diagram of high step up converter with PI-filter. Using MATLAB, the circuit is simulated and the results are discussed.

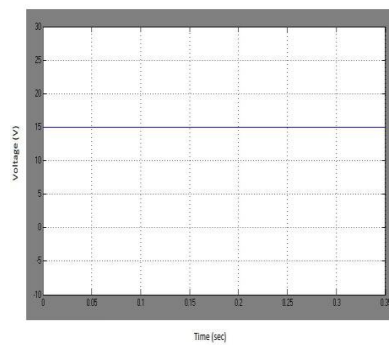


Fig. 10 DC source input voltage

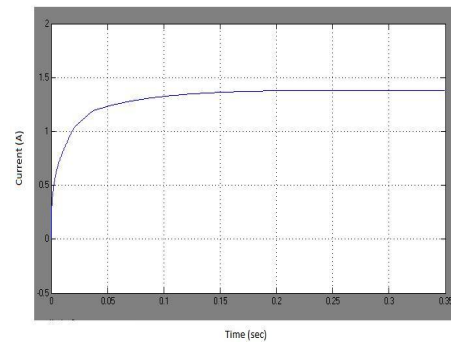


Fig. 11 Output current

Fig. 10 and 11 show the variation of voltage and current with respect to time. The proposed converter is given an input voltage of 15 V. An output current of 11.37 amp is obtained after the $t=0.2$ sec.

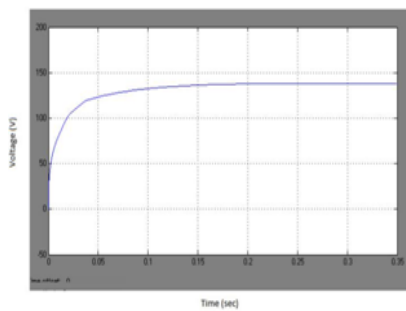


Fig. 12 Output voltage

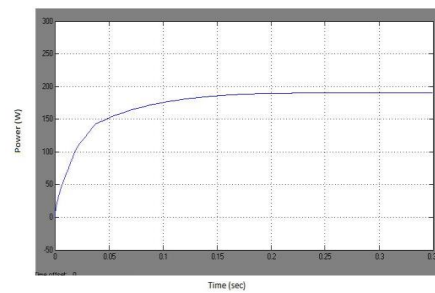


Fig. 13 Output power

Fig. 12 and 13 show the variation of voltage and power with respect of time. The output voltage becomes constant at 138 V after the $t=0.2$ s. The power output becomes constant at 190 W after $t=0.2$ s. It is observed that using high step up converter, the output voltage is increased compared to its input value.

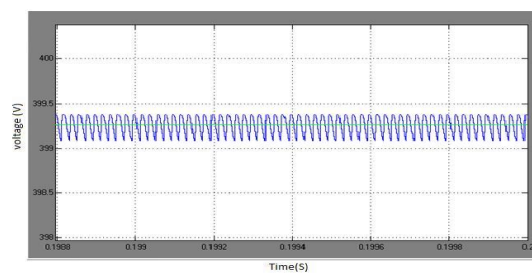


Fig. 14 Ripple voltage of proposed system

Fig. 14 shows the variation of ripple voltage of proposed system with respect to time where the ripple of proposed system is found to be very less .

IV. HARDWARE IMPLEMENTATION

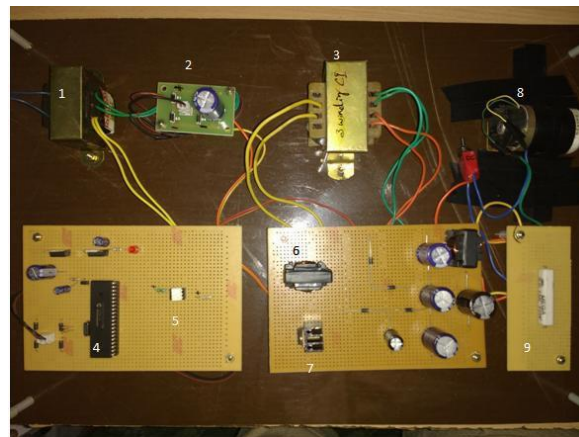


Fig. 15. Hardware for High step up converter

The hardware components used in fig.15 are Step – down transformer (230/0-15)V, Bridge rectifier ,Three winding coupled inductor, Peripheral interface controller(PIC), Driver circuit,, Magnetising Inductor ,MOSFET and load.

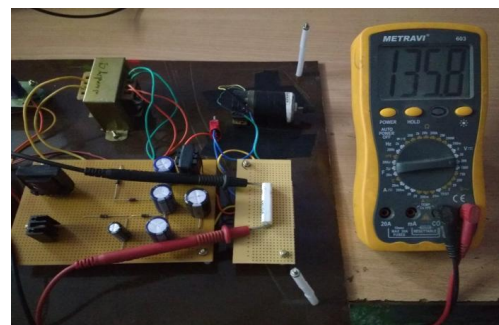


Fig. 16 Real time measurement of Input and Output Voltage

Fig. 16 shows the input and output voltage measurement. It is measured using the multimeter across the diode D3 and D4 of bridge rectifier and load. It is found that the output voltage 135.8 V is step up from the input value of 14.8V.

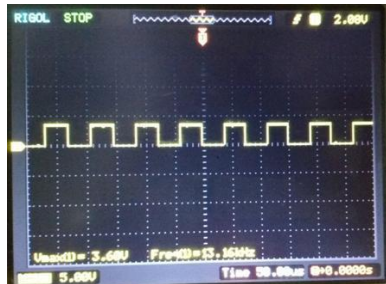


Fig. 17 Controller Output Voltage

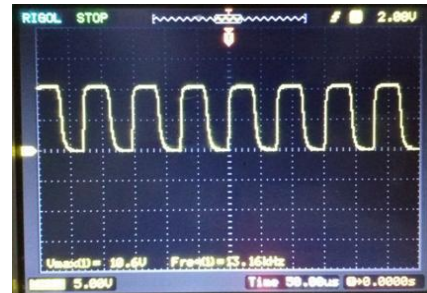


Fig. 18 Driver Output Voltage

Fig. 17 shows the controller output voltage where the peak voltage is 3.6 V at the frequency of 13.16 kHz. Fig. 18 shows the driver output voltage and its value is 10.6 V at the frequency of 13.16 kHz



FIG. 19 OUTPUT RIPPLEVOLTAGE

Fig. 19 shows the output ripple voltage and from the figure it is observed that its value is almost 0 indicating its high performance.

Table. 1 Comparison Btween Hardware And Simulation

Parameters	Hardware	Simulation
Input voltage	14.8V	15V
Output voltage	135.8V	137V
Ripple voltage	0.0006V	0.0006V

Table. 1 shows the comparison result of 15V prototype and simulation result. From the table it can be concluded that the hardware prototype which is being used satisfies the simulation result.

V. CONCLUSION

A high step-up DC–DC converter is clearly analyzed and successfully verified. By using technologies of three-winding coupled inductor, switched capacitor and voltage doubler circuit with PI-Filter, the high step-up conversion can be efficiently obtained. The Ripple Voltage is reduced to almost Zero. The voltage stress is limited and the efficiency is improved at low Duty Cycle value. The full-load efficiency is up to 91.32% and the maximum efficiency is up to 96.81%. The proposed converter is suitable for high-power applications as fuel cell systems in hydroid Electric Vehicles, Traction Motor, etc.

References

- [1]. Deng Y, Li W., Lv X., J. Liu, and X, A review of non-isolated high step-up DC/DC converters in renewable energy applications, in Proc. IEEE Appl. Power Electronics, Conf. Expo., 2009, pp. 364–369.
- [2]. Dwari S. M and Parsa L., “A novel high efficiency high power interleaved coupled-inductor boost DC–DC converter for hybrid and fuel cell electric vehicle, in Proc. IEEE Vehicle Power Propulsion Conf., 2007, pp. 399–404.
- [3]. Jiang W. and Fahimi B., Active current sharing and source management in fuel cell-battery hybrid power system, IEEE Trans. Ind. Electronics, 2010, vol. 57, no. 2, pp. 752–761 .
- [4]. Khaligh and Z. Li, Battery, ultra capacitor, fuel cell, and hybrid energy storage systems for electric, hybrid electric, fuel cell, and plug-in energy source applications: State of the art, IEEE Trans. Vehicle Technology, 2010, vol. 59, no. 6, pp. 2806–2814.

- [5]. Ksiazek P. F. And Ordonez M., Swinging bus technique for ripple current elimination in fuel cell power conversion, IEEE Trans. Power Electronics, 2014, vol. 29, no. 1, pp. 170–178.
- [6]. Laughton M. A. Fuel cells, IEEE Eng. Sci. Edu. J., 2002, vol. 11, no. 1, pp. 7–16.
- [7]. Li W. and He X., Review of non-isolated high-step-up DC/DC converters in photovoltaic grid-connected applications, IEEE Trans. Ind. Electronics, 2011, vol. 58, no. 4, pp. 1239–1250.
- [8]. Marchesoni M. and Vacca C., New DC–DC converter for energy storage system interfacing in fuel cell energy source applications, IEEE Trans. Power. Electron., 2007, vol. 22, no. 1, pp. 301–308.
- [9]. Su G.-J. And L. Tang, A reduced-part, triple-voltage DC-DC converter for EV/HEV power management, IEEE Trans. Power Electronics, 2009, vol. 24, no. 10, pp. 2406–2410.
- [10]. Thounthong P., Rael S., and Davat B., Analysis of super capacitor as second source based on fuel cell power generation, IEEE Trans. Ind. Electronics, 2009, vol. 24, no. 1, pp. 247–255.
- [11]. Tseng K. C. and Huang C. C., High step-up high-efficiency interleaved converter with voltage multiplier module for renewable energy system, IEEE Trans. Ind. Electron., 2014, vol. 61, no. 3, pp. 1311–1319.
- [12]. Wang L. and H. Li, Maximum fuel economy-oriented power management design for a fuel cell vehicle using battery and ultra capacitor, IEEE Trans. Ind. Appl., 2010, vol. 46, no. 3, pp. 1011–1020.
- [13]. Wai R. J. and Duan K. Y., High-Efficiency DC-DC converter with high voltage gain and reduced switch stress, IEEE Trans. Power Electron., 2007, vol. 54, no. 1, pp. 354–364.
- [14]. Xuwei P. and Rathore A. K., Novel interleaved bidirectional snubberless soft-switching current-fed full-bridge voltage doubler for fuel cell vehicles, IEEE Trans. Power Electronics, 2013, vol. 28, no. 12, pp. 5535–5546.

- [15]. Zhang Z., Ouyang Z, O. Thomsen C., and M. A. E. Andersen, Analysis and design of a bidirectional isolated dc–dc converter for fuel cells and super capacitors hybrid system, IEEE Trans. Power Electronics., 2012, vol. 27, no. 2, pp. 848–859.

