International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in

Vol.4., Issue.2., 2016
(Mar-Apr)

RESEARCH ARTICLE

ISSN: 2321-7758

A MODIFIED KY CONVERTER SUITABLE FOR PV APPLICATIONS

R.RANJITHA[1], P. NAMMALVAR[2]

[1]U.G Scholar, [2]Associate Professor

Department of Electrical and Electronics Engineering, IFET College of Engineering, Villupuram, Tamilnadu India

ABSTRACT

In this paper a voltage bucking/boosting converter named as KY converter is presented herein. This converter is suitable for fuel cells and photovoltaic systems. It possesses fast transient load responses similar to buck converter with synchronous rectification. This converter has continuous input and output inductor currents different from traditional boost converter. This type of converter provides non pulsating output current without increasing the current stress at output capacitor but also reduces the output voltage ripple. Besides 1 plus 2D and 2 plus D converters, derived from this KY converter with different pulse width modulation techniques. This converter is combined with one charge pump and one coupled inductor with the voltage gain has been improved. A PI controller based feedback circuit is used to get a constant output voltage irrespective of the changes in input voltage and load. A double loop controller is used in this converter which consists of hysteresis current controller as inner loop and PI controller as outer loop. The effectiveness of converter is going to be verified using MATLAB simulation and also hardware.

Keywords—step up, transient response, reduced ripple, double loop controller, constant output voltage.

I. INTRODUCTION

Nowadays, renewable energy systems have a major role in power sector. These systems may be photovoltaic cells, fuel cells, wind power, etc. The power generated from these systems are not suitable to drive large loads. To make the output of these systems as effective, an interface is required [1]. Power electronics boost converters can be used as a best interface for this application. The traditional non isolated voltage boosting converters have pulsating output current which causes the large output voltage ripple. This ripple may affect the sensitive power electronics devices in a circuit. To overcome this problem, a capacitor with a low equivalent series resistance (ESR) is added or an inductance-capacitance (LC) filter is added or the switching frequency is increased. In recent days inductors are coupled with these converter circuits to improve the output voltage [2]. By adding this inductor, the voltage gain is improved and the voltage stress is reduced [3, 4]. This converter's voltage conversion ratio depends on the number of turns of this inductor [5]. So the efficiency can be improved. But this traditional buck boost converter has some disadvantages in steady state and transient responses [6-8]. To avoid these kind of problems, a KY converter is used which is voltage boosting converter. The converter has fast load transient response [9, 10]. To get high output voltages its second order derivatives are used [11]. But the voltage gain is too low. This KY converter is combined with the traditional buck boost converter to improve the voltage gain. This arrangement increases the voltage conversion ratio [12, 13]. It has one charge pump along with the coupled inductor [14, 15]. A part of leakage inductance energy from this inductor is recycled to the output capacitor of the traditional buck boost converter [16, 18]. To get this constant output voltage, a PI controller based feedback circuit is added with this arrangement [17]. It makes the converter as efficient with less output voltage ripple.

Based on the aforementioned, a modified step up converter is presented herein. It has fast load transient responses similar to the buck converter with synchronous rectification. It is combined with one charge pump and one coupled inductor. So that the converter provides non pulsating output current without increasing the current stress at the output capacitor but also reduces the output voltage ripple. Finally, a detailed description is provided along with some simulation results to prove the effectiveness of the converter.

II. SYSTEM CONFIGURATION

Figure 1 shows the proposed converter which has two metal oxide semiconductor field effect transistors (MOSFET) S_1 and S_2. These two switches are used to form buck boost converter as well as KY converter. A coupled inductor composed of primary winding with N_p turns and secondary windings with N_s turns. The converter also has one diode D, one energy transferring capacitor C_1, one charge pump capacitor which is large enough to keep the voltage across itself constant at the value of the input voltage. Along with this, one output inductor L_0 and one output capacitor C_0 which form an LC filter. In addition, the input voltage is V_i and output voltage is V_0.

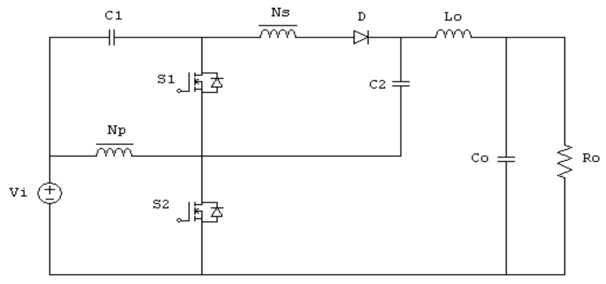

Fig.1. Proposed converter

III. PROPOSED BLOCK DIAGRAM

Double loop controller is used in this converter. It has inner loop controller as PI controller and outer loop as hysteresis current controller. It gives the control over the output voltage. PI controller is used for voltage control and it produces reference current. Hysteresis controller has dc output current from KY converter and reference current from PI controller.

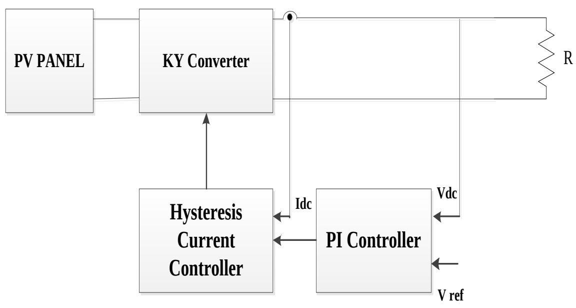

Fig.2. Proposed block diagram

PI Controller: PI controller has two constants K_p and K_i which is used to control the circuit. It compares the voltage from KY converter and reference voltage. It generates reference current which is compared by hysteresis controller.

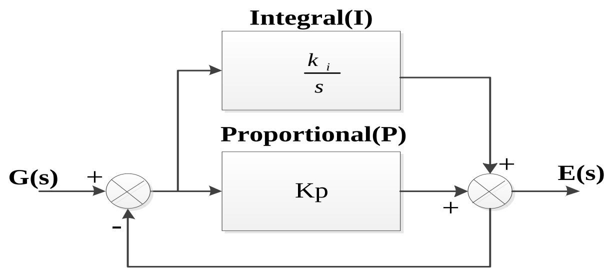

Fig.3. Block diagram of PI controller

Hysteresis Current Controller: The principle of this controller is to generate a new reference signal which is deduced from the sum of the reference current (I_{ref}) and a DC voltage generated from the KY converter.

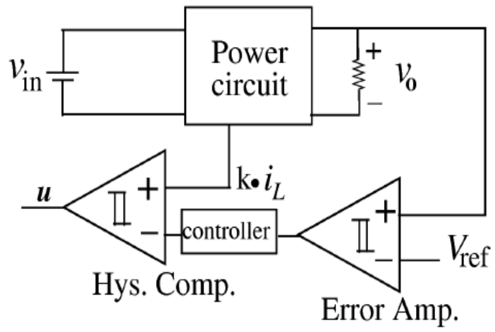

Fig.4. Block diagram of hysteresis controller

IV. BASIC OPERATING PRINCIPLES

MODE 1: When the switch S_1 is in open condition, the inductance is magnetising and capacitor C_1 is charging. Diode D is forward biased.

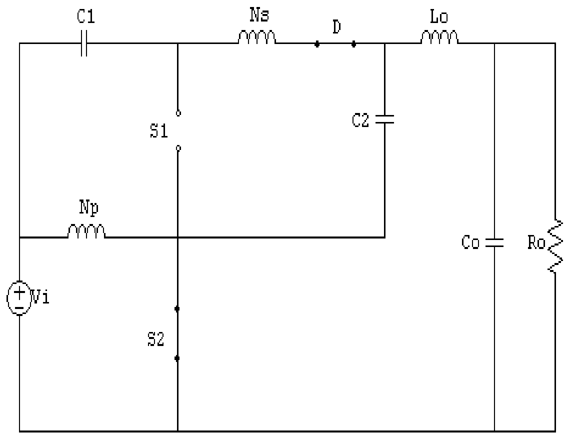

Fig.5. Mode 1 of operation

MODE 2: When switch S_2 is in open condition, output inductor is magnetising and capacitor C_2 is charging. Diode D is reverse biased.

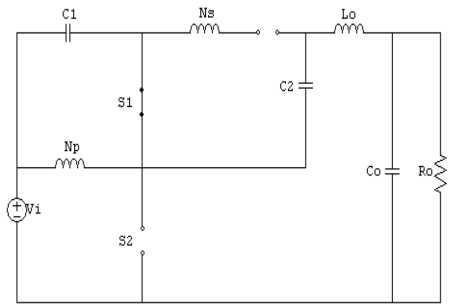

Fig.6. Mode 2 of operation

There are some assumptions made for explaining this section. The coupled inductor is modeled as an ideal transformer except that one magnetising inductor L_m is connected in parallel with primary winding and one leakage inductor L_{l1} is connected in series with primary winding. Therefore coupling coefficient k is defined as $\frac{L_m}{L_m + L_{l1}}$.

1) The converter operates in positive current mode. So that the current flow in the magnetising inductor L_m and output inductor L_0 are positive.
2) The dead times between the two MOSFET switches are neglected.
3) The MOSFET switches and diodes are assumed to be ideal components.
4) The values of all capacitors are large enough. So that the voltage across those capacitors are kept constant at some values.
5) The magnitude of switching ripple is negligible. Therefore the small ripple approximation will be adopted in this analysis.

The analysis has the explanation of power flow path for each mode, along with corresponding equations and voltage gain. Inherently there are two operating modes in this converter. Moreover the gate driving signals V_{gs1} and V_{gs2} are given to switches S_1 with duty cycle of (1-D) and S_2 with duty cycle of D, respectively, where D is DC quiescent duty cycle created from the controller. In addition, the input current is denoted by i_i, the current through the N_p winding is signified by i_{Np}, the current through the N_s winding is represented by i_{Ns}, the current through L_m is denoted by i_{Lm}, the current through L_0 is indicated by i_{L0}, and the current through R_0 is signified by I_0. On the other hand, the voltage across L_m or the voltage across the N_p winding is signified by V_{Np}, the voltage across the N_s winding is represented by V_{Ns}, the voltage across C_1 is indicated by V_{c1}, the voltage across C_2 is denoted by V_{c2}, and the voltage across L_0 is described by V_{L0}. Its operation is analyzed in two ways:

Voltage Gain Considering Coupling Coefficient Equal To One:

Mode 1: During this interval, S_1 is turned off but S_2 is turned on. Therefore, input voltage V_i is imposed on N_p, thus causing L_m to be magnetized and the voltage across N_s to be induced, equal to $V_i \times N_s/N_p$. In addition, D_1 becomes forward-biased; C_2 is charged to $V_i + V_{c1} + V_i \times N_s/N_p$; and the voltage across L_0, i.e., V_{L0}, is a negative value, equal to $V_{C2} - V_0$, thus making L_0 demagnetized. As a consequence, input voltage V_i, together with the voltage across C_1 (V_{C1}), plus the induced voltage on N_s (V_{Ns}), plus the voltage across L_0 (V_{L0}), provides the energy to the load. In addition, the associated equations are as follows:

$$V_{Np} = V_i \quad (1)$$

$$V_{L0} = V_{C2} - V_0 \quad (2)$$

Mode 2: During this interval, S_1 is turned on but S_2 is turned off. Therefore, the $-V_{C1}$ voltage is imposed on N_p, thereby causing the magnetizing inductor L_m. to be demagnetized and the voltage across N_s to be induced, equal to $-V_{C1} \times N_s/N_p$. In addition, D_1 becomes reverse biased, the voltage on Lo is a positive value, equal to $V_i + V_{C1} + V_{C2} - V_0$, thus causing L_0 to be magnetized. As a result, the input voltage V_i, together with the voltage across $L_m(V_{Np})$,plus the voltage across C_2 (V_{C2}), provides the energy to L_0 and the load. In addition, the corresponding equations are as follows:

$$V_{Np} = -V_{C1} \quad (3)$$

$$V_{L0} = V_i + V_{C1} + V_{C2} + V_0 \quad (4)$$

By applying the voltage-second balance principle to L_m over one switching period, the following equation can be obtained:

$$V_i \times D + \left(-V_{C1}\right) \times \left(1-D\right) = 0 \quad (5)$$

In addition, by rearranging the above equation, the voltage across C_1, i.e., V_{C1}, can be obtained as follows:

$$V_{C1} = \frac{D}{1-D} \times V_i \quad (6)$$

Likewise, by applying the voltage-second balance principle to L_0 over one switching period, the following equation can be obtained:

$$(V_{C2} - V_0) \times D + (V_i + V_{C1} + V_{C2} - V_0) \times (1-D) = 0 \quad (7)$$

The voltage across C_2, i.e., V_{C2}, can be represented by

$$V_{C2} = V_i + V_{C1} + V_i \times \frac{N_s}{N_p} \quad (8)$$

Next, based on (6)–(8), the corresponding voltage gain can be expressed to be

$$\frac{V_0}{V_i} = \frac{2-D}{1-D} + \frac{N_s}{N_p} \quad (9)$$

From (9), it is shown that $0 < D < 1$.

A. Voltage Gain Considering Coupling Coefficient Not Equal To One:

In this case, the coupling coefficient k is not equal to one, i.e., the leakage inductor L_{l1} is taken into account. Moreover, the operating modes are also the same as those mentioned in mode1 of previous case.

*Mode 1:*The following equations, containing coupling coefficient k, can be obtained. At the same time, both L_m and L_{l1} are simultaneously magnetized. Hence, the corresponding equations are as follows

$$V_{Np} = \frac{L_m}{L_m + L_{l1}} \times V_i \quad (10)$$

$$V_{Ns} = V_{Np} \times \frac{N_s}{N_p} = kV_i \times \frac{N_s}{N_p} \quad (11)$$

In addition, the voltages on C_2 and L_0 can be depicted as follows

$$V_{C2} = V_i + V_{C1} + V_{Ns} = V_i + V_{C1} + kV_i \times \frac{N_s}{N_p} \quad (12)$$

$$V_{L0} = V_{C2} - V_0 \quad (13)$$

Mode 2: During this interval, the voltages across L_0 and C_1 are to be expressed as follows. Above all, part of the energy stored in L_m and L_{l1} be transferred to C_1. Hence, the corresponding equations are

$$V_{Np} = -kV_{C1} \quad (14)$$

$$V_{L0} = V_i + V_{C1} + V_{C2} - V_0 \quad (15)$$

By applying the voltage-second balance to both L_m and L_{l1} over one switching period, one can get

$$V_i \times D + \left(-V_{C1}\right) \times 1 - D = 0 \quad (16)$$

Sequentially, by rearranging the above equation, the voltage across C1, i.e., VC1, can be obtained to be

$$V_{C1} = \frac{D}{D+1} + V_i \quad (17)$$

Likewise, by applying the voltage-second balance principle to Lo over one switching period, the following equation can be obtained to be

$$(V_{C2} - V_0) \times D + (V_i + V_{C1} + V_{C2}) - V_0 \times (1 - D) = 0 \quad (18)$$

Next, substituting (12) and (17) into (18) yields the voltage gain

$$\frac{V_0}{V_i} = \frac{2-D}{1-D} + k\frac{N_s}{N_p} \quad (19)$$

From equation 19 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.

V. **SYSTEM DESIGN OF THE CONVERTER**

How to design the magnetizing inductor L_m, the energy transferring capacitor C_1, the charge pump capacitor C_2, the output capacitor C_0, and the output inductor L_0 is shown as follows.

Table.1. System design

System parameters	**Specifications**
Input voltage(V_i)	12V
Rated output voltage(V_0)	72V
Rated output current($I_{0,rated}$)	0.833A
Power($P_{0,rated}$)	60W
Minimum output current($I_{0,min}$)	0.1A
Power($P_{0,min}$)	7.2W
Switching frequency(f_z)	100kHz

CALCULATION OF MAGNETIZING INDUCTOR:

To make sure that Lm always operates in the positive region, the required equation is as follows

$$L_m \geq \frac{V_i D T_s}{\Delta i_{Lm}} = \frac{V_i D T_s}{2 \times I_{Lm,\min}} \quad (20)$$

Where $I_{Lm,min}$ is the minimum dc current in Lm. Finally, the value of Lm is set at 148.7 µH.

CALCULATION OF OUTPUT INDUCTOR: From the industrial viewpoint, the output inductor is generally designed to have no negative current when the output current is above 20%–30% of the rated output current [20]. Therefore, in this paper, the boundary between the positive and negative currents is assumed to be at 20% of the rated output current. Hence, the value of L_0 can be obtained in (33), shown at the bottom of the page. Eventually, the value of L_0 is set at 188 µH.

$$L_0 = \frac{L_0 \Delta t}{\Delta i_{Lm}}$$

$$= \frac{(V_i + V_{C1} + V_{C2} - V_0(1-\mathrm{D})\mathrm{T}_s}{\Delta i_{L0}} \quad (21)$$

CALCULATION OF ENERGY-TRANSFERRING CAPACITOR:

Assuming the peak-to-peak value of the capacitor voltage during the charge period, i.e., ΔV_{C1}, is set to 1% of V or less, i.e., ΔV_{C1} is smaller than 120 mV, the value of C_1 be obtained as follows:

$$C_1 \geq \frac{i_{C1}\Delta t}{\Delta V_{C1}} \quad (22)$$

$$= \frac{(I_{i,rated} - I_{0,rated})(1-\mathrm{D})\mathrm{T}_s}{(0.001 \times V_{C1})}$$

where I_i,rated is the dc input current I_i under rated conditions. Eventually, two 470µF capacitors with positive terminals connected in series are selected for C_1.

CALCULATION OF CHARGE PUMP CAPACITOR:

Assuming the variation in capacitor voltage during the discharge period, i.e., ΔV_{C2} is set to 0.1% of V_{C2} or less, i.e., ΔV_{C2} is smaller than 60 mV, the value of C_2 can be obtained as follows:

$$C_2 \geq \frac{i_{C2}\Delta t}{\Delta V_{C2}} = \frac{I_{L0,rated}(1-\mathrm{D})\mathrm{T}_s}{(0.001 \times V_{C2})} \quad (23)$$

where I_{L0} ,rated is the dc current in L_0 under rated conditions. Finally, two 47µF capacitors connected in parallel are chosen for C_2.

CALCULATION OF OUTPUT CAPACITOR:

As generally known, the output filter is used to filter out the output current ripple as much as possible. Prior to designing C_0, the output voltage ripple ΔV_0 is assumed to be smaller than 0.1% of the rated output voltage, i.e., ΔV_0 is smaller than 72 mV.

International Journal of Engineering Research-Online
A Peer Reviewed International Journal
Email:editorijoer@gmail.com http://www.ijoer.in
Vol.4., Issue.2., 2016 (Mar-Apr)

Therefore, the equivalent series resistance of the output capacitor, i.e., ESR, can be represented by

$$ESR \leq \frac{\Delta V_0}{\Delta i_L} = \frac{0.001 \times V_0}{\Delta i_{L0}} \quad (24)$$

Eventually, two 220µF capacitors connected in parallel are selected for C_0.

VI. SIMULATION RESULTS

OPEN LOOP SYSTEM: Fig.7 shows the exact open loop circuit that was used in the MATLAB simulation. In this circuit, gate pulses have been provided by the pulse generator connected with the circuit.

This is the simulation diagram of open loop KY converter which has variable output voltage and current. These have been shown in fig.8 and 9.

CLOSED LOOP SYSTEM: Fig.10. shows the closed loop control of a KY converter. It has a double loop controller consisting of PI controller and hysteresis current controller. PI controller compares the output voltage from KY converter and reference voltage. It produces a reference current and gives it to the hysteresis current controller.

Output voltage and output inductor current are shown in fig.11 and 12. The controller gives constant output voltage without any ripples at the output side.

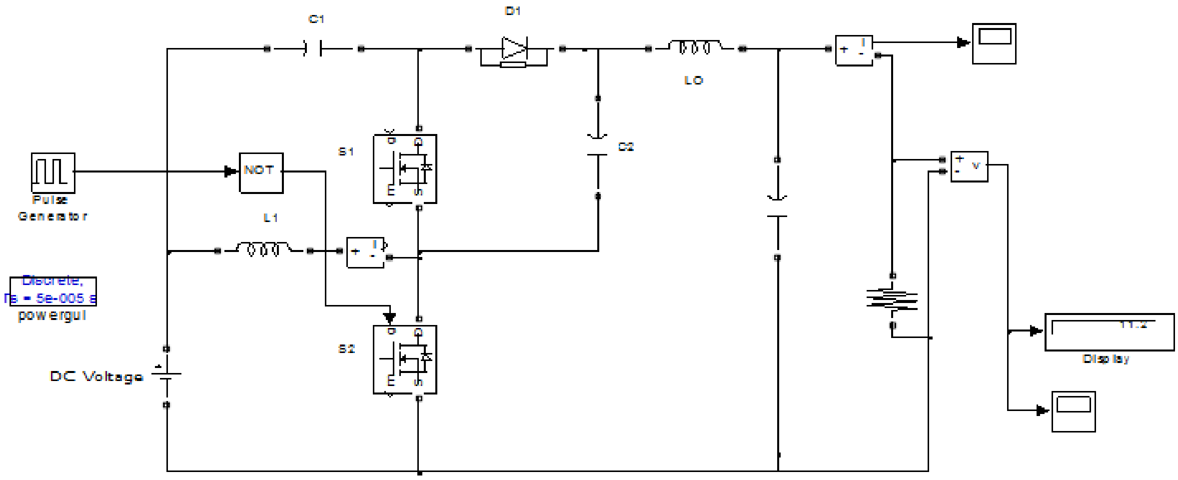

Fig.7. simulation model of open loop KY converter

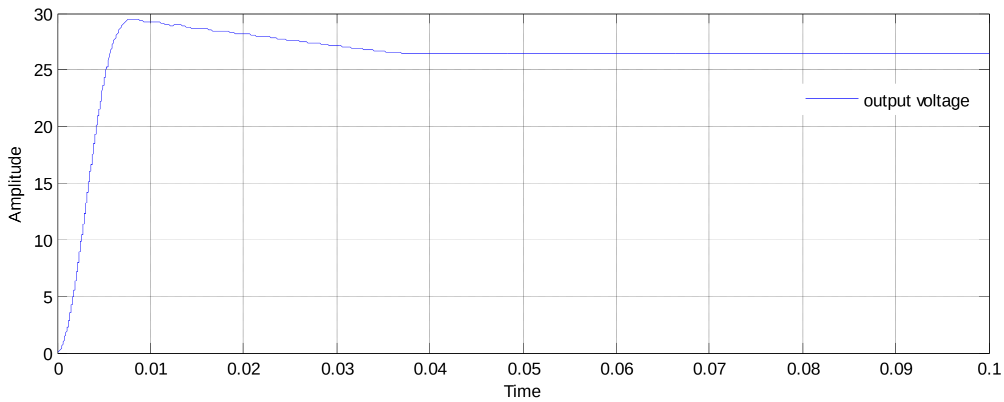

Fig.8. output voltage for open loop KY converter

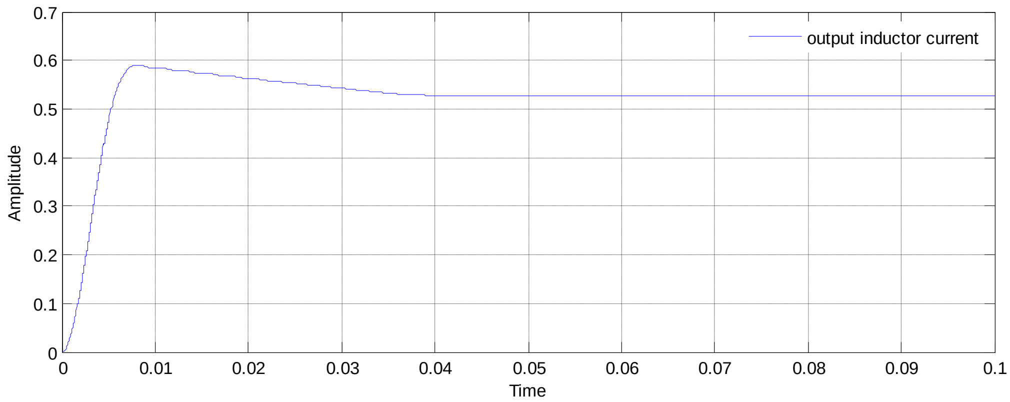

Fig.9.output inductor current for open loop KY converter

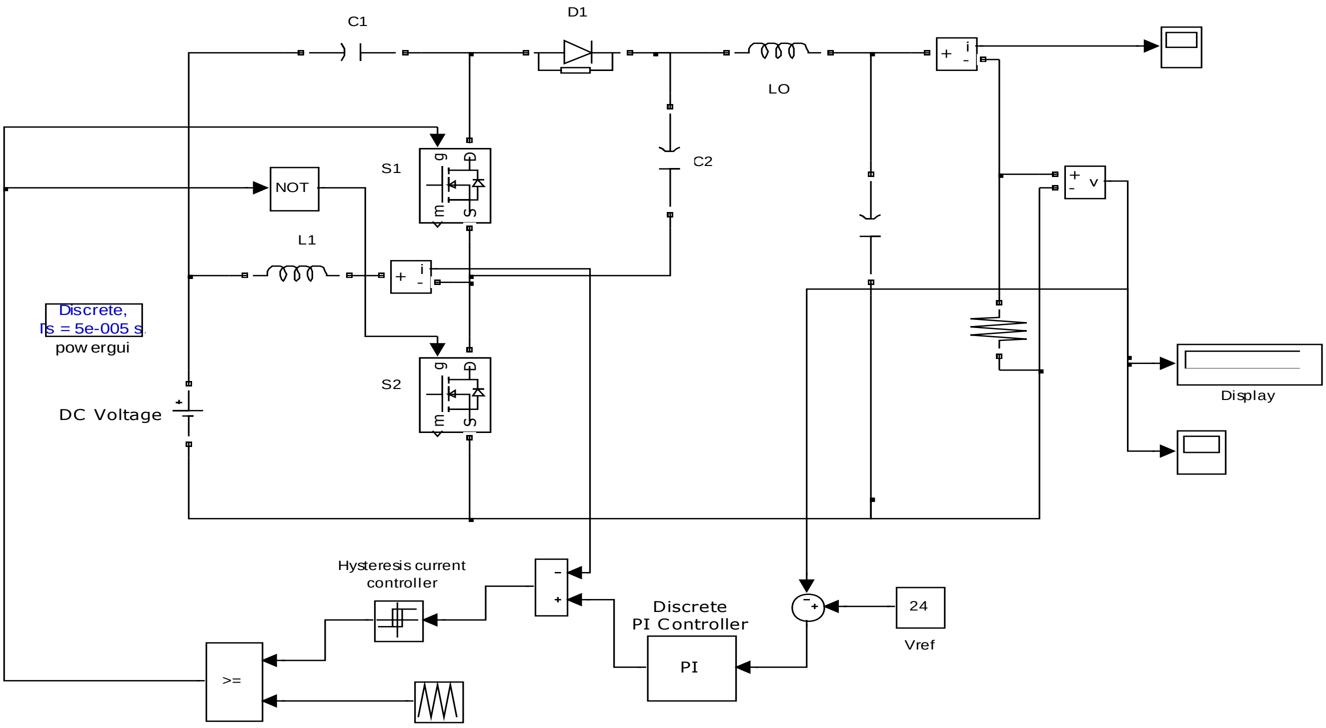

Fig.10. simulation model of closed loop KY converter

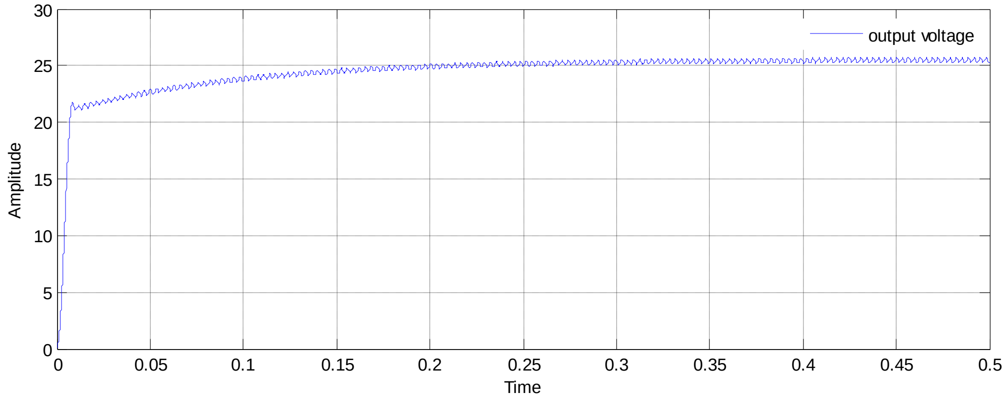

Fig.11. Output voltage for closed loop KY converter

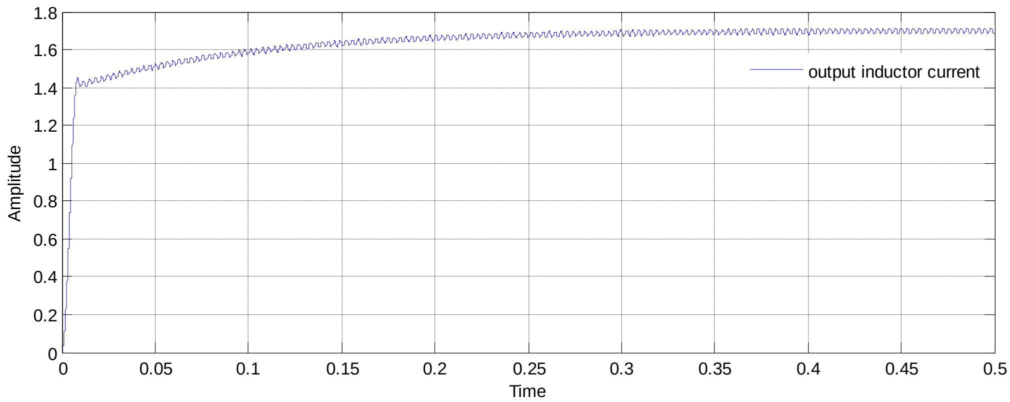

Fig.12.Output inductor current for closed loop KY converter

VII. EXPERIMENTAL RESULTS

It deals with the hardware components used in the KY converter and detail about its components. It consists of gate driver circuit and power circuit. Fig.13. shows the hardware module of the project.

Fig.13.Hardware module

Source of AC supply is given to a step down transformer and it produces 12V of supply. This reduced voltage has been given to a bridge rectifier unit which has the output of DC with some ripples. Capacitor is used to reduce this ripple and produces constant DC voltage of 12V. This 12V is given to the power circuit and gate driver circuit.

It has a microcontroller unit to generate pulses for switching operation of MOSFET. So that the on and off condition of switches are possible to get two modes of operation of KY converter. KY converter is a type of voltage boosting converter. When we give 12V of DC input power circuit provides 24V DC output at the load.

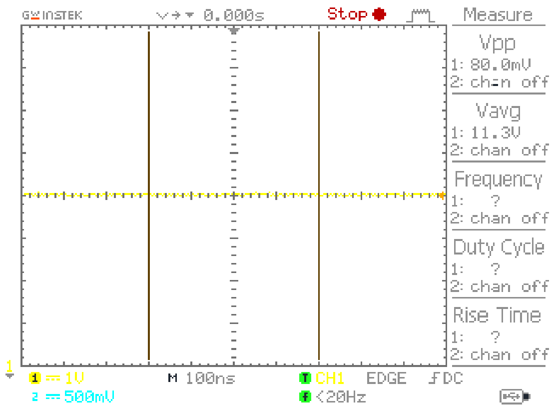

Fig.14. Waveform of input voltage

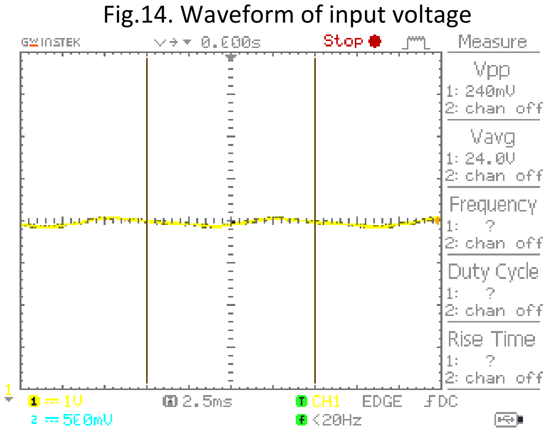

Fig.15. Waveform of boosted DC output voltage

VIII. CONCLUSION

A step-up converter is presented here which is formed by the combination of KY and buck-boost converter. The converter has non pulsating current and voltage at the output side. So that the output is ripple free. This converter is combined with one charge pump and one coupled inductor with this the voltage gain has been improved. It is suitable for low voltage applications such as fuel cells and photovoltaic systems. A double loop controller is used in this circuit which has hysteresis current controller as inner loop and PI controller as outer loop. Here, the output voltage is constant irrespective of the changes in input voltage and load. In an existing system, any one type of controller is used. But in this project, two controllers have been used in a single microcontroller. This improves the performance of the converter.

REFERENCES

[1]. Barry W.Williams.: "Basic DC-to-DC Converters", IEEE Transactions on Power Electronics, Vol. 23, No. 1, January 2008

[2]. M.Jahanmahin, A.Hajihosseinlu, E.Afjei, M.mesbah: "Improved Configurations for Dc to Dc Buck and Boost Converters", IEEE Transactions on Power Electronics, vol. 24, no. 5, pp. 1267-1279, May 2012.

[3]. Ali Ajami, Hossein Ardi, Amir Farakhor.: "Design, analysis and implementation of a buck–boost DC/DC converter", IET Power Electronics, 2014, Vol. 7, Iss. 12, pp. 2902–2913.

[4]. Y. Berkovich, B. Axelrod.: "High Step-up DC-DC Converter with Coupled Inductor and Reduced Switch-Voltage Stress", IEEE Transactions on Industrial Electronics, vol. 55, pp. 154-162, Jan. 2012.

[5]. Kuo-Ing Hwu, Tso-Jen Peng.: "High-voltage-boosting converter with charge pump capacitor and coupling inductor combined with buck–boost converter", IET Power Electronics, 2014, Vol. 7, Iss. 1, pp. 177–188.

[6]. Hamed Mashinchi Mahery, Ebrahim Babaei.: "Mathematical modelling of buck–boost dc–dc converter and investigation of converter elements on transient and steady state responses", 2012 Elsevier Ltd.

[7]. Mario Cacciato, Alfio Consoli, Vittorio Crisafulli.: "A High Voltage Gain DC/DC Converter for Energy Harvesting in Single Module Photovoltaic Applications", IEEE Transactions on Industrial Electronics, Vol. 57, no. 5, May 2010.

[8]. H.-B. Shin, J.-G. Park, S.-K. Chung, H.-W. Lee and T.A. Lipo.: "Generalised steady-state analysis of multiphase interleaved boost converter with coupled inductors", IEEE Proc.-Electr. Power Appl., Vol. 152, No. 3, May 2005.

[9]. K. I. Hwu, Y. T. Yau.: "A Novel Voltage-boosting Converter: KY Converter", IEE Proc. Electr. Power Appl., vol. 146, no. 4, pp. 415-432, 1999, Jan. 2007.

[10]. K. I. Hwu, Y. T. Yau.: "A KY boost converter", IEEE Transactions on Power Electronics, vol. 25, no. 11, pp. 2699 2703, Nov. 2009.

[11]. K. I. Hwu, Y. T. Yau.: "KY converter and its derivatives", IEEE Transactions on Power Electronics, vol. 24, no. 1, pp. 128 137, Jan. 2009.

[12]. K. I. Hwu, Y. T. Yau.: "Two types of KY buck-boost converters", IEEE Transactions on Industrial Electronics, vol. 56, no. 8, pp. 2970 2980, Aug. 2009.

[13]. K. I. Hwu, K. W. Huang, and W. C. Tu.: "Step-up converter combining KY and buck-boost converters", IET Electronic Letters, vol. 47, no. 12, pp. 722 724, Jun. 2011.

[14]. K. I. Hwu, W. Z. Jiang.: "Applying Coupled Inductor to Step-Up Converter Combining KY and Buck-Boost Converters", IEEE Transactions on Power Electronics, vol. 20 no. 5, 2013, pp.1025-1035.

[15]. K. I. Hwu, W. Z. Jiang.: "Voltage Gain Enhancement for a Step-Up Converter Constructed by KY and Buck-Boost Converters", IEEE Transactions On Industrial Electronics, Vol. 61, No. 4, April 2014.

[16]. Kuo-Ing Hwu, Wen-Zhuang Jiang, "Improvement in voltage conversion ratio for step up converter established by KY and buck–boost converters based on coupled inductor", IET Power Electronics, 2014, Vol. 7, Iss. 6, pp. 1457–1465.

[17]. Sreelakshmy Suresh, Rima V Ajayakumar, Nishi N.S.: "Line and Load Regulated KY

Buck – Boost Converter", International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, Vol. 4, Issue 4, April 2015.

[18]. Kuo-Ing Hwu, Wen-Zhuang Jiang.: "Improvement on voltage gain for KY converter", IET Power Electronics, 2015, Vol. 8, Iss. 3, pp. 361–370.

[19]. Fa-Qiang Wang, Xi-Kui Ma.: "Stability and bifurcation in a voltage controlled negative-output KY Boost converter", 2011 Elsevier Ltd.