

Identification of controller requirements for voltage regulation of KY Converter for PV Applications

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Abstract:

All renewable energy conversion requires DC to DC Converter for shaping of the voltage generated. The intermittent nature of renewable energy resources concerns the converter for its control. Most of the renewable energy applications involve a buck converter or a buck boost converter for regulating the voltage. These converters have drawback of low efficiency and high ripple contents in the output. A recently developed KY converter is capable of stepping up the DC voltage and is characterised with its high efficiency, lower ripple content and high voltage gain. The KY converter operates in continuous conduction mode and is capable of driving all types of loads. However, the input output voltage relationships of KY converter are nonlinear. This paper is organised to identify the controller needs for voltage regulation of KY converter for PV applications. The effects of variations in frequency, duty cycle and input voltage on the output are discussed.

Keywords: KY Converter, duty cycle, frequency, voltage regulation

I. Introduction

The KY converter is named after the initials of K. I. Hwu and Y. T. Yao [1]. The detailed operation of KY converter is presented in [2]. The KY converter has been identified as low ripple content converter. Various configurations of KY converter [3] have been reported for reducing the output voltage ripple contents. It is combined with boost converter, SR converter and control with advanced controllers for the same purpose. Its efficiency is reported to be around 97% [4]. The basic configuration of KY converter is modified by combining it with SR converter for enhancing the voltage gain [5]. This converter configuration has no floating output and possesses one output inductor so the output current is non-pulsating because of synchronous rectification. And hence, such a converter is suitable for low-ripple applications.

When compared with SEPIC converter the KY converter has higher voltage gain, lower voltage ripple and lower ripple current [6]. These characteristics makes it ideal choice for renewable energy applications. The modified Inductor coupled topology [7] of KY converter is deployed for speed control of electric bike. KY converter has shown a high level of stability during the transients, as the output remained within the limits during the switch over. With the proposed modification of integrating an OLTC with KY Converter, multiple output voltage levels are attained as per the design which enables variable speed operation.

The comparative study of boost converter and KY converter for speed control of PMDC motor [8] demonstrates the suitability of KY converter in step up converter, with high voltage ratio, and can be used in the PMDC motor drives for compact electric vehicles. The KY converter can be operated in buck as well as boost mode [9]. This functionality can be fine-tuned with conventional PI controller [10, 11].

An improved KY converter based on coupling inductor and one central-tap coupling inductor is presented by [12] to improve the voltage conversion ratio of the KY converter. It has a passive clamping snubber is used to decrease the voltage spike on the switch so as to increase the efficiency of this converter above half load. A variety of KY converter configurations are explored by various designers, engineers and researchers [13 – 17]. Among these configurations, a basic configuration is selected for the study to identify the controller requirements for voltage regulation.

II. Operation of KY Converter

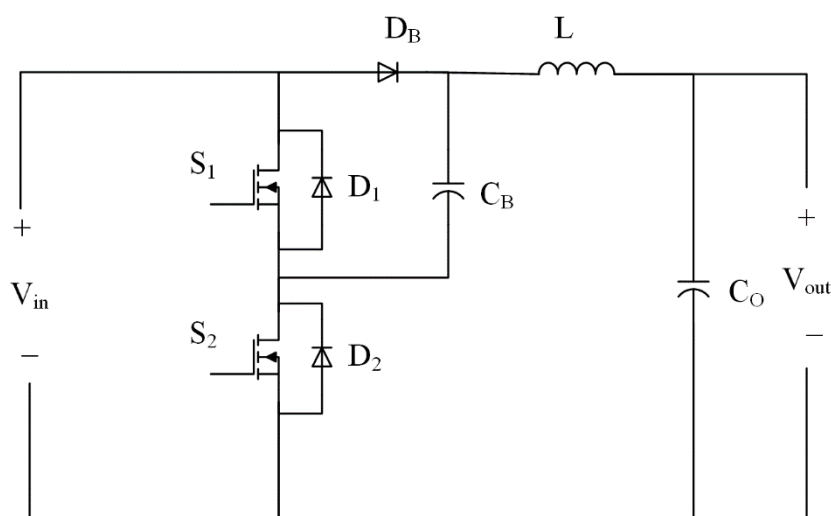


Figure 1: Circuit Scheme of KY Converter

Figure 1 shows the KY boost converter. It is constructed with two semiconducting switching devices S_1 and S_2 , a diode D , energy transferring capacitor C_b , output inductor L , and the output capacitor C_0 . The working of KY converter can be explained in two modes [6] as follows:

Mode 1: $S_1 = ON, S_2 = OFF$

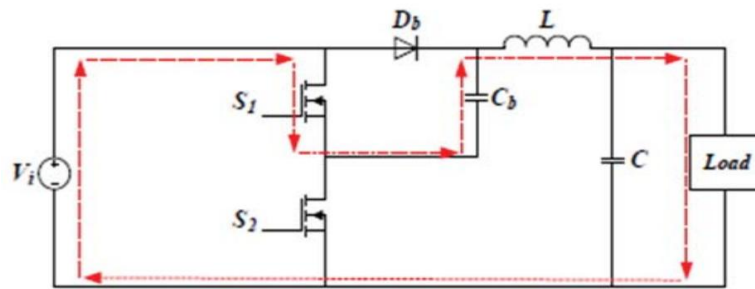


Figure 2: circuit path in mode 1 operation

In this mode, the inductor L is magnetized as the voltage across inductor L is,

$$V_L = V_{in} + V_C - V_O$$

Neglecting voltage drop across diode D ,

$$V_C = V_{in}$$

$$\therefore V_L = 2V_{in} - V_O$$

Here the capacitor C_b is discharged.

Mode 2: $S_1 = OFF, S_2 = ON$

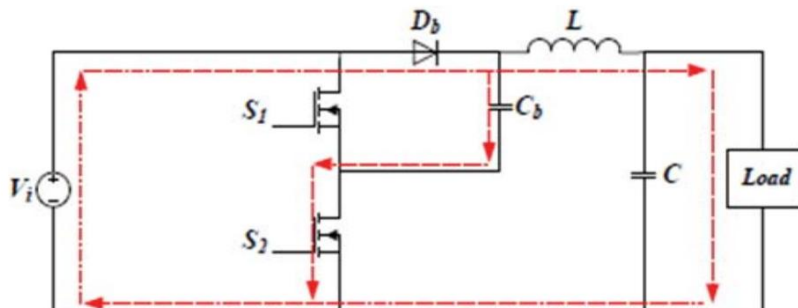


Figure 3: circuit path in mode 2 operation

In this mode, the inductor L is demagnetized as the voltage across inductor is,

$$\therefore V_L = V_{in} - V_O$$

Here the capacitor C_b is quickly charged to the input voltage level in very short interval.

The voltage gain is thus given as

$$\frac{V_O}{V_{in}} = 1 + D$$

From the equation of voltage gain it is seen that the output voltage of KY converter is a function of duty cycle. However, the design parameters of KY converter as mentioned in table 1 attracts the researchers to further investigate the effect of variation in input voltage, switching frequency and load on the output voltage of KY converter. This would be helpful for researchers to particularly develop a voltage controller for the converter.

Calculation of KY Converter Components:

For identifying the controller requirements for voltage regulation, a KY converter is designed first as per the specifications of input voltage, output voltage, switching frequency and load as mentioned in table 1. The calculations are done for finding values of the duty cycle, inductor and capacitor.

Table 1: KY converter rating

Particulars	Specification
Input Voltage (V_{in})	12V
Output Voltage (V_O)	20V
Frequency	10Khz
Power	100W

The output current of KY converter is,

$$I_o = \frac{P_O}{V_O} = \frac{100}{20} = 5A$$

The input current of KY converter is,

$$I_{in} = \frac{P_{in}}{V_{in}} = \frac{100}{12} = 8.33A$$

The voltage gain is

$$A = \frac{V_o}{V_{in}} = \frac{20}{12} = 1.66$$

Therefore, the duty cycle of converter is calculated as,

$$A = 1 + D \therefore D = 0.66$$

For calculating inductor value, the voltage across inductor is considered.

By KVL, the voltage across inductor is,

$$V_L = 2 V_{in} - V_o = 4V$$

The basic equation of inductor is,

$$V_L = L \frac{di}{dt}$$

$$\therefore L = V_L \frac{dt}{di}$$

Here, the interval dt is,

$$dt = \frac{D}{f}$$

The current di is ripple current of the inductor. It is assumed that the inductor ripple current is 30%

The inductor current is,

$$I_L = 2 I_{in} = 2 * 8.33 = 16.66A$$

$$\therefore di = 0.40 * 16.66 = 6.66A$$

Substituting these values in the equation of inductance,

$$L = V_L \frac{dt}{di} = V_L \frac{D}{f \cdot di} = 4 \frac{0.66}{10000 \times 6.66} = 39\mu H$$

The current through capacitor C_b is,

$$I = C_b \frac{dV}{dt}$$

$$C_b = I \frac{dt}{dV} = I_{in} \frac{D}{f dV}$$

Assuming dV , the ripple voltage across capacitor to be 2% of the source voltage,

$$dV = 0.01 \times 12 = 0.24$$

$$C_b = I_{in} \frac{D}{f dV} = 8.33 \frac{0.66}{10000 \times 0.24} = 2199 \mu F$$

For output capacitor,

$$I = C_o \frac{dV}{dt}$$

Assuming dV , the ripple voltage across capacitor to be 1% of the output voltage,

$$dV = 0.01 \times 20 = 0.2$$

$$C_o = I_{out} \frac{D}{f dV} = 5 \frac{0.66}{10000 \times 0.2} = 1650 \mu F$$

Table 2 summarizes the component specifications of the KY converter

Table 2: KY Converter Components Specifications

Duty cycle	66%
Inductance (L)	39 μ H
Capacitor (Cb)	2200 μ F
Capacitor (C)	1650 μ F
MOSFET	IRF 250

III. Simulation and results

In the simulation part, for analysing the effect of variations in switching frequency, duty cycle, input voltage and duty cycle the simulation is run and output voltage is measured (plotted) by

varying one of the above parameters and maintaining others constant. Thus, the simulation results are noted in four parts.

In first part the switching frequency (10KHz), input voltage (12V) and duty cycle (33%) are held constant and the effect of variations in load values is noted. The corresponding response of the KY converter is plotted in figure 4. It is seen that the increase in load causes a decrease in output voltage. The graph of output voltage vs load is shown in figure 5. A voltage controller shall cater the requirements of varying loads wherein, it shall adjust the duty cycle accordingly to regulate the output voltage to a constant level.

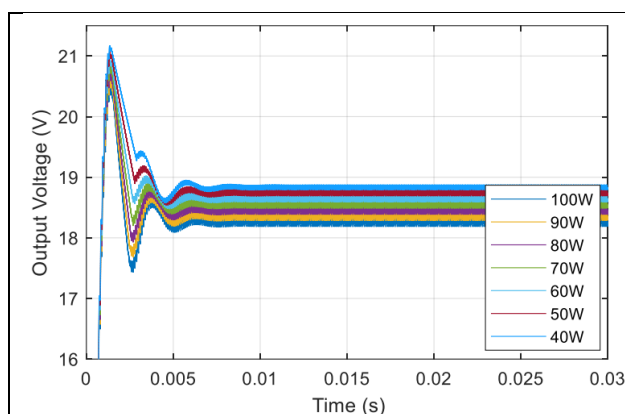


Figure 4: output voltage for various values of loads

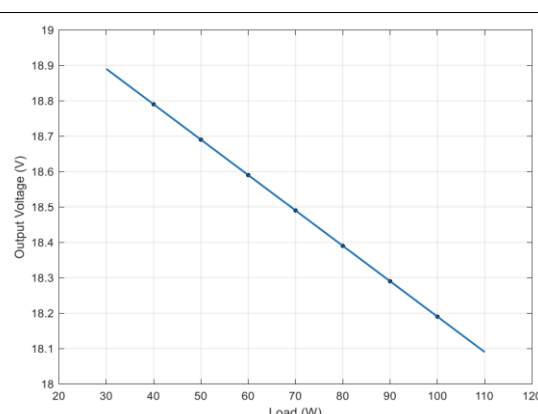


Figure 5: output voltage vs Load

In the second part, the input voltage (12V), duty cycle (33%) and load (100W) are held constant and the effect of variations in switching frequency on output voltage is noted. The corresponding response is plotted in figure 6. It is seen that the output voltage of the KY converter drops sharply with decrease in the value of switching frequency as compared to the desired (rated / selected) switching frequency. However, a minor change is observed if switching frequency exceeds the selected value. A graph of output voltage vs. switching frequency is shown in figure 7.

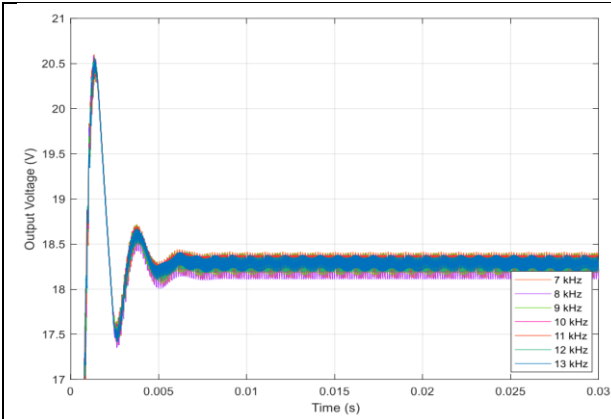


Figure 6: output voltage for various values of switching frequency

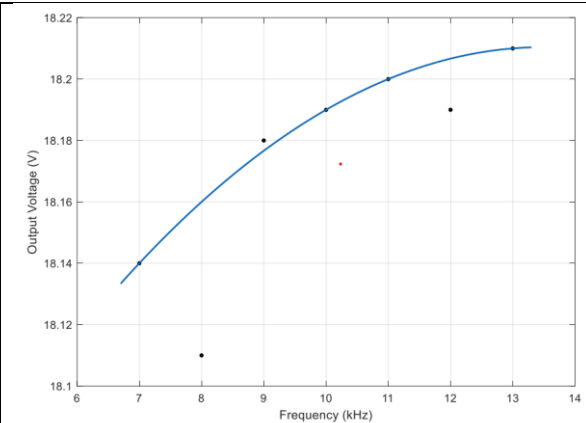


Figure 7: output voltage vs switching frequency

In the third part of the simulation, the input voltage (12V), switching frequency (10KHz) and load (100W) are held constant and the effect of variations in duty cycle on output voltage is noted. It is seen that the increase in duty cycle causes a fall in output voltage. the corresponding response is shown in figure 8. A graph of output voltage vs. duty cycle is shown in figure 9.

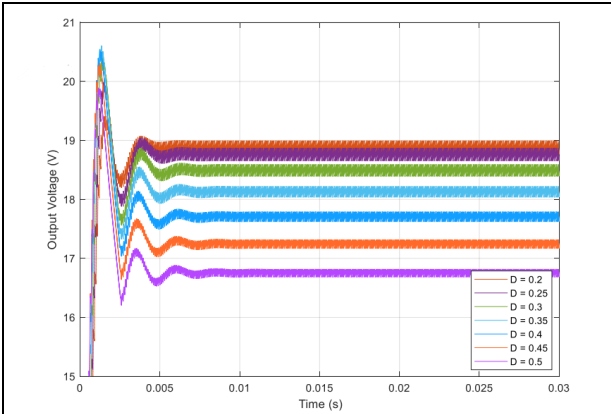


Figure 8: output voltage for various values of duty cycle

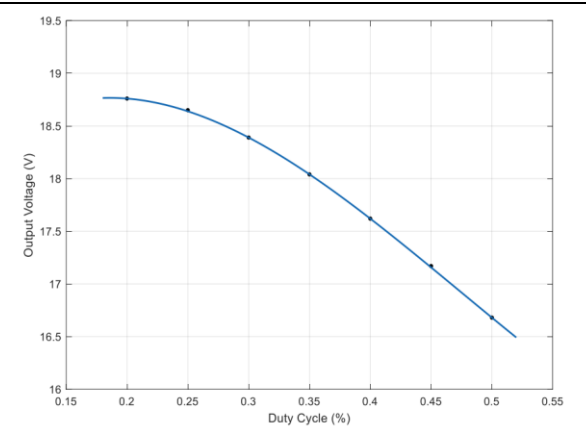


Figure 9: output voltage vs duty cycle

In the fourth part of the simulation, the duty cycle (33%), switching frequency (10KHz) and load (100W) are held constant and the effect of variations in input voltage on output voltage is noted. It is seen that the increase in input voltage causes an increase in output voltage. the corresponding response is shown in figure 10. A graph of output voltage vs. input voltage is shown in figure 11.

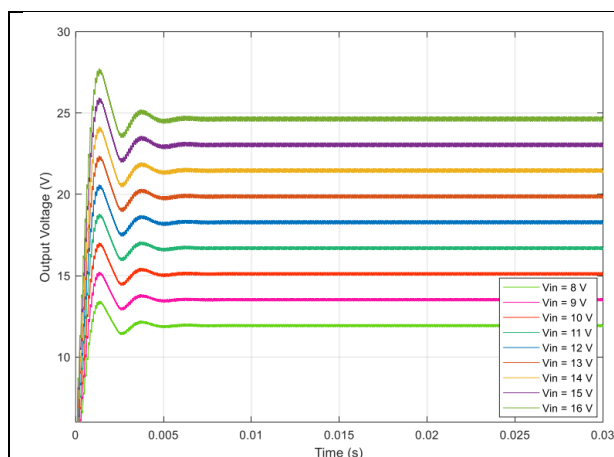


Figure 10: output voltage for various values of input voltage

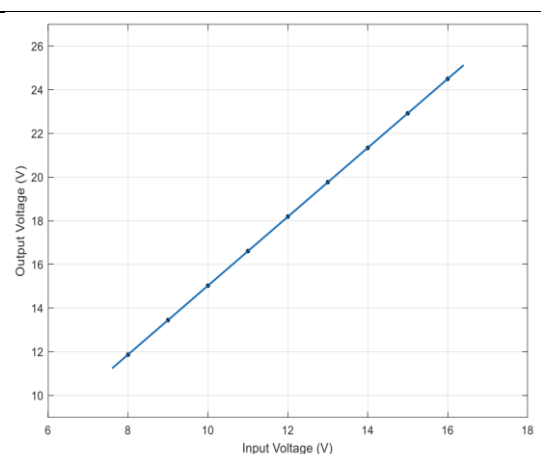


Figure 11: output voltage vs input voltage

IV. Conclusion

In this paper, the operation of KY converter is discussed in detail with operating modes and voltage gain equation. From the equation of voltage gain, it is seen that the output voltage is dependant on duty cycle and input voltage only. However, the simulation investigations shows that the switching frequency and load on the converter also forces the output voltage to change from the designed values. Hence, it can be concluded that the designers, engineers and researchers shall take into account these parameters as well while developing the voltage controller. An ideal voltage controller for KY converter shall be operating at fixed switching frequency and shall regulate the output voltage with the help of duty cycle control for any variations in load or input voltage. In PV applications, the input and load are often varying in nature. Hence, appropriate measures shall be included in the controller to regulate the output voltage.

References

- [1] K. I. Hwu and Y. T. Yau, "A KY boost converter," IEEE Trans. Power Electron., vol. 25, no. 11, pp. 2699–2703, Nov. 2010.
- [2] Praveena A & Sathish Kumar K, "Reduction of output voltage ripple with DC-DC conversion using KY converter Available at SSRN: <http://dx.doi.org/10.2139/ssrn.4091276>
- [3] S. Radhika, B. S. M. Prabhu and G. Irusapparajan, "Introduction to KY converter for voltage ripple reduction: A technological literature survey," IET Chennai Fourth

- International Conference on Sustainable Energy and Intelligent Systems (SEISCON 2013), Chennai, 2013, pp. 217-221
- [4] H. J. Wen, C. -S. Lam, W. -H. Choi, C. -K. Wong and M. -C. Wong, "A 97.0% maximum efficiency, fast response, low voltage ripple KY boost converter for photovoltaic application," 2018 IEEE International Conference on Industrial Electronics for Sustainable Energy Systems (IESES), Hamilton, New Zealand, pp. 71-75, 2018
 - [5] Kuo-Ing Hwu, Wen-Zhuang Jiang, "Improvement on voltage gain for KY converter", IET Power Electronics, Vol. 8, Iss. 3, pp. 361–370, 2015
 - [6] Gayathri Devi Ramaraj, Booma Nagarajan, "Comparative Analysis and Simulation Study of Non-Isolated High Gain Boost Converters", International Journal of Innovative Technology and Exploring Engineering (IJITEE) ISSN: 2278-3075, Volume-8 Issue-8S, June 2019
 - [7] Varun Krishnan K. S. & Preethi Thekkath, "A Real-Time Application of Modified Inductor Coupled KY Converter Topology in Speed Control of E-Bikes", Electric Power Components and Systems, Vol. 47, issue:16-17, pp. 1524-1533, 2019
 - [8] Varun Krishnan & Preethi Thekkath, "Performance Evaluation of Step-Up KY Converter as a PMDC Drive – A Comparative Study", IJLTET, Vol. 6, issue 3, pp. 182 – 187, 2016
 - [9] Janjanam Naveen and Mukti Barai, "Design and Implementation of KY Buck-Boost Converter with Voltage Mode Control", International Journal of Scientific & Engineering Research, Volume 8, Issue 6, June-2017
 - [10] G. Saritha, D. Kirubakaran, "Design and Implementation of KY Buck-Boost Converter with Voltage Mode Control", International Journal of Engineering and Advanced Technology (IJEAT), Volume-8 Issue-5, June 2019
 - [11] Nikhitha C and Sheryl Grace Colaco, "Proposed Buck-Boost Converter Combing KY and Buck Converter", International Journal of Electrical & Electronics Engg. & Telecoms. Special Issue, Vol. 1, No. 1, pp. 133 – 140, March 2015
 - [12] K. I. Hwu, W. Z. Jiang and H. M. Chen, "Improved KY Converter", Journal of Electrical Engineering Technology, Vol. 10, issue 4, pp. 1578-1588, 2015
 - [13] Y. Xie, S. Fan, C. Yuan, and L. Geng, "Design of improved KY converter with low power ZCD circuit for wide load current application," in Proc. IEEE Int. Conf. Integr. Circuits, Technol. Appl. (ICTA), pp. 45–46, Nov. 2020

- [14] K. R. Kumar, K. R. Raja, S. Padmanaban, S. M. Muyeen and B. Khan, "Comprehensive Review of KY Converter Topologies, Modulation and Control Approaches with Their Applications," in IEEE Access, vol. 10, pp. 20978-20994, 2022
- [15] Hwu K.I., Jiang W.Z., "Voltage Gain Enhancement for a Step-Up Converter Constructed by KY and Buck-Boost Converters", Industrial Electronics IEEE Trans, vol.61, no.4, pp.1758-1768, Apr. 2014
- [16] G. Karthikeyan and R. E. Raj, "KY converter for renewable energy systems," Int. J. Pure Appl. Math., vol. 118, no. 24, 2018
- [17] 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.