Voltage Gain Enhancement Using Ky Converter

Meera R Nair\textsuperscript{1}, Ms. Priya Jose\textsuperscript{2}
\textsuperscript{1} (EEE, ASIET KALADY / M G University, India)
\textsuperscript{2} (EEE, ASIET KALADY / M G University, India)

Abstract: The KY Converter, Which is a step up converter, The name given to this converter is first letter of the authors, K.I. Hwu, Y. T. Yau. This converter always operate in CCM, and the output current is non-pulsating, and low output voltage ripple and higher voltage boosting capability. In this paper, different modes of KY Converters are studied. The simulation is carried out to study the performance of the combinations of KY Converter in MATLAB/SIMULINK. Simulation result are studied. The result help to find the most suitable converter for the Micro-source applications.

Keywords: KY Converter, One Plus D Converter, Inductor coupled KY Boost Converter, Step up Converter combining KY and buck-boost Converter

I. Introduction

The over usage of fuel energy cause the global warming, environmental pollution and rise in price of the petroleum and diesel. The studies reveals that the demand of fuel energy rises with 8-10 percent per annum. This can be avoid by using non-renewable energy.

In such condition micro-source are obtaining more importance. The micro-source are either DC Source or High frequency AC Source. These categories of source are mainly used for renewable energy applications. Mainly for solar cell modules, fuel cell stacks wind turbines and reciprocating engines. If the output of the micro-source is DC, the magnitude of output is very low. So there arise the needs of a high voltage boosting converter output voltage. Different boosting converters are available now such as boost, buck-boost, CUK and SEPIC converter. And KY Converter like. Among these KY converter is most acceptable one. KY converter is a DC to DC voltage boosting converter \cite{1}.

Which is always operate in CCM and and the output current is non-pulsating. The output voltage has less ripples. For many applications the output voltage gain ripples and gain is need to taken in to consideration. Regarding the traditional non-isolated voltage-boosting converters \cite{2}, \cite{3}, such as the traditional boost converter and buck-boost converter, their voltage gains are not high enough for some circuits. So KY converter can use instead of all other boost converters.

The KY Converter and the combinations of other converters with KY Converter will have more voltage gain and less ripple. The example is that One plus D KY Converter is the basic form of KY Converter. Which has less ripples when compared with the boost converter. But the KY Converter has less voltage gain. In that situation we can use the combinations of KY converter with other boost converter such as Step-Up Converter Constructed by KY and Buck-Boost Converters. In the micro-source applications we can use the Converter constructed by KY and buck-boost converter. Because we can obtain more voltage gain with less output voltage and output current ripples. So it will be more advantageous than the normal KY Converter.

II. DC-DC Boost Converters

The available converters for boosting the voltage are boost converter, KY Converter and the Converter constructed by KY and buck-boost converter are studied and found out the most acceptable one for the micro-source application.

2.1 Boost Converter

A Boost converter is switch mode DC to DC converter in which the output voltage is greater than the input voltage. The principle behind the boost Converter is the tendency of an inductor to resist changes in current by increasing and destroying a magnetic field.

![Boost converter diagram](image-url)
When switch S is ON: The diode will be open circuited since the diode is at higher voltage compared to the side which is shorted to ground through the switch. During this state the inductor charges and the inductor current increases. The inductor stores some energy by generating a magnetic field. Polarity of the left side of the inductor is positive. The current flowing through the diode is expressed as:

$$I_{L,ON} = \frac{1}{L} \times V_{in}\times D \times T_S + I_{L,ON}$$

For the OFF state,

$$i'_{L,OFF} = \frac{1}{L} \times (V_{in} - V_{OUT}) \times (1-D) \times T_S + i'_{L,OFF}$$

Using these equations we get,

$$\frac{1}{L} \times V_{in} \times D \times T_S = -\frac{1}{L} \times (V_{in} - V_{OUT}) \times (1-D) \times T_S$$

$$V_{in} \times D = (V_{in} - V_{OUT}) \times (1-D)$$

$$\frac{V_{OUT}}{V_{in}} = \frac{1}{1-D}$$

Modes of operation of Boost converter are,

- Continuous conduction mode in which the current through inductor never goes to zero
- Discontinuous conduction mode in which the current through inductor goes to zero

### 2.2 KY Converter

KY converter is a step up converter. The behavior of KY converter can be considered as synchronous rectification. In the case of synchronous rectification, the diode is replaced by a MOSFET switch to develop the efficiency and to reduce the conduction losses. But this can be achieved only in the case of light loads. The feature of KY converter, which makes it different from other converters, is that it always operates in. Also the output voltage ripple is very low since the output current is not pulsating. Above all, its behavior is similar to that of the buck converter with synchronous-rectification (SR), and hence, this converter possesses good load transient response. However, its ratio of the output voltage to the input voltage is one plus D, where D is the duty cycle of the pulse width-modulation (PWM) control signal for the main switch.

**Working:**

Mode 1: In Fig., as soon as S1 is turned on and S2 is turned off, the voltage across L is the input voltage $v_i$ plus the voltage $v_i$ across $C_b$ minus the output voltage $v_0$, thereby causing L to be magnetized. Also, the current flowing through C is equal to the current $i$ flowing through L minus the current flowing through R. Besides, in this mode, $C_b$ is discharged. And hence, the corresponding differential equations are,

$$L \frac{di}{dt} = 2v_i - v_0$$

$$C \frac{dv_0}{dt} = i - \frac{v_0}{R}$$

$$i_l = I$$
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Mode 1 operation of KY Converter

Mode 2: In Fig., as soon as $S_1$ is turned off and $S_2$ is turned on, the voltage across L is the input voltage $v_i$ minus the output voltage $v_o$, thereby causing L to be demagnetized. Also, the current flowing through the C is equal to the current $i$ flows through L minus the current flowing through R. Besides, in this mode, Cb is abruptly charged to $v_i$ within a very short time, which is much less than $T_s$. And hence, the corresponding differential equations are,

$$L \left( \frac{di}{dt} \right) = v_i - v_o$$
$$C \left( \frac{dv_o}{dt} \right) = i - v_o/R$$

$$ii = i + ib$$

2.3 Step-Up Converter Constructed by KY and Buck-Boost Converter

This converter contains two MOSFET switches S1 and S2, one coupled inductor composed of the primary winding with $N_p$ turns and the secondary winding with $N_s$ no. of turns, and one energy-transferring capacitor $C_1$, and one charge pump capacitor $C_2$, also one diode $D_1$, one output inductor $L_o$, and one output capacitor $C_o$. In addition, the input voltage is represented by $V_i$, the output voltage is signified by $V_o$, and the output resistor is represented by $R_o$.

Before taking up this section, there are some assumptions to be made as follows.

1. The coupled inductor is modeled as an ideal transformer except that one magnetizing inductor $L_m$ is connected in parallel with the primary winding and one leakage inductor $L_l$ is connected in series with the primary winding. Therefore, the coupling coefficient $k$ is defined as $L_m/(L_m + L_l)$.

2. The converter operates in the positive current mode. That is, the currents flowing through the magnetizing inductor $L_m$ and the output inductor $L_o$ are always positive.

3. Dead times between two MOSFET switches are omitted.

4. The MOSFET switches and the diodes are assumed to be ideal components.

5. The values of all the capacitors are large enough such that the voltages across them are kept constant at some values.

6. The magnitude of the switching ripple is negligible. Therefore, the small ripple approximation will be adopted herein in analysis.

These following analysis contains the explanation of the power flow path for each mode, along with the corresponding equations and voltage gain. Inherently, there are two operating modes in the proposed converter. **Mode 1:** During this interval, as shown in Fig. 3, $S_1$ is turned off, but $S_2$ is turned on. Therefore, the 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 $V_i N_s / N_p$. In addition, $D_1$ becomes forward-biased $C_2$ is charged to $V_i + V_C1 + V_i N_s / N_p$, and the voltage across $L_o$, $v_{Lo}$, is a negative value, equal to $V_C2 V_o$, thus making $L_o$ demagnetized. As a consequence, the 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 $L_o$, $v_{Lo}$, provides the energy to the load.
Also, the associated equations are shown below:

\[
V_{NP} = V_i \\
V_{L0} = V_{C2} - V_0
\]

**Mode 2:** During this interval, as shown in Fig., S1 is turned on, but S2 is turned off. Therefore, the voltage \( V_{C1} \) 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 \( V_{C1} \frac{N_s}{N_p} \). In addition, \( D_1 \) becomes reverse biased, the voltage on \( L_o \) is a positive value, equal to \( V_i + V_{C1} + V_{C2} + V_0 \), thus causing \( L_o \) 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 \( L_o \) and the load.

The voltage gain can be expressed to be,

\[
\frac{V_o}{V_i} = \frac{2 - D}{1 - D} + n \quad 0 < D < 1
\]

### III. Design Considerations

For the inductor design,

\[
V(t) = L \frac{di}{dt}
\]

Where \( v \) is the voltage over the inductor, \( L \) is the value of the inductor in Henrys, and \( \frac{di}{dt} \) is the change in current over time in the inductor. Operating frequency, \( f = 195 \text{ KHz} \).

For the capacitor design,

\[
C = \frac{(I_o D)}{(f \Delta V_o)}
\]

For the Boost Converter the component specification are,

<table>
<thead>
<tr>
<th>Components</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>inductor</td>
<td>5e-5</td>
</tr>
<tr>
<td>capacitor</td>
<td>5.7e-5</td>
</tr>
<tr>
<td>Resistor</td>
<td>100 Ohm</td>
</tr>
</tbody>
</table>
For the case of KY Converter prior to taking up this section, there are some specifications given as follows:
1) Rated input voltage \( V_i \) is set to 12 V.
2) Rated output voltages \( V_o \) are set to 24V, 18 V and 72V or the Boost converter, KY converter and the step up converter constructed with KY and buck-boost converter respectively.
3) Switching frequency \( f_s \) is set to 100 kHz.
4) The duty ratio for the switch is set to 0.5
5) Rated output powers \( P_o \)-rated are 50 W, 50W and 60 W for the Boost Converter KY converter and the step up converter constructed with KY and the buck-boost converter, respectively.

For the KY converter to be considered, there are some assumptions used to obtain the value of \( C_b \) as follows:
1) \( C_b \) is abruptly charged to \( V_i \) in mode 2; 2) percentage \( \varepsilon \) of decreased variation in voltage on \( C_b \) during the discharge period is set to 0.1% in mode 1; 3) input voltage is an infinite bus, i.e., the input voltage is always kept constant and possesses infinite capacitance that is much larger than the value of \( C_b \);

\[
E_e = \frac{1}{2} C_b [(2 Vi)^2 - [(2 - \varepsilon) Vi]^2] \\
= \frac{1}{2} (4\varepsilon - \varepsilon^2) C_b V_i^2
\]

Also, in mode 1, the energy \( E_s \) is sent to the load, and can be represented as,

\[
E_s = \frac{(P_0 - \text{rated} D)}{\eta f_s}
\]

According to energy conservation, \( E_e \) is equal to \( E_s \), and hence, value of \( C_b \) can be expressed as

\[
C_b = \frac{(2P_0 - \text{rated} D)}{(4\varepsilon - \varepsilon^2) V_i^2 \eta f_s}
\]

\( C_b \) here selected as 1.7e-3 and \( C_0 \) as 1F.

From the industrial view point, the output inductor is generally designed to have no negative current when output current is above 20%~40% of rated output current. Therefore, in this paper, boundary between positive current and negative current is assumed to be 40% of the rated output current. The value of \( L \) is 18\( \mu F \).

For the KY Converter the component specification are,

<table>
<thead>
<tr>
<th>Components</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_b )</td>
<td>1.7e-3 F</td>
</tr>
<tr>
<td>( L )</td>
<td>1.8e-5 H</td>
</tr>
<tr>
<td>( C_0 )</td>
<td>1F</td>
</tr>
<tr>
<td>( R_0 )</td>
<td>100 Ohm</td>
</tr>
</tbody>
</table>
Simulation for KY Converter

For the case of step up converter constructed by KY and buck-boost Converter, the Magnetizing inductor design: To make sure that \( L_m \) always operates in the positive region, the required equation is as follows.

\[
L_m \geq \frac{V_iDT_s}{\Delta i_{m,\text{min}}}
\]

where \( IL_{m,\text{min}} \) is the minimum dc current in \( L_m \). And finally, the value of \( L_m \) is set at 148.7\( \mu \)H.

Output inductor design: From the industrial viewpoint, output inductor is generally designed to have no negative current when the output current is above 20%~30% of the rated output current. Eventually, the value of \( L_o \) is set at 188\( \mu \)H.

Energy-transferring capacitor design: Assuming the peak-to-peak value of the capacitor voltage during the charge period, \( \Delta v_{C1} \), is set to 1% of \( VC_1 \) or less, that is, \( \Delta v_{C1} \) is smaller than 120mV, the value of \( C_1 \) can be obtained as follows:

\[
C_1 \geq \frac{(i_{c1}\Delta t)}{\Delta V_{C1}}
\]

Charge pump capacitor design: Assuming the variation in capacitor voltage during the discharge period, \( \Delta v_{C2} \), is set to 0.1% of \( VC_2 \) or less, that is, \( \Delta v_{C2} \) is smaller than 60mV, the value of \( C_2 \) can be obtained as follows:

\[
C_2 \geq \frac{i_{c2}\Delta t}{\Delta V_{C2}}
\]

For the KY Converter the component specification are:

<table>
<thead>
<tr>
<th>Components</th>
<th>Specifications</th>
</tr>
</thead>
<tbody>
<tr>
<td>( C_1 )</td>
<td>470e-6 F</td>
</tr>
<tr>
<td>Coupled inductor</td>
<td>( L_m=148.7 \text{M} \mu )H</td>
</tr>
<tr>
<td>( L_1 )</td>
<td>1.3( \mu )H, ( L_2=4 \times 10^{-4}, k=0.997 )</td>
</tr>
<tr>
<td>( L_o )</td>
<td>188e-6 H</td>
</tr>
<tr>
<td>( C_o )</td>
<td>220e-6 F</td>
</tr>
</tbody>
</table>

Simulation Diagram for the step up converter constructed with KY and buck-boost converter

IV. Simulated Results

The available converters i.e. boost converter and ky converter and the step-up converter constructed by combining ky and the buck-boost converters are studied under the same condition with the same duty ratio and frequency under the same load. The boost converters are very simple circuits and we obtain the maximum output voltage. But the output voltage ripples are very high and output current is pulsating when compared with the others.
The applications of the power supply using the low voltage battery, analog circuits, such as RF amplifier, audio amplifier, etc., sometimes need high voltage to obtain enough output power and voltage amplitude. This is achieved by boosting the low voltage to the required high voltage. For such applications, the output voltage ripple must be taken into account seriously.

Regarding the conventional non-isolated voltage-boosting converter such as the boost converter, their output currents are pulsating, thereby causing the corresponding output voltage ripples to tend to be large.
In the case of the KY Converter, the above problems are solved, the output voltage ripples for converter are very small and the output current is non-pulsating. But the voltage gain is not that much suitable for high power applications. Because the voltage gain is small when compared with other higher converters. So we need to consider the step up converter constructed by KY Converter and buck-boost converter. In this case this converter voltage gain is high. And the output voltage ripples are very small and the output current is non-pulsating. So the KY Converter constructed with buck-boost converters are used for high voltage industrial applications.

Comparative study for various DC-DC Converter topologies,

<table>
<thead>
<tr>
<th>NO. OF SWITCHES</th>
<th>BOOST</th>
<th>1+D</th>
<th>[(2-D)/(1-D)] +n</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input Voltage</td>
<td>12</td>
<td>12</td>
<td>12</td>
</tr>
<tr>
<td>Output current</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Output voltage ripple</td>
<td>0.025</td>
<td>2.3e-4</td>
<td>2e-3</td>
</tr>
<tr>
<td>Voltage Ripple percentage</td>
<td>0.1054</td>
<td>5.22e-5</td>
<td>5.025e-3</td>
</tr>
<tr>
<td>Output current</td>
<td>0.25</td>
<td>0.25</td>
<td>0.48</td>
</tr>
<tr>
<td>Duty Ratio</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
</tbody>
</table>

V. Conclusion

From the study of the various DC-DC converters high step-up converter is presented is very useful when compared with the other conventional boost Converter and the KY Converter. By combining the coupled inductor with the turns ratio, and the switched capacitor, the corresponding voltage gain is higher than that of the existing step-up converter combining KY and buck-boost converters. Furthermore, the converter has no floating output, and has one output inductor so the output current is non-pulsating. Moreover, the structure of the proposed converter is quite simple and very suitable for industrial applications.

References