DC-DC KY Converter in Renewable energy Applications

Ruchi Acharya
SRM University, B.tech, Electrical and Electronics Engineering, Chennai, India
ruacharya@gmail.com

Abstract*— In this paper, a voltage-boosting converter, named KY converter is presented. Unlike the traditional non-isolated boost converter, this converter possesses fast load transient responses which are similar to the buck converter with synchronous rectification. It also process non-pulsating output current thereby not decreasing the current stress on the output capacitor but also reducing the output voltage ripples. The corresponding voltage gain is greater than existing step up converter. It has an added benefit of an output inductor which minimizes the output ripple. It has a charge pump capacitor and a couple inductors which reduces the switching stress of the converter for the boosting operation. The proposed converter is compared with the conventional boost converter and then is stimulated PI controller. All the necessary DSP hardware or software techniques and algorithms can be demonstrated in this project. The steady state and dynamic response performance of the controller is presented.

Index Terms*—KY Converter, coupled inductor and buck converter.

I. INTRODUCTION

The use of renewable energy is on rise. In the recent times many industries are also incorporating the green energy to sustain their tasks. One such application is solar powered water pumping utilizing a centrifugal pump. This pump works with a aid a DC motor. This application is used in water purification. Desalination of water involves filter membrane through which the impure or the saline water has to pass. This suction force of the centrifugal pump is generated by the DC motor. The DC motor which

gets its input power from the DC- DC converter is capable of varying the speed according to the load demand. Different journals have been thoroughly studied for the understanding of the work to be performed in the project. The list of journals which has been the source of information covers topics on boosting of DC-DC converters, techniques used to design controllers, isolated DC-DC converters and DC drives system. The set of journals listed below gives a clear insight on modelling of DC-DC converters, stability analysis of converter system, how to incorporate different techniques for converter parameter design etc.

Smitha K et al., [4] have discussed about the steady state analysis of the traditional Boost converter. They have analysed the DC-DC converter incorporating state space averaging technique and small signal modelling. The stability of the converter system has been analysed using root locus method. The designed PID controller has been used to simplify the compensation of the traditional Boost converter.

Varun Krishnan K S et al., [18] in their paper titled, "Performance Evaluation of Step-Up KY Converter as a PMDC Drive -A Comparative Study" have presented the growing interest of PMDC drives in electric vehicle. They carried out their work on the basis of a comparative study between traditional Boost converter and novel step-up KY converter. They concluded their journal, proving that the DC-DC Boost converter is inferior to the later in terms of static voltage gain, stability and voltage stress.

K. I. Hwu et al., [11] in their journal titled, "KY Converter and Its Derivatives" proposed and analysed different voltage boosting converter of non-isolated DC-DC converter topology. They have presented KY converters namely, 1-plus-D, 1-plus-2D and 2-plus-D derived from KY converter. They have proved in their paperwork that the derived converters have higher voltage gain and compared to KY converter at the same duty cycle.

Y. T. Yau et al., [7] have presented a new converter in the field of isolated DC-DC converter. They named the converter KY after their initials. In the journal they have presented a detailed analysis of the proposed boost converter which is nothing but a combination of SR boost converter and KY

converter. X. Liang et al., [14] presented a novel step-up boost converter in their paper. This derived KY converter is a combination of SR boost converter and a coupled inductor. This novel step-up converter is efficient than the other converters of its family and traditional Boost converter. A detailed modelling of the proposed converter has been done in the paper, which also includes performance analysis at different load conditions. Authors have proved in this journal that the efficiency of this converter lies in the range of 88-95% over all load conditions. Switching stress has also been reduced due to its design. So, this step-up novel boost converter has been accepted to work upon in this thesis.

Mitalkumar R Dave et al., [20] have worked on modelling of Boost converter and controller design in this journal. They have designed a PI controller and tuned it for perfect output voltage. The method they have used for obtaining the values of Kp and Ki is Zeigler-Nichols method.

II. SOLAR ENERGY AND DC-DC CONVERTER

Renewable energy sources are completely uncertain and tremendously fluctuating. In case of solar energy, it depends completely on the weather and natural calamities. It is totally time variant and unpredictable. This limitation of voltage fluctuation of solar system has been successfully adopted and rectified using DC-DC converters. There are three topologies of DC-DC converters, namely, step-up converter, step down converter and combination of step- up and step down converter. Different topologies are used depending on their specific applications.

Besides, the three aforesaid topologies of the DC-DC converter, there is another topology i.e. isolated and non-isolated DC-DC converter. Although non-isolated dc-dc converter is popular in the market but the growing demand of power and limitations of electric noise in non-isolated converters isolation of dc-dc converter would gain interest in the recent future.

III. CONVERTERS TOPOLOGIES

A. General Converter topologies

- Boost Converter
- Buck Converter
- Cuk Converter
- KY Converter

B. Boost Converter

It is a step up converter. When the switch is ON, the diode is reverse biased, thus isolating the output stage. The input supplies energy to the inductor. When the switch is OFF, the output stage receives energy from the inductor as well as from the input. Its main application is in regulated DC power supplies and the regenerative breaking of DC motors. In Boost converter the output voltage is always greater than the input voltage.

C. Buck Converter

It is a step down converter produces a lower average output voltage then the DC input voltage. Its main application is in regulated DC power supplies and DC motor speed control. During the interval when the switch is ON, the diode becomes reverse biased and the input provides energy to the load as well as the inductor. During the interval when the switch is OFF, the inductor current flows through the diode, transferring some of its stored energy to the load.

D. Cuk Converter

This converter is obtained by using the duality principle on the circuit of Buck-Boost converter.

E. KY CONVERTER

KY converter is one of the recent inventions in the field of DC-DC converter. The converter is named after the initials of its inventors Hwu and Yau. This isolated DC-DC converter is designed to have low ripple and fast transients. It is very effective in applications where low ripple and fast transient is necessary. KY converter is very efficient in boosting of low input voltage to a very high output value. For this advantage of KY converter, it finds its application in RF amplifiers, personal digital assistants and low battery power supply applications. This converter topology utilizes few techniques for its boosting operation namely, switches capacitors, centre tapped transformers and coupled inductors.

For analysis of the converter some assumptions have been taken into consideration. These assumptions are listed below:

(i) The coupled inductor is assumed to be an ideal transformer. The magnetizing inductance (Lm) of the transformer is considered to be connected in parallel with the primary. Leakage inductance (Llk) of the coupled inductor is also assumed to be connected in series with the input side of the coupled inductor.

(ii) The input and the output inductor current are assumed to be positive throughout the operation of the proposed converter.

(iii) The MOSFET switches and the diode is considered to be ideal.
(iv) The dead time between the two switches is taken as zero.
(v) The mutual inductance (K) of the coupled inductor is taken to be unity.
(vi) Switching ripple is assumed to be negligible. Hence small ripple approximation is adopted for analysis.

IV. KY CONVERTER OPERATION

The DC-DC step-up boost converter is a simple structured chopper which includes an input side inductor, a pair of switch (one diode and one MOSFET) and output capacitor. The converter operates in two modes.

A.Mode 1
During this mode, the switch (S) receives the positive gate pulse thus magnetizing the input inductor (L). The output remains isolated from the input side by the reverse biased diode (D) of the converter throughout the ON period of the switch. During this ON period the filter capacitor (C) supplies the required output to the load.

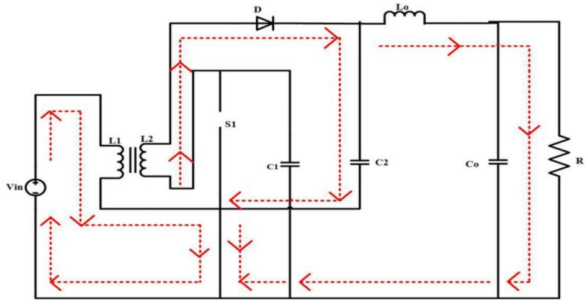

Fig.1 KY Converter- Open Loop

The following equations describe the working of the boost converter in this mode.

$$L_1\frac{di_{L1}}{dt} = V_1 \quad [5.1]$$

$$L_o\frac{di_{Lo}}{dt} = V_{C1} - V_1\frac{N_s}{N_n} - V_o \quad [5.2]$$

$$C_1\frac{dV_{C1}}{dt} = -(i_{C2} + i_{Lo}) \quad [5.3]$$

$$C_o\frac{dV_o}{dt} = i_{Lo} - \frac{V_o}{R} \quad [5.4]$$

B. Mode 2
During this mode the switch (S1) receives positive gate pulse and the switch (S2) behaves as a complimentary switch. The inductor voltage across L1 is the difference between the input and the buffer capacitor voltage. Thus, the primary of the coupled inductor is demagnetizing in this mode.

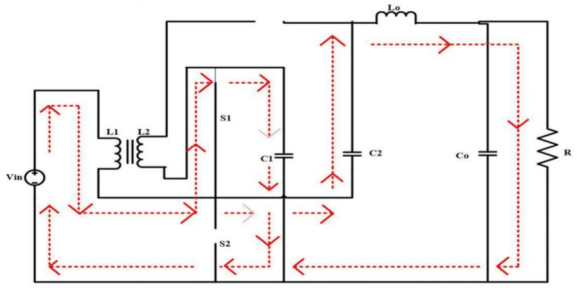

Fig.2 KY Converter- Closed Loop

But the output inductor and the secondary of the coupled inductor (L2) is storing energy. The diode (D) here is reverse biased by the voltage across the inductor (L2). The output voltage of the converter in this mode is the difference of the summation of the input voltage source, voltage across the inductor (L1), capacitor voltage (VC2) and the output inductor voltage (VLo).

The following equations describe the working of the boost converter in this mode.

$$L_1\frac{di_{L1}}{dt} = V_1 - V_{C1} \quad [5.5]$$

$$L_o\frac{di_{Lo}}{dt} = 2V_{C1} - V_1\frac{N_s}{N_n} - V_o \quad [5.6]$$

$$C_1\frac{dV_{C1}}{dt} = i_{L1} - i_{Lo} \quad [5.7]$$

$$C_o\frac{dV_o}{dt} = i_{Lo} - \frac{V_o}{R} \quad [5.8]$$

V. DESIGN PARAMETERS

The converter parameters of the modified KY converter are designed for maximum power of 60W at the output. The pair of switches of the converter is driven at a frequency of 100 KHz. The converter is designed for an output ripple of 0.5V. Table 1 and Table 2 gives the system specification and design parameters respectively.

SYMBOL	SPECIFICATION PARAMETER	SPECIFICATION
Vin	Input Voltage	12V
Vout	Output Voltage	72V
Prated	Rated Output Power	60W
Iinrated	Rated Input Current	5A
Iorated	Rated Output Current	0.833A
Pmin	Minimum Output Power	7.2W
Ioutmin	Minimum Output Current	0.1A
Fs	Switching Frequency	100KHz

Table 1: System specification of KY Converter

SYMBOL	PARAMETER	MAGNITUDE
Lm	Magnetizing inductance	100µH
Vout	Output inductance	180µH
Prated	Buffer Capacitor	174µH
Iinrated	Charge pump Capacitor	69.4µH
Iorated	Filter Capacitor	300µH

Table 2: Design parameters for KY Converter

Hence, the Voltage stress of Switch S1 & S2 =24V.
Current stress of Switch S1= 1.71A and S2= 9.01A

VI. SIMULATION MODEL OF KY CONVERTER

A.Open Loop

The open loop simulation of the modified KY converter is done at rated load and duty cycle. Figure 3 gives the Simulink model of the open loop KY converter. The output waveform of voltage and current of the modified KY converter has been shown in the figure 4 The voltage boosting ratio of the proposed converter at different load conditions has been obtained digitally from MATLAB Simulink environment, which is shown. Here the figures depict the efficiency analysis of the KY converter at various load conditions and is concluded that the maximum efficiency of the converter can be attained up to 95%

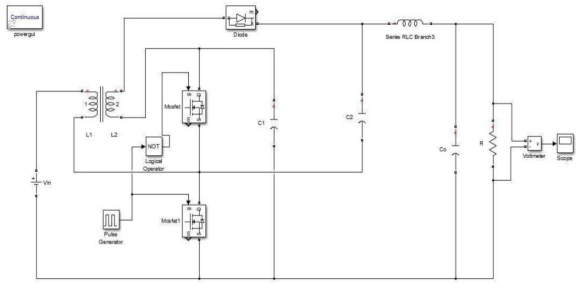

Fig 3 represents simulation for the Open Loop

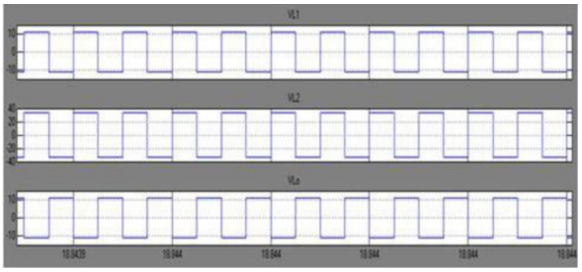

Fig 4 represents the output waveform for Open Loop

B. Closed Loop

In the closed loop model of the modified KY boost converter, the output voltage is referenced at 72V. Figure 5 shows the simulation model of the closed loop converter. The output waveform of the proposed converter has been simulated at rated conditions and been depicted in the figure 6.

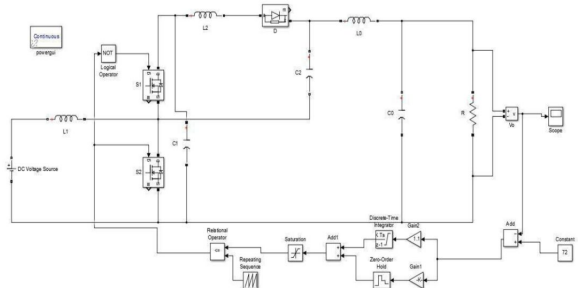

Fig 5 represents the Simulink for Closed loop model

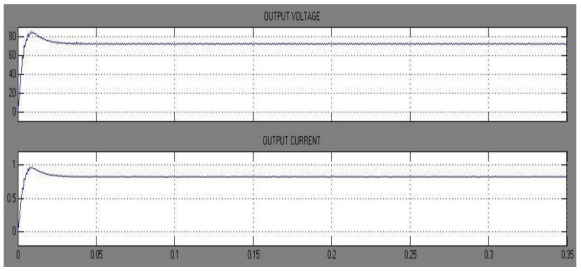

Fig 6 represents the closed loop output waveform

VII. CONVERTER SETUP

The modified KY boost converter in hardware has been designed with a coupled inductor with a turns ratio of unity. The capacitors used in the hardware include one 1000µF/100V capacitor, two 220µF/100µ capacitors as the buffer and energy transfer capacitors. The figure 7 shows the converter hardware setup.

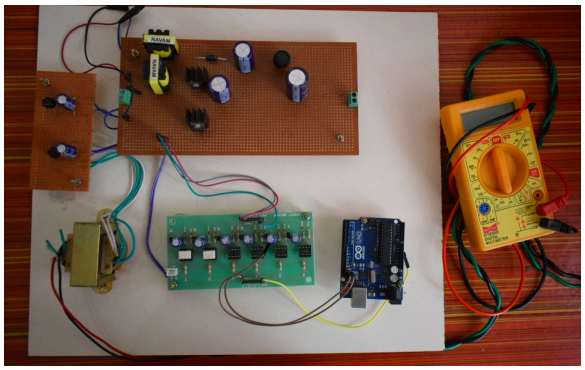

Fig 7. Converter setup

VIII. OUTPUT VERIFICATION

The modified KY converter in the hardware has been given with an input voltage of 12V DC which at 40 percent duty cycle the converter has boosted to a voltage of 36V. The input and the output verification graphs are shown in figure 8 and 9.

Fig 8. Converter input voltage

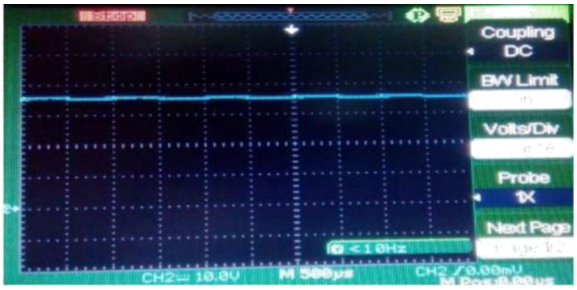

Fig 9 Converter output voltage

The hardware of the converter output has been designed and assembled with a coupled inductor of unity turns ratio. The C programming embedded in the Arduino microcontroller gives an output pulse width modulation with a duty cycle of 30 percent. The output achieved is satisfactory with an output voltage level of 36.84V.

IX. CONCLUSION

In the project, titled DC-DC Modified KY Converter In Renewable Energy Application, the novel step-up boost converter has been designed with an rated output power and voltage of 60W and 72 volts. The voltage and current ripple of the converter has come in the desirable range. The objective of switch stress reduction has been attained which is made to be independent of the output voltage. The modified step-up KY converter with an output inductor achieves a maximum efficiency of 95%

X. ACKNOWLEDGEMENT

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