

Voltage Gain Enhanced Step-Up Converter Based Switched Mode Power Supply

P.R Arya¹, Vidhya.N.Elayath², Saritha Sathyan³

¹(Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

²(Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

³(Dept. of EEE, Sree Narayana Gurukulam College of Engineering, Kolenchery, Ernakulum, Kerala, India)

Abstract : *In this paper, a voltage-boosting converter based dual output switched mode power supply is presented. This converter is a combination of KY and synchronous BUCK-BOOST converter. High voltage gain is enhanced by using coupled inductor with turns ratio and one charging pump. The output current of the converter is non pulsating, hence the voltage stress across the output capacitor is very less. The proposed Switched mode power supply is specially designed for low power applications as it is having a KY Buck-Boost converter front end. As multiple outputs at low power levels are obtained, it can be used for low power applications with a high efficiency. Transformer is being used for energy storage and transfer device in SMPS. The converter has only two switch which is controlled using a voltage follower approach. The advantages of the SMPS are high efficiency, improved power factor and reduced number of components. The proposed concepts have been verified using MATLAB simulations.*

Keywords: *Buck-Boost converter, Charging pump, Coupled inductor, KY converter, switched mode power supply*

I. INTRODUCTION

In several applications, high-voltage-conversion converters play a vital role in boosting the low output voltage to high voltage with the load requirement. Traditional nonisolated voltage-boosting converters [1], [2], such as the traditional boost converter, is simple in structure, but the voltage conversion ratio is not so high. Whereas flyback converter possesses a high voltage conversion ratio but the corresponding leakage inductance is large. Up to now, many

kinds of voltage-boosting techniques have been presented, including several inductors that are magnetized and then pump the stored energy into the output with all inductors connected in series [3], coupled inductors with turns ratios, [4] voltage superposition based on switching capacitors [9],[13] auxiliary transformers with turns ratios [12]. The voltage-lift technique is used to step-up the output voltage, but the voltage conversion ratios are not high. The voltage conversion ratios can be promoted by increasing the number of voltage-boosting cells, floating active switches. Sometime extra components are required. This would make the complete circuits complicated and would require the corresponding isolated drivers etc. In [8] and [10] the output terminal is floating, thereby increasing application complexity. In [3] and [15], the output currents are pulsating, thereby causing the output voltage ripple to be enormous. In [12]–[14] and [18], although the output currents are non pulsating, their voltage gains are not high enough.

KY and Buck-Boost converter is a recently introduced converter which works in CCM, keeping the output current non-pulsating, hence suppressed voltage stress will come across the output capacitor [18-19]. Reasonably better candidate in the family of DC-DC converters, the KY-BBC is considered for this study. It converts the positive DC source voltage into positive DC load voltage with reduced output ripple voltage. Here the voltage gain can be enhanced by synchronous buck-boost converter and coupled inductor. A synchronous buck-boost converter is similar to buck boost converter with the diode being replaced by a MOSFET switch. So, the voltage gain of this converter will be higher than the converters discussed above [14] and can be changed by adjusting both the duty cycle and the turn's ratio. Furthermore, the duty cycle and the turns ratio are independent, which means, change in duty cycle does not affect the turns ratio and vice versa.

In many applications, multiple outputs are required. These outputs may be required to electrically isolate from each other, depending on the application. As opposed to linear power supplies, in switching power supplies, the transformation of DC voltage from one level to another is accomplished by using dc-dc converter circuits. These circuits employ solid-state devices, which operate as a switch either completely off or completely on. The power devices are not required to operate in their active region. The emergence of the switching power supplies are mainly contributed by relatively lower cost of the device.

This paper proposes a voltage boosting converter with dual output switched mode power supply. The step-up converter is constructed by a combination of a KY converter and synchronous buck-boost converter. The converter contains only two power electronic switches, which simplifies the circuit configuration. The proposed converter reduced the switching losses. The converter output will be non pulsating so the output voltage ripple is very less. This controlled dc voltage is given to half-bridge VSI for obtaining dual-output dc voltages. The half-bridge voltage source inverter is designed in continuous conduction mode to reduce the component stress.

II. Study Of Proposed System

The system configuration of the proposed step-up converter based switched-mode power supply is shown in fig.1. This system is composed of a DC power supply feeding step-up converter which combines one KY converter and synchronously rectified buck-boost converter with a half-bridge voltage source inverter and multiple –output HFT at the load end . Prior to taking up this section, for the convenience of analysis, the step-up converter consist of two MOSFET switches Q_1 and Q_2 along with their body diodes Q_{D1} and Q_{D2} . A coupled inductor with primary turns N_p and secondary turns N_s which is used to obtain high voltage gain. Capacitor C_1 and C_2 are energy transferring capacitor and charge pump capacitor respectively, one diode D_1 and inductor L_O is the output inductor. The input capacitors (C_{11}, C_{12}) of the half bridge voltage source inverter perform as the filter at the output of the KY and Buck-Boost converter. The output dc voltage of the KYBB converter is controlled by using PI closed-loop control. The regulated dc output voltage of the KYBB converter is fed to the half-bridge voltage source inverter for obtaining dual dc voltages. The half-bridge voltage source inverter consists of two input capacitors C_{11} and C_{12} , two high-frequency switches S1 and S2, and one multiple output high-frequency transformer. The high-frequency transformer is having one primary winding and two secondary windings which are coupled in center-tapped arrangement to decrease the losses. At the secondary side, there is a multiple diode rectifier followed by a filter circuit to decrease the current and voltage ripples, which makes a pure DC output.

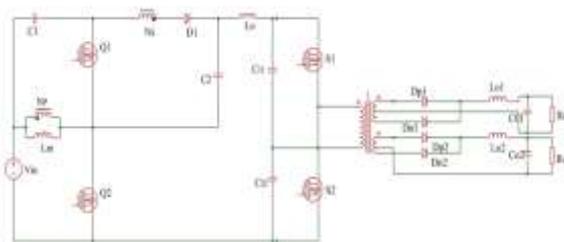


Fig .1. Configuration of the proposed step-up converter with SMPS

2.1 DC-DC Step up converter

Several types of non-isolated voltage-bucking/boosting converters are there, like the buck–boost converter, Cuk converter, SEPIC converter and Zeta converter, etc. The DC-DC converters can be used as switching mode regulators to convert an unregulated dc voltage to a regulated dc output voltage. The regulation is normally achieved by PWM at a fixed frequency and the switching device is generally BJT, MOSFET or IGBT. However, these converters work in continuous current mode have right-half-plane zeroes, thereby causing the system steadiness to be low, load transient responses to be slow, nearly several milliseconds and, hence, the corresponding design for accelerating transient responses is difficult. As for Cuk, SEPIC, and Zeta converters, each not only possesses the weaknesses of the right-half-plane zero but also needs two inductors, thereby causing the corresponding overall system volume to be enlarged.

Here the DC–DC step-up converter consisting of a KY and Buck-Boost converter is a recently introduced converter which keeps the output current non-pulsating, hence the voltage and current stress will be suppressed across the output capacitor. The control methodologies for KY converter topologies are studied for future applications. Reasonably KY-BBC is considered better candidate in the family of DC-DC converters. It converts the positive DC source voltage into positive DC load voltage with reduced output ripple voltage. The main objective is to improve the Voltage Gain of the Step-up Converter and also to reduce voltage stress of the circuit. Further the voltage drift problem is reduced using closed loop control of the step-up converter PI controller. The switching in a converter is done through a MOSFET or IGBT.

The circuit operation of the KY Buck-Boost converter can be divided into two distinct topological stages. Before taking up this segment, there are some assumptions to be made.

- The coupled inductor is modeled as an ideal transformer except that one magnetizing inductor L_m is connected in parallel with the primary winding.
- The dead times between the two MOSFET / IGBT switches are omitted.
- The switches and the diodes are assumed to be ideal components
- The values of all the capacitors are large enough such that the voltages across them are kept constant at some values.

The following study contains the description of the power flow path for each mode, along with the corresponding equations and voltage gain. Fundamentally, there are two operating modes in the step-up converter. Moreover, the gate driving signals v_{gs1} and v_{gs2} of the two switches $S1$ and $S2$ have the duty cycles of D and $(1 - D)$ respectively. In addition, the input current is denoted by i_i , the current through the primary and secondary winding are represented by i_{NP} and i_{NS} respectively. The current through L_m is denoted by i_{Lm} , the current through L_o is denoted by i_{L0} , and the current through R_o is described by I_o . On the other hand, v_{NP} is denoted by the voltage across L_m or primary winding and v_{NS} is denoted by voltage across the secondary winding. The voltage across C_1 and C_2 are represented by V_{C1} and V_{C2} respectively and the voltage across L_o is described by v_{L0} .

Fig.2 (a) and fig.2(b) shows the operating circuit of the KYBBC converter when Q_2 is turned ON - Q_1 is turned OFF and Q_1 is turned ON- Q_2 is turned OFF respectively.

Mode I: During this mode Q_2 is turned ON and Q_1 is turned OFF, positive input voltage V_i is imposed on N_p , therefore L_m will be magnetized and the voltage induced in the secondary winding equal to $V_i \times N_s/N_p$. In addition, D_1 comes to be forward-biased; so C_2 is charged to $V_i + V_{C1} + V_i \times N_s/N_p$; and V_{L0} , is a negative value, equal to $V_{C2} - V_o$, consequently L_o is demagnetized. As a consequence, the energy delivers to the load equal to $V_{C2} + V_{L0}$.

The associated equations are as follows:

$$V_{Ns} = V_i \times \frac{N_s}{N_p} \quad (1)$$

$$V_{c2} = V_i + V_{c1} + \left(V_i \times \frac{N_s}{N_p} \right) \quad (2)$$

$$V_{L0} = V_{c2} - V_o \quad (3)$$

$$V_o = V_{c2} + V_{L0} \quad (4)$$

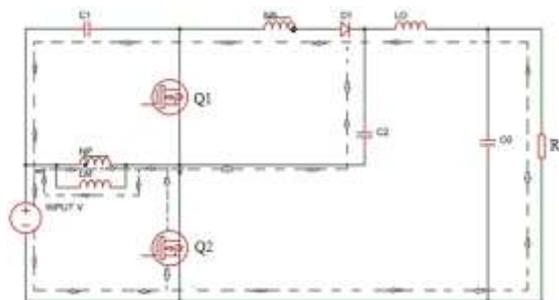


Fig.2 (a) Operation of KYBBC: Q_2 ON and Q_1 OFF

Mode II: During this mode Q_1 is turned ON- Q_2 is turned OFF. So, the $-V_{C1}$ voltage is imposed on primary winding, consequently the magnetizing inductor L_m to be demagnetized and the voltage induced in the secondary winding, equal to $-V_{C1} \times N_s/N_p$. In addition, D_1 becomes reverse biased, and V_{L0} is a positive value, equal to $V_i + V_{C1} + V_{C2} - V_o$, thus causing L_o to be magnetized. As a result, the energy delivers to the load equal to $V_i + V_{Np} + V_{c2} + V_{Lm}$

The associated equations are as follows:

$$V_{Ns} = -V_{c1} \times \frac{N_s}{N_p} \quad (5)$$

$$V_{Lo} = V_i + V_{c1} + V_{c2} - V_o \quad (6)$$

$$V_o = V_i + V_{Np} + V_{c2} + V_{Lm} \quad (7)$$

Q₂ON and Q₁OFF condition

$$v_{Np} = -V_{c1} \quad (8)$$

$$v_{Lo} = V_i + V_{c1} + V_{c2} - V_o \quad (9)$$

By applying the voltage-second balance principle to L_m over one switching period

$$V_i \times D + (-V_{c1}) \times (1 - D) = 0 \quad (10)$$

By rearranging the above equation, the voltage across C_1 , i.e., V_{c1}

$$V_{c1} = \frac{D}{1-D} \times v_i. \quad (11)$$

Similarly, by applying the voltage-second balance principle to L_o over one switching period

$$(V_{c2} - V_o) \times D + (V_i + V_{c1} + V_{c2} - V_o) \times (1 - D) = 0 \quad (12)$$

The voltage across C_2 , i.e., V_{c2}

$$V_{c2} = V_i + V_{c1} + V_i \times \frac{N_s}{N_p} \quad (13)$$

From the above equations, Voltage gain,

$$\frac{V_o}{V_i} = \frac{2-D}{1-D} + \frac{N_s}{N_p} \quad (14)$$

From voltage gain equation, it is clear that voltage gain can be changed by adjusting duty cycle and turns ratio independently. So this converter can achieve much higher gain than that of other converters. And also it is shown that $0 < D < 1$.

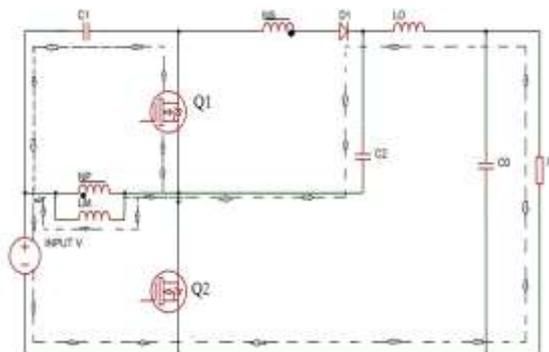


Fig.2 (b) Operation of KYBBC: Q₁ ON and Q₂ OFF

2.2 Operation of half bridge VSI

The controlled output dc voltage of the front end KY Buck-Boost converter is fed to the half-bridge VSI for high-frequency isolation, for voltage scaling, and for obtaining multiple dc output voltages. The operation of the half-bridge VSI in one switching cycle is described in four states. In the first state, the upper switch S1 is turned on; the input current circulates through the primary winding of the HFT to the lower input capacitor C₁₂. Upper diodes at the secondary side start conducting, and the inductors associated with the windings start storing energy, as shown in Fig.3(a). Therefore, inductor currents increase, and output filter capacitors discharge through the loads. In the second state [Fig.3 (b)], both switches are turned off, and all secondary diodes free wheel the stored energy until the voltage across the HFT becomes zero. Therefore, inductor currents start decreasing. In the third state of the switching cycle the second switch S2 is turned on, and the input current flows through upper capacitor C₁₁ and the primary winding, as shown in Fig.3 (c). Lower diodes in the secondary windings conduct, and output inductors start storing energy. When the energy stored in the inductors reaches maximum values, the switch is turned off. In the last state, all secondary diodes start conducting; this is similar to the second state. The same operating states repeat in each switching cycle. In the fourth state mode is similar to the second state and occur twice in each switching cycle, as shown in Fig.3 (b).

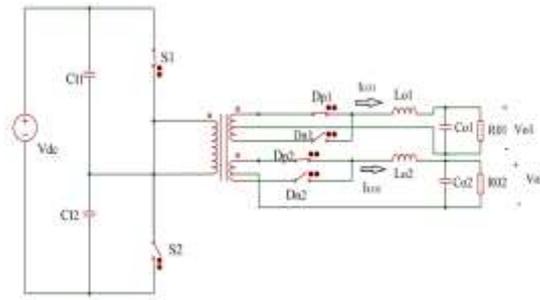


Fig. 3(a) Half bridge VSI First state - When switch S₁ ON

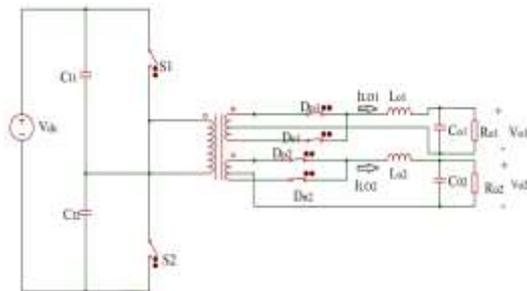


Fig.3(b) Half bridge VSI Second state -When both switches are OFF

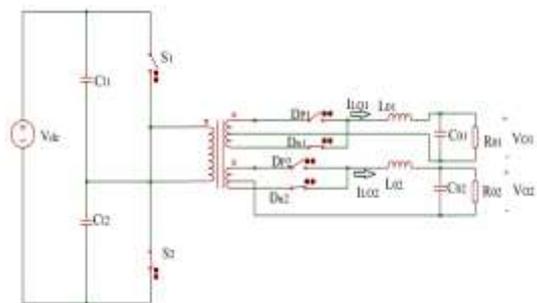


Fig.3(c) Half bridge VSI Third state – When switch S₂ is ON

2.3 Operation of HFT and diode rectifier

The half bridge VSI is connected to the high frequency transformer (HFT) and followed by multiple diode rectifiers. Corresponding to the first state of VSI, upper diodes in the secondary winding starts conducting and the inductors starts charging. In the second state and in the fourth state freewheeling of diodes in the secondary of the transformer takes place. In the third state lower diodes connected in the secondary starts conducting and the inductors gets discharged.

III. Simulation results and analysis

To verify the feasibility and validity of the proposed converter, MATLAB/ Simulink software is applied for the simulation of the switched mode power supply at an operating point of input voltage $V_{dc} = 12$ V. Performance of the proposed dual-output switched mode power is simulated in MATLAB/Simulink environment using Sim-Power- System toolbox and discrete time sampling. The duty cycle is set to 50%. Fig.4 shows the Simulink model of the proposed switched mode power supply. The simulation model in the figure.4 consists of a DC power supply, DC-DC converter and a switched mode power supply. Instead of coupled inductor, here using transformer. The 12V supply given to a DC -DC converter .Converter step-up the voltage to 72_{dc} . The regulated dc output voltage of the KY Buck-Boost converter is fed to the half-bridge VSI for obtaining dual dc voltages. Simulation parameters are given in the table I.

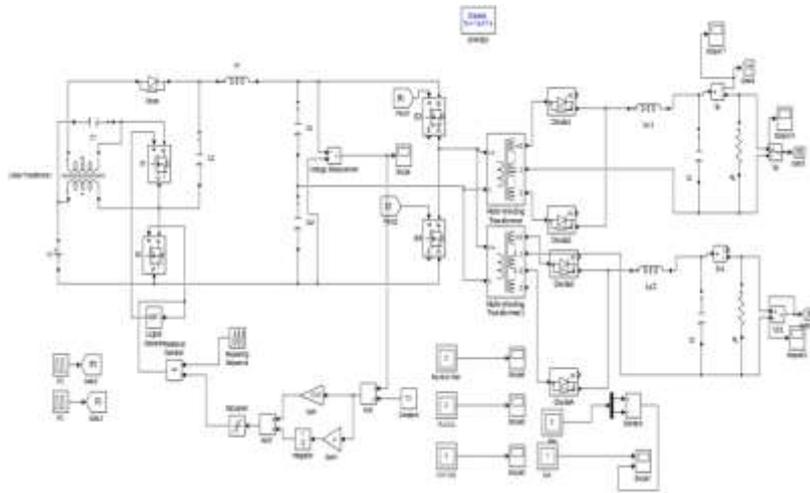


Fig. 4.Simulation model for a proposed system

Table I: Simulation parameters

Parameters	Value
C_1	470 μ F
C_2	94 μ F
C_0	440 μ F
L_0	188 μ H
R_0	720 Ω
C_{11} & C_{12}	1000 μ F
C_{01} & C_{02}	600 μ F
L_{01} & L_{02}	1 μ H

12V DC is given to the input of the converter is shown in Fig.6.

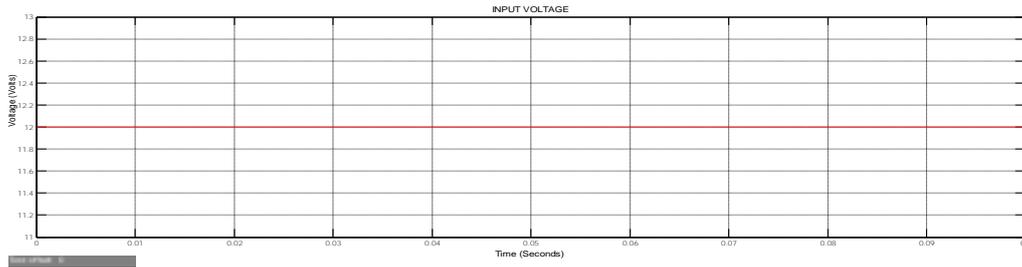


Fig. 6. Input voltage 12V

Gating pulses for the switches Q_1 and Q_2 in step-up converter are shown in Fig.7 with a duty cycle of 50%. Gating pulses are generated by the PWM control method. Switching frequency is 100 kHz.

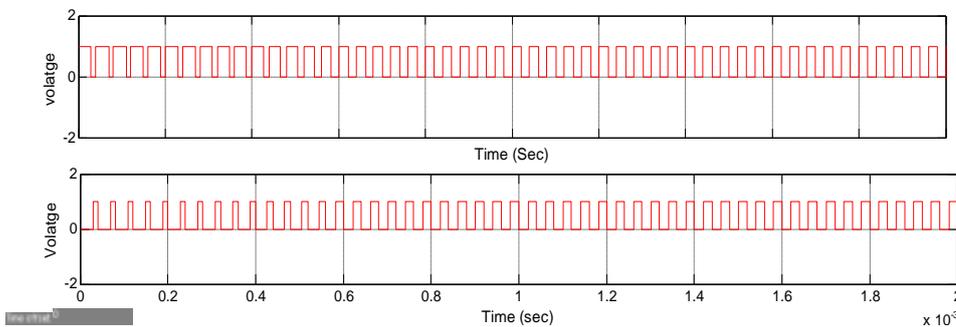


Fig.5.7 Gating pulses for the switch Q_1 and Q_2

The current passing through the primary side of the coupled inductor ($i_{Np} + i_{Lm}$), and the current passing through the secondary side of the coupled inductor (i_{Ns}).

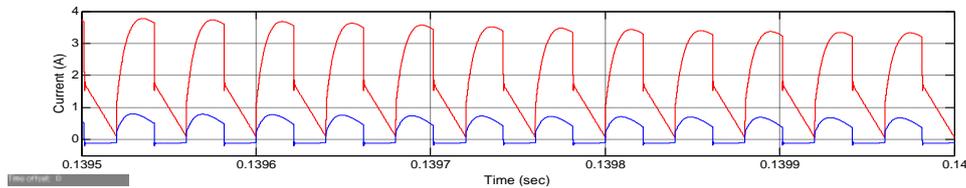


Fig. 8 $i_{Np} + i_{Lm}$, i_{Ns}

Fig.9 show the voltage across the energy transferring capacitor C_1 , $V_{C1}=12V$ and charge pump capacitor C_2 , $V_{C2} =60V$.

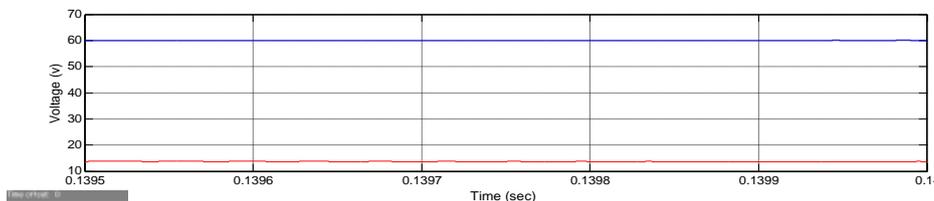


Fig.9 Voltage across C_1 and C_2

Fig.10 shows the output voltage waveforms. V_{dc} indicates the KY Buck-Boost converter output DC voltage. It is maintained constant at a value of 72 V for varying input voltages due to the DC link voltage follower approach. Where the converter gating pulses are regulated according to the variations in the DC link voltage.

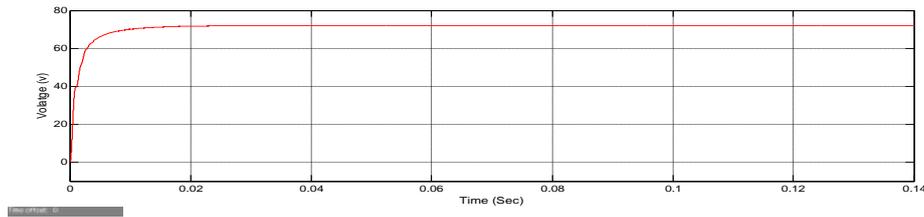


Fig.10 KY Buck-Boost converter output Voltage Waveform

Gating pulses for the switch S_1 and S_2 in half bridge inverter is shown in Fig.11 with a duty cycle of 40%. Switches are operating at a frequency of 50 kHz. Pulses are generated by pulse generator

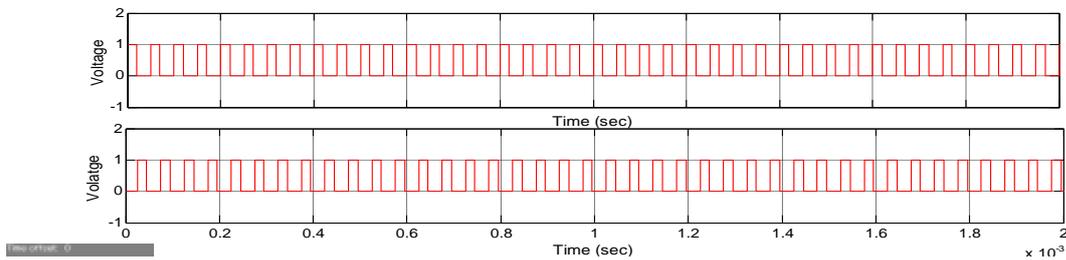


Fig.11 Gating pulses for the switch S_1 and S_2

Fig.12 and 13 shows the SMPS output voltages. $V_{01} = 14 \text{ V}$ and $V_{02} = 10 \text{ V}$ are the two output voltages of the Switched Mode Power Supplies. The two output voltages are taken from the two isolated tapings at the secondary of the transformer.

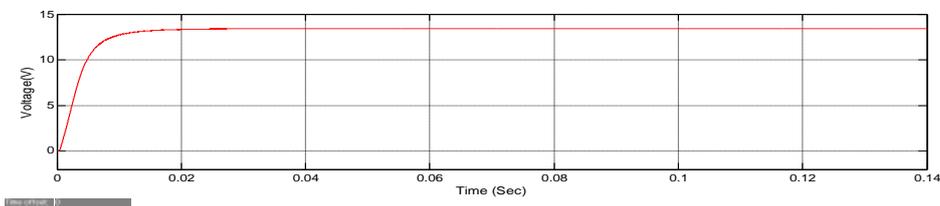


Fig.12 SMPS output voltage waveform V_{01}

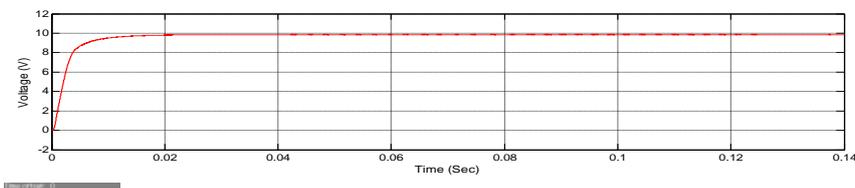


Fig.13 SMPS output voltage waveform V_{02}

Due to the constant Dc link voltage control it is possible to obtain a constant DC voltage at the output with minimum ripples.

IV. CONCLUSION

A high voltage gain step-up converter based dual output switched mode power supply has been designed, modeled and simulated. A high step-up voltage gain is achieved. The corresponding voltage gain is higher than that of the existing step-up converter combining KY and buck-boost converters. An excellent performance of the proposed KY Buck-Boost converter- based multiple-output switched mode power supply is

observed during steady-state condition. As the output voltage of the converter is controlled with PI controller which has minimum overshoot, ripple and produces a constant output voltage. Furthermore, the proposed converter has no floating output, and it has one output inductor; hence, the output current is non pulsating. For an input voltage of 12 V DC, it is possible to obtain step-up output of 72V DC. This indicates high conversion efficiency. From the analysis of the proposed topology and by comparing it with the previous topologies it is concluded that constant voltages can be maintained at both the outputs irrespective of the changes in the input voltage. The constant DC output voltages are at 14V and 10V respectively. Moreover, the structure of the proposed converter is quite simple and very suitable for communication system and photo-voltaic applications.

References

- [1] R. W. Erickson and D. Maksimovic, *Fundamentals of Power Electronics*, 2nd ed. Norwell, MA, USA: Kluwer, 2001.
- [2] A. I. Pressman, *Switching Power Supply Design*, 2nd ed. New York, NY, USA: McGraw-Hill, 1998.
- [3] B. R. Lin, F. Y. Hsieh, and J. J. Chen, "Analysis and implementation of a bidirectional converter with high converter ratio," in *Proc. IEEE ICIT*, 2008, pp. 1–6.
- [4] K. B. Park, G. W. Moon, and M. J. Youn, "Nonisolated high step-up stacked converter based on boost-integrated isolated converter," *IEEE Trans. Power Electron.*, vol. 26, no. 2, pp. 577–587, Feb. 2011.
- [5] A. Canesin and I. Barbi, "A unity power factor multiple isolated outputs switching mode power supply using a single switch," in *Proc. IEEE APEC*, Mar. 1991, pp. 430–436.
- [6] J. Y. Lee, G. W. Moon, and M. J. Youn, "Design of a power-factor correction converter based on half bridge topology," *IEEE Trans. Ind. Electron.*, vol. 46, no. 4, pp. 710–723, Aug. 1999.
- [7] W. Hart, *Power Electronics*. New York, NY, USA: McGraw-Hill, 2011.
- [8] R. J. Wai and R. Y. Duan, "High-efficiency power conversion for low power fuel cell generation system," *IEEE Trans. Power Electron.*, vol. 20, no. 4, pp. 847–856, Jul. 2005.
- [9] F. L. Luo, "Analysis of super-lift Luo-converters with capacitor voltage drop," in *Proc. IEEE ICIEA*, 2008, pp. 417–422.
- [10] L. S. Yang, T. J. Liang, H. C. Lee, and J. F. Chen, "Novel high step-up DC–DC converter with coupled-inductor and voltage-doubler circuits," *IEEE Trans. Ind. Electron.*, vol. 58, no. 9, pp. 4196–4206, Sep. 2011.
- [11] N. Mohan, T. M. Undeland, and W. P. Robbins, *Power Electronics: Converters, Applications and Design*. Hoboken, NJ, USA: Wiley, 2003.
- [12] K. I. Hwu and Y. T. Yau, "KY converter and its derivatives," *IEEE Trans. Power Electron.*, vol. 24, no. 1, pp. 128–137, Jan. 2009.
- [13] K. I. Hwu and Y. T. Yau, "A KY boost converter," *IEEE Trans. Power Electron.*, vol. 25, no. 11, pp. 2699–2703, Nov. 2010.
- [14] K. I. Hwu, K. W. Huang, and W. C. Tu, "Step-up converter combining KY and buck-boost converters," *IET Electron. Lett.*, vol. 47, no. 12, pp. 722–724, Jun. 2011.
- [15] K. I. Hwu and Y. T. Yau, "Inductor-coupled KY boost converter," *IET Electron. Lett.*, vol. 46, no. 24, pp. 1624–1626, Nov. 2010.
- [16] K. I. Hwu and W. C. Tu, "Voltage-boosting converters with energy pumping," *IET Power Electron.*, vol. 5, no. 2, pp. 185–195, Feb. 2012.
- [17] K. I. Hwu, Y. T. Yau, and Y. H. Chen, "A novel voltage-boosting converter with passive voltage clamping," in *Proc. IEEE ICSET*, 2008, pp. 351–354.
- [18] K. I. Hwu and Y. T. Yau, "Two types of KY buck-boost converters," *IEEE Trans. Ind. Electron.*, vol. 56, no. 8, pp. 2970–2980, Aug. 2009.
- [19] K. I. Hwu and W. Z. Jiang, "Voltage Gain Enhancement for a Step-Up Converter Constructed by KY and Buck-Boost Converters," *IEEE Trans. Ind. Electron.*, vol. 61, no. 4, April 2014