ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

Controlled Voltage Single-Input Multiple Output DC to DC Converter

Thasreef H R [1], Siny Paul [2], Annie P Oommen[3]

P.G. Student, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India[1]

Assistant Professor¸ Mar Athanasius College of Engineering, Kothamangalam, Kerala, India[2]

Professor, Mar Athanasius College of Engineering, Kothamangalam, Kerala, India[3]

ABSTRACT: The Controlled Voltage Single Input Multiple Output DC to DC Converter proposes a design of highly efficient coupled inductor single input multiple output (SIMO) dc to dc converter. The converter can boost a low voltage input power source to a controllable high voltage dc bus and middle voltage output terminals. The controllable high voltage dc bus acts as the main power supply for the high voltage dc load. Moreover the middle voltage output terminals can supply powers for charging auxiliary power sources (e.g., battery modules). The Proposed circuit was simulated in PSIM with input voltage of 12 V; the corresponding output voltages obtained are 24V and 200V respectively. The desired theoretical voltage wave forms are obtained using PSIM. Also the controlled output voltage design of the proposed converter is implemented by using a PI controller and the circuit is verified using PSIM.

KEYWORDS: ZCS (zero current switching), Coupled inductor, Single-input multiple-output (SIMO) converter, Soft switching, Voltage clamping**.**

I. INTRODUCTION

In order to protect the natural environment on the earth, the development of clean energy without pollution has the major representative role in the last decade. By dealing with the issue of global warming, clean energies, such as fuel cell (FC), photovoltaic, and wind energy, etc., have been rapidly promoted [5]. But the system components used in these plants; such as storage elements, control boards, etc, usually requires auxiliary power for the balance of plant. Thus various voltage levels should be required in the power converter of a clean energy generation system. So we need a single-input multiple-output (SIMO) converter for increasing the conversion efficiency and voltage gain, reducing the control complexity, and saving the manufacturing cost [1-3]. The Proposed ”Controlled Voltage Single-Input Multiple Output DC to DC Converter” is a new dc-dc multi-output boost converter, which can share its total output between different series of output voltages for low and high-power applications. The proposed converter uses one power switch to achieve the objectives of high-efficiency power conversion, high step-up ratio, and different output voltage levels. In the proposed SIMO converter, the techniques of soft switching and voltage clamping are adopted to reduce the switching and conduction losses via the utilization of a low-voltage-rated power switch with a small R_{DS} (on). The slew rate of the current change in the coupled inductor can be restricted by the leakage inductor, the current transition time enables the power switch to turn ON with the zero current switching property easily, and the effect of the leakage inductor can alleviate the losses caused by the reverse-recovery current. The voltages of middle voltage output terminals can be appropriately adjusted by the design of auxiliary inductor. The output voltage of the high voltage dc bus is controlled by a proportional-integral (PI) control which regulate the firing pulse required for power switch to produce a desired controlled output according to reference signal given by the operator [4].

II. PROPOSED CONVERTER

The system configuration of the proposed high-efficiency SIMO converter topology to generate two different voltage levels from a single-input power source is depicted in Fig. 1. This SIMO converter contains five parts including a low-voltage-side circuit (LVSC), a clamped circuit, a middle-voltage circuit, an auxiliary circuit, and a high-voltage-side circuit (HVSC). The major symbol representations are summarized as follows. $V_{FC}(I_{FC})$ and $V_{01}(I_{01})$ denote the voltages (currents) of the input power source and the output load at the LVSC and the auxiliary circuit, respectively; V_{02} and I_{02} are the output voltage and current in the HVSC. C_{FC}, C_{01}, and C_{02} are the filter capacitors at the LVSC, the auxiliary circuit, and the HVSC, respectively; C_1 and C_2 are the clamped and middle-voltage capacitors in the clamped and middle voltage circuits, respectively. L_P and L_S represent individual inductors in the primary and secondary sides of the coupled inductor T_r respectively, where the primary side is connected to the input power source; L_{aux} is the auxiliary circuit inductor. The main switch is expressed as S_1 in the LVSC; the equivalent load in the auxiliary circuit is represented as R_{01}, and the output load is represented as R_{02} in the HVSC. The corresponding equivalent circuit given in Fig. 2 is used to define the voltage polarities and current directions. The coupled inductor in Fig. 1 can be modeled as an ideal transformer including the magnetizing inductor L_{mp} and the leakage inductor L_{kp} in Fig. 2. The turns ratio N and coupling coefficient k of this ideal transformer are defined as:-

$$N = \frac{N_2}{N_1} \quad ; \qquad k = \frac{L_{mp}}{L_{kp}+L_{mp}} = \frac{L_{mp}}{L_p} \qquad (1)$$

Where N_1 and N_2 are the winding turns in the primary and secondary sides of the coupled inductor T_r.

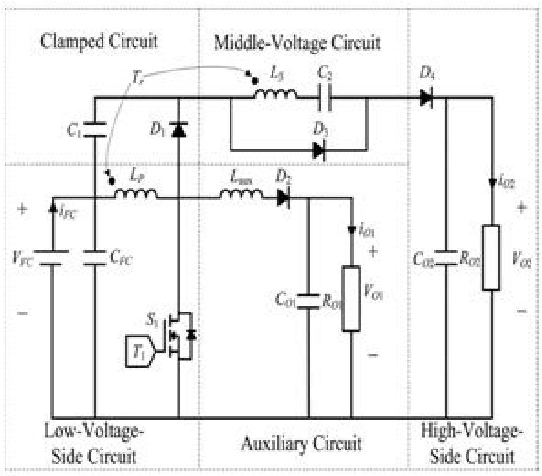


Fig. 1. Configuration of High-Efficiency Single-Input Multiple-Output (SIMO) converter

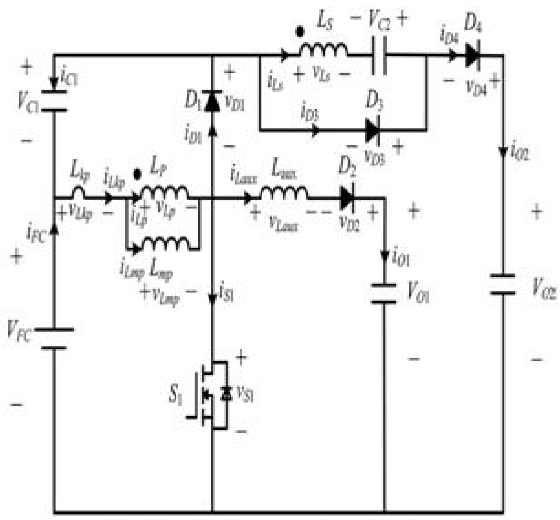


Fig. 2. Equivalent circuit.

III. PRINCIPLE OF OPERATION

The characteristic waveforms are depicted in Fig.3, and the topological modes in one switching cycle are illustrated in Fig.4

A. Operating Modes.

1).Mode 1 (0 –t_1) [Fig. 4(a)]: In this mode, the main switch S_1 was turned ON for a span, and the diode $D4$ turned OFF. Since the polarity of the windings of the coupled inductor T_r is positive, the diode $D3$ turns ON. The secondary current i_{LS} reverses and charges to the middle voltage capacitor C_2. When the auxiliary inductor L_{aux} releases its stored energy completely, and the diode D_2 turns OFF, this mode ends.

2).Mode 2(t_1 –t_2) [Fig. 4(b)]: At time t = t_1, the main switch S_1 is persistently turned ON. Because the primary inductor Lp is charged by the input power source, the magnetizing current i_{Lmp} increases gradually in an approximately linear way. At the same time, the secondary voltage v_{LS} charges the middle-voltage capacitor C_2 through the diode D_3. Although the voltage v_{Lmp} is equal to the input voltage V_{FC} both at modes 1 and 2, the ascendant slope of the leakage current of the coupled inductor (di_{Lkp} /dt) at modes 1 and 2 is different due to the path of the auxiliary circuit. The

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

auxiliary inductor L_{aux} releases its stored energy completely, and the diode D_2 turns OFF at the end of mode 1, it results in the reduction of di_{Lkp}/dt at mode 2.

3). Mode 3(t_2–t_3) [Fig. 4(c)]: At time t = t_2, the main switch S_1 is turned OFF. Then the leakage energy will be released from the secondary side of the coupled inductor and the diode D_3 persistently conducts and releases the leakage energy to the middle-voltage capacitor C_2. When the voltage across the main switch V_{s1} is higher than the voltage across the clamped capacitor V_{c1}, the diode D_1 conducts to transmit the energy of the primary-side leakage inductor L_{kp}into the clamped capacitor C_1.At the same time, partial energy of the primary-side leakage inductor L_{kp} is transmitted to the auxiliary inductor L_{aux}, and the diode D_2 conducts. Thus the current i_{Laux} passes through the diode D_2 to supply the power for the output load in the auxiliary circuit. When the secondary side of the coupled inductor releases its leakage energy completely, and the diode D_3 turns OFF, this mode ends.

4). Mode 4 (t_3–t_4) [Fig. 4(d)]: At time t = t_3 , the main switch S_1 is persistently turned OFF. Then the leakage energy will be released from the primary side of the coupled inductor and the secondary current i_{LS} is induced in reverse from the energy of the magnetizing inductor L_{mp} through the ideal transformer and flows through the diode D_4 to the HVSC. At the same time, partial energy of the primary side leakage inductor L_{kp} is still persistently transmitted to the auxiliary inductor L_{aux}, and the diode D_2keeps conducting. Moreover, the current i_{Laux}passes through the diode D_2 to supply the power for the output load in the auxiliary circuit inductance i_{Laux}.

5).Mode 5 (t_4–t_5) [Fig. 4(e)]: At time t = t_4, the main switch S_1 is persistently turned OFF, and the clamped diode D_1 turns OFF because the primary leakage current i_{Lkp} equals to the auxiliary inductor current i_{Laux}. In this mode, the input power source, the primary winding of the coupled inductor T_r , and the auxiliary inductor L_{aux} gets connected in series to supply power for the output load in the auxiliary circuit through the diode D_2 . At the same time, the input power source, the secondary winding of the coupled inductor T_r , the clamped capacitor C_1 , and the middle voltage capacitor (C_2) gets connected in series to release the energy into the HVSC through the diode D_4 .

6).Mode 6 (t_5–t_6) [Fig. 4(f)]: At time t=t_5 , this mode begins when the main switch S_1 is triggered. The auxiliary inductor current i_{Laux} needs time to decay to zero, the diode D_2 persistently conducts. In this mode, the input power source, the clamped capacitor C_1, the secondary winding of the coupled inductor T_r , and the middle-voltage capacitor C_2 will get connected in series to release the energy stored in capacitor into the HVSC through the diode D_4 . Since the clamped diode D_1 can be selected as a low-voltage Schottky diode, it will be cut off promptly without a reverse-recovery current. Moreover, the rising rate of the primary current i_{Lkp} is limited by the primary-side leakage inductor. Thus, one cannot derive any currents from the paths of the HVSC, the middle-voltage circuit, the auxiliary circuit, and the clamped circuit. As a result, the main switch S_1 is turned ON under the condition of ZCS and this soft-switching property is helpful for alleviating the switching loss. When the secondary current i_{Ls} decays to zero, this mode ends. After that, it begins the next switching cycle and repeats the operation in mode.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

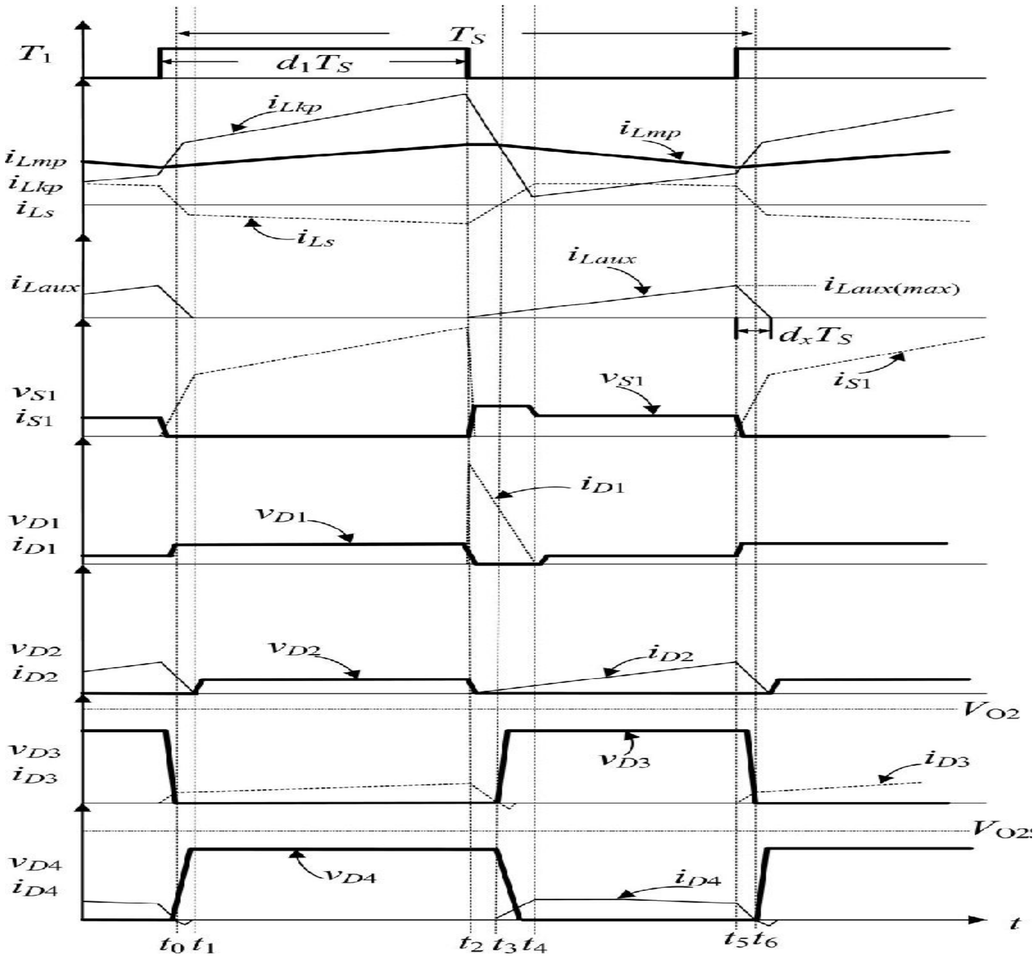
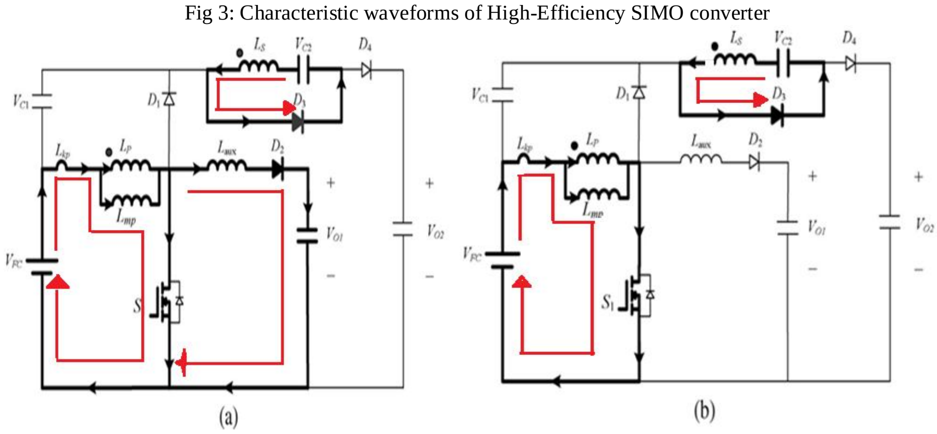


Fig 3: Characteristic waveforms of High-Efficiency SIMO converter



ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

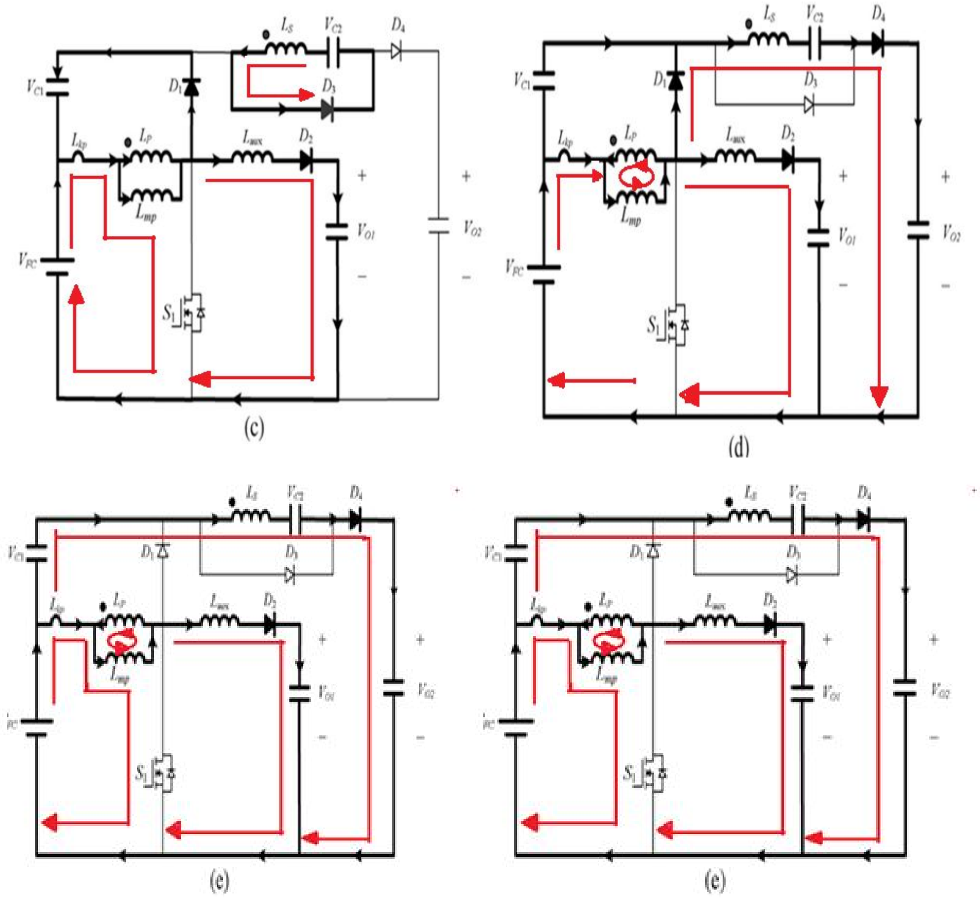


Fig 4: Topological modes: (a) Mode 1 [t_0–t_1]; (b) Mode 2 [t_1–t_2]; (c) Mode 3 [t_2–t_3]; (d) Mode 4 [t_3–t_4]; (e) Mode 5 [t_4–t_5]; (f) Mode 6 [t_5–t_6].

IV. VOLTAGE GAIN EQUATIONS.

Voltage gain G_{VH} of the proposed SIMO converter from the LVSC to the HVSC can be derived from the equivalent circuit as:-

$$G_{VH}=V_{02}/V_{FC}=N+1/\ (1-d_1) \quad (2)$$

Voltage gain G_{VL} of the proposed SIMO converter from the LVSC to the auxiliary circuit can be obtained as,

$$G_{VL}=V_{01}/V_{FC}=\ 1/(1-d_1+dx) \quad (3)$$

Where N = turns ratio of coupled inductor,
 d1 = duty cycle of power switch;
dx is obtained from discharging time of auxiliary inductor (dxTs).
The duty cycle dx can be rewritten as:

$$dx = \frac{-(1-d1) + \sqrt{[(1-d1)+[8Laux/(R01Ts)]}}{2} \quad (4)$$

Where L_{aux} is auxiliary inductance, R_{01} is output resistance & T_s= switching period.

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

V. PSIM MODEL & SIMULATION RESULTS

A. Open loop PSIM Model

The proposed circuit is simulated using PSIM as modeled in fig: 5, with an input voltage of 12V, the output voltages obtained are $V_{01=}$ 24 V and V_{02}= 200V respectively as shown in fig:6.

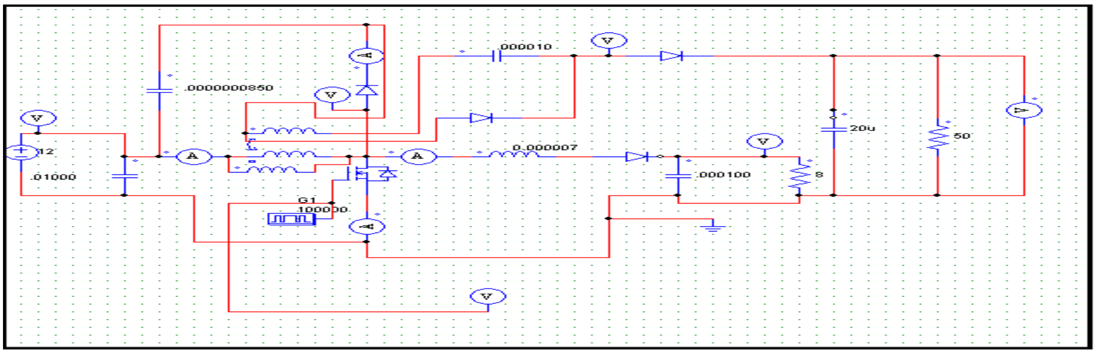


Fig: 5 , Open loop PSIM model

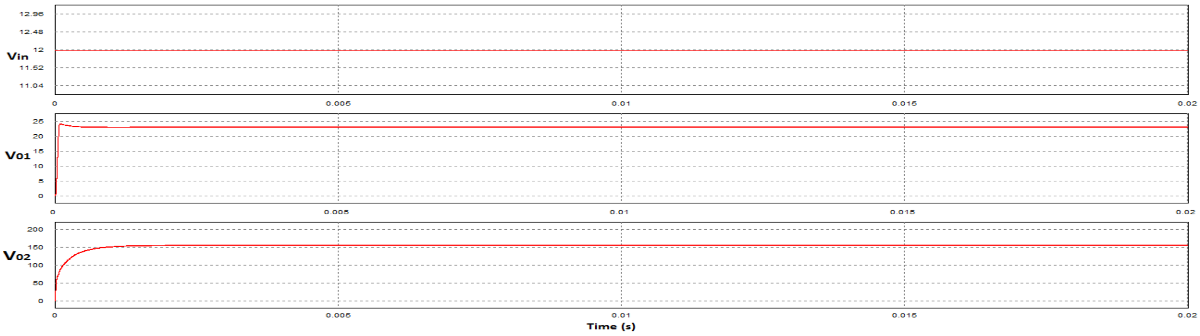


Fig 6:Input Voltage (Vin) and Output Voltages (V_{01}& $V_{02)}$ waveforms

B).Closed loop PSIM Model with PI Controller:

The closed loop circuit of given converter is designed in PSIM using a PI controller having gain value (K)=.0033 and time constant (T) =.001 as shown in Fig 7 in which a reference voltage of 150 V is given in order to obtain a controlled output voltage V_{02}= 150 V by regulating the gate signal of the power switch as shown in Fig: 8.

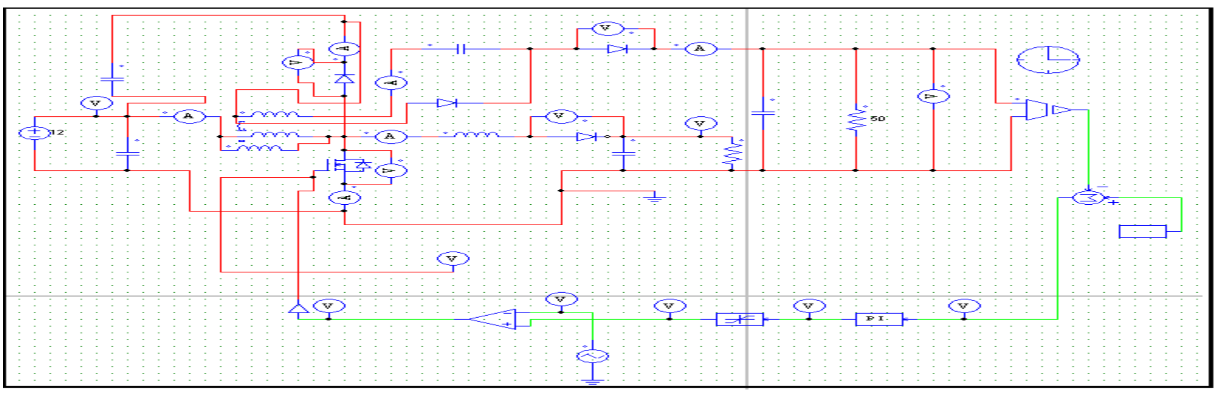


Fig: 7: Closed loop PSIM model

ISSN (Print) : 2320 – 3765
ISSN (Online): 2278 – 8875

International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering

(An ISO 3297: 2007 Certified Organization)

Vol. 3, Special Issue 5, December 2014

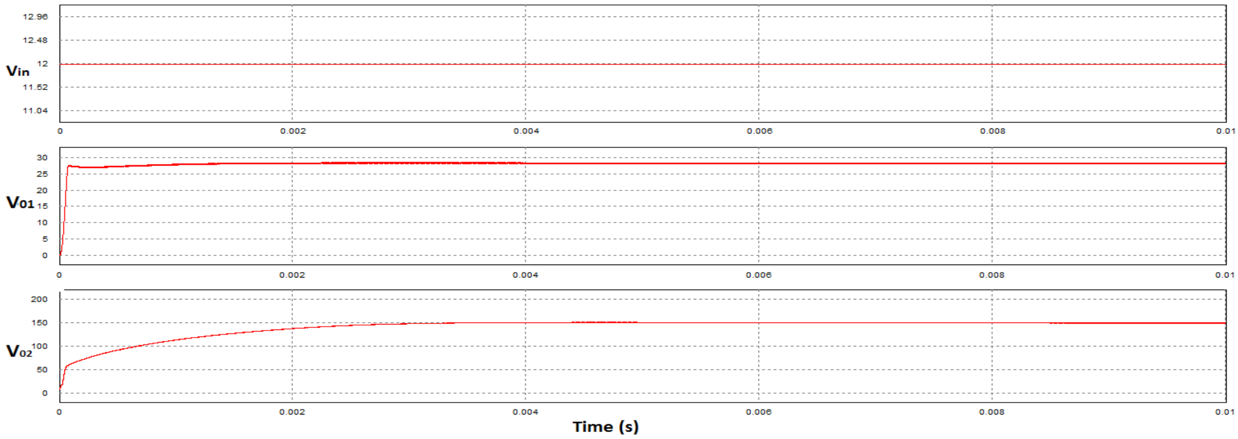


Fig: 8 : Input Voltage (Vin) and Output Voltages (V_{01}& V_{02}) waveforms

VI.CONCLUSION

This study has successfully developed a high-efficiency SIMO dc–dc converter, and this coupled inductor based converter was applied well to a single-input power source plus two output terminals composed of an auxiliary battery module and a high voltage dc bus. The proposed system adopts only one power switch to achieve the objective of high efficiency SIMO power conversion and the voltage gain is substantially increased by using a coupled inductor The Proposed circuit was simulated in PSIM with input voltage of 12V, the output voltages obtained are 24 V and 200 V respectively. Also the output voltage of the high-voltage dc bus is stably controlled by a proportional-integral (PI) control which regulate the firing pulse to produce a desired controlled output voltage (V_{02}) of 150 V in accordance with the reference signal given to the converter.

REFERENCES

[1] Rong-Jong Wai, and Kun-Huai Jheng, “High-Efficiency Single-Input Multiple-Output DC–DC converter”*IEEE Trans.Power Electron.*, vol. 28, no. 2, pp. 3853–3864, Feb. 2013.
[2] A. Nami, F. Zare, A. Ghosh, and F. Blaabjerg, “Multiple-output DC–DC converters based on diode-clamped converters configuration: Topology and control strategy,” *IET Power Electron.*, vol. 3, no. 2, pp. 197–208, 2010.
[3] M. Singh and A. Chandra, “Application of adaptive network-based fuzzy interference system for sensorless control of PMSG-based wind turbine with nonlinear-load-compensation capabilities,” *IEEE Trans. Power Electron.*,vol. 26, no. 1, pp. 165–175, Jan. 2011.
[4] C. T. Pan,M. C. Cheng, and C.M. Lai, “A novel integrated dc/ac converter with high voltage gain capability for distributed energy resource systems,”*IEEE Trans. Power Electron.*, vol. 27, no. 5, pp. 2385–2395, May 2012.
[5] S. D. Gamini Jayasinghe, D. Mahinda Vilathgamuwa, and U. K. Madawala, “Diode-clamped three-level inverter-based battery/ supercapacitor direct integration scheme for renewable energy systems,” *IEEE Trans. Power Electron.*, vol. 26, no. 6, pp. 3720–3729, Dec.2011.