In this study, a novel method is presented for DC DC Cascaded boost converters design using PI controller block. This approach reinforces a same voltage source by using two or more cascade boost converter blocks simultaneously and is very effective in power transmission in renewable energy resources where they produce limited amount of power. In this converter, output voltage and current ripples are lower than 0.1%. One advantage of using this circuit compared to conventional boost converters is its long life because of input current division at the input blocks. A PI block controls voltage production confronting rapid load or input voltage changes by duty cycle changing and drive MOSFETs and restrict output voltage ripple. This circuit is simulated by MATLAB/SIMULINK and CADENCE for preparing to instruction and the results of the simulation confirmed the theoretical design. This design has implemented on a parallel structure with two blocks of cascaded boost converters at a laboratory scale.

Keywords: DC DC Boost Converter; Cascaded Boost Converter; PI Controller; Pulse Width modulation; Renewable Energy Sources.

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1. Introduction

In recent years, researchers have attached great importance to renewable energy sources and due to the limited production capacity in these resources, have put up power transmission in the most optimal situation in their research priorities. DC-DC converters are divided into BUCK, BOOST and BUCK-BOOST categories at different voltage conversion ratios. Among them, we will discuss about Boost converters those used to obtain higher DC output voltage in comparison with the input DC voltage and infact it is a DC to DC voltage converter and it is increasingly employed as front end converters for recently renewable energy sources such battery sources, photovoltaic (PV) systems and fuel cells (FC). Generally, when we need to step up a DC voltage, a boost converter is usually chosen.

Converters, with open loop condition operation, could not control and regulate the output voltage strongly with sudden changes in converter input voltage or output load and exhibits poor dynamic response, and then, this converters are generally equipped with closed loop control for better output voltage regulation. The mode of operation of the converter is containing from ON and OFF states regarding to turning the power switch (normaly IGBT or MOSFET) ON and OFF. Many control strategies are applied differences in time of switch ON and OFF (duty cycle) to obtain the desired output voltage and voltage
gain. To achieve a high voltage gain, the power switch's applied duty cycle should be large, and in result, we will have more conduction losses and lower efficiency in converter. Every switch as a type of transistor has a minimum Off time and then we have a limitation about maximize the switching frequency. Also, a large duty cycle make a small time for diode in a converter to flow the current and this small time make a high momentary current value as a narrow pulse. This kind of current in diode make EMI problems in converter.

There are many ways to increase efficiency of boost converters. For this purpose, some researchers have argued to limit the switching losses and some anothers have discussed on limitation of conductive losses. Also, isolated converters for high operation duty cycles have designed but these kindes of converters generally have high switch voltage stress on IGBTs. No isolation is required in cascaded boost converters [3]. The methods to design the conventional types of cascaded boost converters use two or three or several series blocks of conventional boost converters to increase the output voltage. Although, increasing the number of boost converters in cascade types can decrease the current stress in lower stages and voltage stresses in higher stages but it has more losses due to more elements of the circuit [4–14]. This paper presents a new approach to cascaded boost converters with parallel connection and that’s simulation in MATLAB/SIMULINK. This design has all the advantages of a cascaded boost converter such as reducing voltage and current stress on the converter and the high voltage gain and input current control.

In addition, by considering the parallel converter blocks in input, this circuit has capability of producing the desired voltage at the output with small duty cycles. According to the applied appropriate switching frequency, inductor values are selected about 3 milli Henry. Simulation results are justifying theoretical results.

A conventional boost converter has shown in Figure 1. It contains an inductor, a semiconductor power switch, a diode, a capacitor and a load as output. As it has shown, it has ON and OFF states according to power switch mode [1].

When switch has received a signal at the gate, it goes to ON mode and then the second end of the inductor will be short to ground. In this condition inductor current will be charge by $V_\text{in}$ for $dT$ and voltages on capacitor will be equal with $V_\text{C}$ and will discharge on load. The current flows from inductor will be decrease with $-\left(V_o - V_{\text{in}}\right)$ voltage when power switch is in OFF mode for $(1-d)T$. The ripple on inductor current can come from [1]:

\[
\text{Figure 1. (a) Conventional Boost Converter, (b) circuit when switch is ON, (c) circuit when switch is OFF}
\]
\[ \Delta L = \frac{V_{in}}{L_1}dT = \frac{V_o - V_{in}}{L_1}(1-d)T \]  

In this equation, \( d \) is duty cycle and \( T \) is the square pulse period. In a normal boost converter, the relation between \( V_{in} \) and \( V_{out} \) is:

\[ V_o = \frac{1}{1-d}V_{in} \]  

and the voltage gain is consequently:

\[ G = \frac{V_o}{V_{in}} = \frac{1}{1-d} \]  

Inductor current average:

\[ I_{L_1} = (1-d)\frac{V_o}{R} \]  

And then variation ratio on inductor current is:

\[ \xi = \frac{\Delta I L/2}{I_{L_1}} = \frac{dT V_{in}}{(1-k)^2 V_o / R} = \frac{d R}{2 J L} \]  

For working in CCM (Continuous Current Mode), \( \xi \) should be less than 1 [1]. Also, the ripple on output voltage on capacitor can be calculated as simply:

\[ \Delta V_o = \frac{\Delta Q}{C} = \frac{I_o (1-d)T}{C} = \frac{1-d}{fC R} \]  

Variation ratio on capacitor voltage is coming from:

\[ \epsilon = \frac{\Delta V_o/2}{V_o} = \frac{1-d}{2fR C} \]

because of being the switching frequency in Kilo Herz and capacitor in micro Farad, this ratio is about a few percents [1].

Two stages cascade boost converter is obtained by adding a block to a normal boost converter [1]. It has shown in Figure 2. This structure uses only one power switch. Figure 3 is presenting conventional cascade DC DC boost converter which has two power switches. This structure has a simple serial connections between normal boost converters.

![Figure 2](image-url)
As it can be seen in Figure 2, it contains of two normal boost structures. When switch is ON, current flow from $L_1$ is charging by $V_i$ for $dT$ and when it is in OFF mode, current is decharging with $-(V_o - V_i)$ for $(1-k)T$. The volage across $C_1$ is charging to $V_i$ and this value for $C_2$ is $V_o$. Then current ripple on $L_2$ is calculated from:

$$\Delta L_2 = \frac{V_i}{L_2}dT = \frac{V_o - V_i}{L_2}(1-d)T$$

(8)

Output volatge and vltage gain are:

$$V_o = \frac{1}{1-d}V_i = (\frac{1}{1-d})^2V_m$$

(9)

$$G = \frac{V_o}{V_m} = (\frac{1}{1-d})^2$$

(10)

From (10) the currents flow from $L_1$ and $L_2$ are consequently:

$$\Delta i_{L_1} = \frac{\Delta \Delta i_{L_1}}{L_1} dT = \frac{I_{L_1}}{(1-d)^2}$$

(11)

$$\Delta i_{L_2} = \frac{\Delta \Delta i_{L_2}}{L_2} dT = \frac{I_{L_2}}{(1-d)}$$

(12)

Then current variation on $L_1$ and $L_2$ will be equal to:

$$\xi_1 = \frac{\Delta \Delta i_{L_1}}{I_{L_1}}/2 = \frac{d(1-d)^2TV_m}{2L_1I_o} = \frac{d(1-d)^2}{2} \frac{R}{fL_1}$$

(13)

$$\xi_2 = \frac{\Delta \Delta i_{L_2}}{I_{L_2}}/2 = \frac{d(1-d)^2TV_i}{2L_2I_o} = \frac{d(1-d)^2}{2} \frac{R}{fL_2}$$

(14)

Variation ratio of Output voltage on $C_2$ is:

$$\varepsilon = \frac{\Delta V_o}{V_o} = \frac{1-d}{2RfC_2}$$

(15)

2. Small signal analysis of the proposed converter and PI controller design

This section is explaining PI controller design method step by step with dynamical model of circuit. When switch is ON mode, we can write the state equations as below for all inductors and capasitors [2]:

$$\begin{align*}
L_1 \frac{di_{L_1}}{dt} &= V_o \\
L_2 \frac{di_{L_2}}{dt} &= v_{c_1} \\
C_1 \frac{dv_{c_1}}{dt} &= -i_{L_2} \\
C_2 \frac{dv_o}{dt} &= -\frac{v_o}{R}
\end{align*}$$

$$\Rightarrow \begin{align*}
\frac{di_{L_2}}{dt} &= \frac{V_o}{L_1} \\
\frac{di_{L_2}}{dt} &= \frac{v_{c_1}}{L_2} \\
\frac{dv_{c_1}}{dt} &= -\frac{i_{L_2}}{C_1} \\
\frac{dv_o}{dt} &= -\frac{v_o}{C_2R}
\end{align*}$$

(16)
And when switch goes to OFF mode these equations will be as below:

\[
\begin{align*}
L_1 \frac{di_{L1}}{dt} &= (V_{in} - v_{C1})(1-d) \\
L_2 \frac{di_{L2}}{dt} &= (v_{C1} - v_o)(1-d) \\
C_1 \frac{dv_{C1}}{dt} &= (i_{L1} - i_{L2})(1-d) \\
C_2 \frac{dv_o}{dt} &= (i_{L2} - \frac{v_o}{R})(1-d)
\end{align*}
\]

\[
\begin{align*}
\frac{di_{L1}}{dt} &= \frac{V_{in} - v_{C1}}{L_1} (1-d) \\
\frac{di_{L2}}{dt} &= \frac{v_{C1} - v_o}{L_2} (1-d) \\
\frac{dv_{C1}}{dt} &= \frac{i_{L1} - i_{L2}}{C_1} (1-d) \\
\frac{dv_o}{dt} &= \frac{i_{L2} - \frac{v_o}{R}}{C_2} (1-d)
\end{align*}
\]  

(17)

System average model for considering ON and OFF modes together can be written as (18):

\[
\begin{align*}
\frac{di_{L1}}{dt} &= -\frac{(1-d)}{L_1} v_{C1} + \frac{1}{L_1} V_{in} \\
\frac{di_{L2}}{dt} &= \frac{1}{L_2} v_{C1} - \frac{(1-d)}{L_2} v_o \\
\frac{dv_{C1}}{dt} &= \frac{(1-d)}{C_1} i_{L1} - \frac{1}{C_1} i_{L2} \\
\frac{dv_o}{dt} &= \frac{(1-d)}{C_2} i_{L2} - \frac{1}{RC_2} v_o 
\end{align*}
\]

(18)

They key point for PI control designing is find a equation between \( V_o \) and one of inductors currents derivatives or voltage derivative on \( C_1 \), and it can be obtained from fourth part of (17):

\[
C_2 \frac{dv_o}{dt} + \frac{1}{R} v_o = (1-d)i_{L2} = u
\]

(19)

\( u \) is the PI controller output and \( d \) is the duty cycle to get signals to IGBT’s gate [2], it has shown in Figure 3.

\[
d = 1 - \frac{u}{i_{L2}}
\]

(20)

Figure 4. Voltage comparision, PI control and PWM modulator blocks
General form of a PI controller comes from:
\[ G(s) = k_p + \frac{k_i}{s} = k_p s + k_i \]  
(21)
We can put (19) in a feedback loop by a PI controller as Figure 4.

![Figure 5. Closed loop form of the PI controlled cascade boost structure](image)

The transfer function of closed loop form of this feedback is equal with:
\[ G_F = \frac{G_o}{1 + G_o} = \frac{1}{C_2} \frac{(k_p + k_i)}{s^2 + \frac{(1+Rk_p)}{RC_2} + \frac{k_i}{C_2}} \Rightarrow G_F = \frac{1}{C_2} \frac{(k_p s + k_i)}{s^2 + 2\xi\omega_o s + \omega_o^2} \]  
(22)
It is easy to gain [2]:
\[ \begin{align*}
\frac{1+Rk_p}{RC_2} &= 2\xi\omega_o \\
\frac{k_i}{C_2} &= \omega_o^2
\end{align*} \Rightarrow \begin{align*}
k_p &= 2\xi\omega_o C_2 - \frac{1}{R} \\
k_i &= \omega_o^2 C_2
\end{align*} \]  
(23)

2-1. Losses comparison between conventional and proposed power converters

Particularly in low power sources such as Photovoltaic (PV) or Fuel Cells (FC) and other renewable energy sources it is important to increase efficiency of the converter as much as possible to transmit the input power to load. Power losses of the converter can be divided to: conductive, dynamic and fixed losses. The total power loss \( P_{\text{loss}} \) is given with the relation:
\[ P_{\text{loss}} = P_{\text{cond}} + P_{\text{fixed}} + W_{\text{TOT}} \cdot f_{\text{sw}} \]  
(24)

Where:
\( P_{\text{cond}} \) – conductive losses which are directly dependent on the load current and very little dependent on the switching frequency \( f_{\text{sw}} \),
\( P_{\text{fixed}} \) – fixed losses that are independent on the switching frequency and load,
\( W_{\text{TOT}} \) – the total energy of dynamic losses during one period (\( W_{\text{transistor}}, W_{\text{diode}}, W_{\text{core}} \)). Term \( W_{\text{TOT}} \cdot f_{\text{sw}} \) in relation (24) represents overall dynamics losses and is proportional to the switching frequency \( f_{\text{sw}} \) [17].
Table 1: Loss equations for both converters operating in CCM

<table>
<thead>
<tr>
<th>Name of elements</th>
<th>Type of loss</th>
<th>Conventional Cascade</th>
<th>Proposed Cascade</th>
</tr>
</thead>
<tbody>
<tr>
<td>Input inductor’s current</td>
<td>—</td>
<td>$I_{L1} = \frac{1}{(1-d_1) \cdot (1-d_2)} * \frac{V_{c1}}{R}$</td>
<td>$I_{L1} = \frac{1}{(1-d_1)^2} * \frac{V_{c1}}{R}$</td>
</tr>
<tr>
<td>Second inductor’s current</td>
<td>—</td>
<td>$I_{L2} = \frac{1}{(1-d_1) \cdot (1-d_2)} * \frac{V_{c1}}{R}$</td>
<td>$I_{L2} = \frac{1}{(1-d_1)} * \frac{V_{c1}}{R}$</td>
</tr>
<tr>
<td>First MOSFET</td>
<td>Conductive</td>
<td>$P_{conM1} = R_{dsM1} \cdot D_1 \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
<td>$P_{conM1} = R_{dsM1} \cdot D_1 \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
</tr>
<tr>
<td>Second MOSFET</td>
<td>Conductive</td>
<td>$P_{conM2} = R_{dsM2} \cdot D_2 \cdot (i_{L2}^2 + \frac{\Delta i_{L2}^2}{12})$</td>
<td>$P_{conM2} = 0$</td>
</tr>
<tr>
<td>First inductor</td>
<td>Conductive</td>
<td>$P_{L1} = R_{L1} \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
<td>$P_{L1} = R_{L1} \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
</tr>
<tr>
<td>Second inductor</td>
<td>Conductive</td>
<td>$P_{L2} = R_{L2} \cdot (i_{L2}^2 + \frac{\Delta i_{L2}^2}{12})$</td>
<td>$P_{L2} = R_{L2} \cdot (i_{L2}^2 + \frac{\Delta i_{L2}^2}{12})$</td>
</tr>
<tr>
<td>First MOSFET</td>
<td>Switching</td>
<td>$P_{swM1} = (w_{on1} + w_{off1}) \cdot f_s$</td>
<td>$P_{swM1} = (w_{on1} + w_{off1}) \cdot f_s$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$w_{off1} = 0.5i_{L1} \cdot V_{c1} \cdot t_{off1}$</td>
<td>$w_{off1} = 0.5i_{L1} \cdot V_{c1} \cdot t_{off1}$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$w_{on1} = 0.5i_{L1} \cdot V_{c1} \cdot t_{on1}$</td>
<td>$w_{on1} = 0.5i_{L1} \cdot V_{c1} \cdot t_{on1}$</td>
</tr>
<tr>
<td>Second MOSFET</td>
<td>Switching</td>
<td>$P_{swM2} = (w_{on2} + w_{off2}) \cdot f_s$</td>
<td>$P_{swM2} = 0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$w_{off2} = 0.5i_{L2} \cdot V_{c2} \cdot t_{off2}$</td>
<td>$w_{off2} = 0$</td>
</tr>
<tr>
<td></td>
<td></td>
<td>$w_{on2} = 0.5i_{L2} \cdot V_{c2} \cdot t_{on2}$</td>
<td>$w_{on2} = 0$</td>
</tr>
<tr>
<td>First Diode</td>
<td>Conductive</td>
<td>$P_{cond1} = V_{f1} \cdot i_{L1} \cdot D_1^i + R_{ond1} \cdot D_1^i \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
<td>$P_{cond1} = V_{f1} \cdot i_{L1} \cdot D_1^i + R_{ond1} \cdot D_1^i \cdot (i_{L1}^2 + \frac{\Delta i_{L1}^2}{12})$</td>
</tr>
<tr>
<td>Second Diode</td>
<td>Conductive</td>
<td>$P_{cond2} = V_{f2} \cdot i_{L2} \cdot D_2^i + R_{ond2} \cdot D_2^i \cdot (i_{L2}^2 + \frac{\Delta i_{L2}^2}{12})$</td>
<td>$P_{cond2} = V_{f2} \cdot i_{L2} \cdot D_2^i + R_{ond2} \cdot D_2^i \cdot (i_{L2}^2 + \frac{\Delta i_{L2}^2}{12})$</td>
</tr>
<tr>
<td>Third Diode</td>
<td>Conductive</td>
<td>$P_{cond3} = 0$</td>
<td>$P_{cond3} = 0$</td>
</tr>
<tr>
<td>First Diode</td>
<td>Switching</td>
<td>$P_{swD1} = V_{c1} \cdot Q_{rel1} \cdot f_s$</td>
<td>$P_{swD1} = V_{c1} \cdot Q_{rel1} \cdot f_s$</td>
</tr>
<tr>
<td>Second Diode</td>
<td>Switching</td>
<td>$P_{swD2} = V_{c2} \cdot Q_{rel2} \cdot f_s$</td>
<td>$P_{swD2} = V_{c2} \cdot Q_{rel2} \cdot f_s$</td>
</tr>
<tr>
<td>Third Diode</td>
<td>Switching</td>
<td>$P_{swD3} = 0$</td>
<td>$P_{swD3} = 0$</td>
</tr>
</tbody>
</table>

Because of the constant losses which depend on the nature of the circuit elements used in it, are negligible. Table 1 presents all elements losses including current equations of inductors:
2-2. Parameters of the conventional and proposed converters

To perform the designed circuit, simulation of the converter by CADENCE is used and a comparision between sigle block proposed and conventional converter has given. The used elements of circuits is given in Table 1.

Table 2: Converter's elements values table

<table>
<thead>
<tr>
<th>Proposed converter</th>
<th>Conventional converter</th>
</tr>
</thead>
<tbody>
<tr>
<td>$L_1 (mH) = 3$</td>
<td>$L_1 (mH) = 7$</td>
</tr>
<tr>
<td>$L_2 (mH) = 3$</td>
<td>$L_2 (mH) = 3$</td>
</tr>
<tr>
<td>$C_1 (\mu F) = 33$</td>
<td>$C_1 (\mu F) = 33$</td>
</tr>
<tr>
<td>$C_2 (\mu F) = 330$</td>
<td>$C_2 (\mu F) = 330$</td>
</tr>
<tr>
<td>$RL_1 (\Omega) = 0.3$</td>
<td>$RL_1 (\Omega) = 0.7$</td>
</tr>
<tr>
<td>$RL_2 (\Omega) = 0.3$</td>
<td>$RL_2 (\Omega) = 0.3$</td>
</tr>
<tr>
<td>$V_{in} (DC) = 30$</td>
<td>$V_{in} (DC) = 30$</td>
</tr>
<tr>
<td>$R (\Omega) = 450$</td>
<td>$R (\Omega) = 450$</td>
</tr>
<tr>
<td>$M_1$ Duty-cycle = 0.5</td>
<td>$M_1,2$ Duty-cycle = 0.5</td>
</tr>
<tr>
<td><strong>MOSFET</strong>: IRF150</td>
<td><strong>MOSFET</strong>: IRF150</td>
</tr>
<tr>
<td>Diode 1,2,3: MUR880</td>
<td>Diode 1,2: MUR880</td>
</tr>
<tr>
<td>Frequency (Hz) = 10000</td>
<td>Frequency (Hz) = 10000</td>
</tr>
</tbody>
</table>

Figure 6. A comparision between two structures output voltages and input inductor currents at $d = 0.5$ around 30W for output power
Figure 7 illustrates efficiency comparison between two structures according to different output power values and it shows that proposed structure is more efficient particularly at higher values of output power.

3. Proposed topology

Figure 8 shows proposed structure of our design. Using lower rated converters in parallel instead of a single, larger rated converter offers several advantages such as higher efficiency, better dynamic response, better load regulation, higher reliability, ease of maintenance, and smaller size energy storage devices. [15,16]. Two converters can be connected in parallel to form the parallel PFC scheme. To achieve both unity power factor and tight output voltage regulation, only the difference between the input power and output power needs to be processed twice. Therefore, high efficiency can be obtained by this method. Normally, boost converters are used as active Power factor correctors.
Some of the applications for connecting power modules in parallel include:

- To increase the Output Power capability on the supplying unit by connecting two or more converters in parallel.
- The use of multiple power modules distributes the thermal heat load over a larger board area.
- Higher power requirements can be achieved using lower power modules in parallel.

The main idea is to connect two or more cascade boost converter with PI controller and PWM modulator block parallely at input and output. Some advantages of this kind of connection are listed as below:

1. For example, with \( d = 0.35 \), by applying 18VDC in input, if we can get maximum 75VDC in output of a normal two stages cascade boost converter we can get around 150VDC from this new structure if series their outputs.
2. When we apply this structure input current will divide to two or more parts according to number of parallel blocks and it means the circuit long life will increase because of decreasing of current values in inductors.
3. This structure provides us a multi output circuit. for example with applying different duty cycles for every blocks separately we can get different values of voltages in output and if we need to Time-varying voltage in different timescales this structure can be useful. For this purposes we should series blocks outputs and apply different reference voltages and PI controllers for per block.
4. Any of the circuits when disrupted for any reason, at least one circuit will be in continuing to transfer input power to output.
5. Output voltage ripple is less than 0.1%.
6. Input current ripple is acceptable and under the 5%.

As we pointed above, this is one of the circuit characteristics, the output voltage can work in a flexible way to generate different voltages by applying different reference voltages with serial output structure. Following the results of the simulation in Simulink environment confirms this topic. the reference voltage change to 30VDC, 50VDC and 70VDC and then output value in alternating order was appropriate 60VDC, 100VDC and 140VDC. It has shown in Figure 9.
4. Simulation results for parallel connections

One of the features of the boost converter circuit is no change in output voltage with fast load or input voltage values changes. Simulations were performed when the load was from $R = 450\Omega$ with input voltages from $V_{in} = 15$ to $V_{in} = 45VDC$ and has obtained average voltage of 50VDC in output with a 2% ripple for our proposed structure. According to efficiency evaluation of two structures, we obtained the curve of Figure 10 for different values of output powers.

![Figure 10. Efficiency comparison between parallel proposed and parallel conventional boost converters according to output power](image)

5. Experimental results

To evaluate performance of the proposed structure and accuracy of the theoretical analysis, a 60 W laboratory prototype is implemented. In first step, we tested the structure without PI controller and PWM modulator according to Table 3 and has given around 110VDC as output voltage and finally the proposed structure has compared with different values of voltages from 15VDC till 30VDC as input source. This test has been done with PI controller block to fix output voltage to 120VDC. Figure 12. a, b and c has shows output voltage at different input voltages and duty cycle of pulses generated by PIC18F2550
microcontroller according to changes in load and input voltage source values as explained in section 1 for implementation to MOSFETs gate pins. As it illustrates, for higher values of input voltages, duty cycle is being shorter. Table 3 shows all parameters values have used in circuit.

<table>
<thead>
<tr>
<th>Table 3: Main parameters of the implemented prototype</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Proposed converter</strong></td>
</tr>
<tr>
<td>$L_1 (mH) = 3$</td>
</tr>
<tr>
<td>$L_2 (mH) = 3$</td>
</tr>
<tr>
<td>$C_1(\mu F) = 33/100VDC$</td>
</tr>
<tr>
<td>$C_2(\mu F) = 330/400VDC$</td>
</tr>
<tr>
<td>$IGBT, 1,2: IRFP450$</td>
</tr>
<tr>
<td>$Diode, 1−6: MUR880$</td>
</tr>
<tr>
<td>$V_{in}(DC) = 30VDC$</td>
</tr>
<tr>
<td>$R(\Omega) = 450$</td>
</tr>
<tr>
<td>$V_o(DC) = 120VDC$</td>
</tr>
<tr>
<td>$M_1, Duty, Duty−cycle = 0.5$</td>
</tr>
<tr>
<td><strong>Conventional converter</strong></td>
</tr>
<tr>
<td>$L_1 (mH) = 7$</td>
</tr>
<tr>
<td>$L_2 (mH) = 3$</td>
</tr>
<tr>
<td>$C_1(\mu F) = 33/100VDC$</td>
</tr>
<tr>
<td>$C_2(\mu F) = 330/400VDC$</td>
</tr>
<tr>
<td>$IGBT, 1−4: IRFP450$</td>
</tr>
<tr>
<td>$Diode, 1−4: MUR880$</td>
</tr>
<tr>
<td>$V_{in}(DC) = 30VDC$</td>
</tr>
<tr>
<td>$R(\Omega) = 450$</td>
</tr>
<tr>
<td>$V_o(DC) = 120VDC$</td>
</tr>
<tr>
<td>$M_{1,2}, Duty−cycle = 0.5$</td>
</tr>
<tr>
<td><strong>Frequency (Hz) = 10000</strong></td>
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</tbody>
</table>

Figure 12. Generated output voltage (120VDC) and MOSFET switching pulses, (a) Input voltage = 15VDC, (b) Input voltage = 20VDC, Input voltage = 25VDC
Figure 13 shows pulses which generate by PIC for different values of input voltages and shows same duty cycle for two MOSFETs and shows different duty cycles for various values of input voltage. For applying the output voltage to PIC and compare with reference voltage, we simply used 2 serial resistances to sense and sample output voltage and connected it to PIC microcontroller. Figures 14 shows drain - source and gate - source voltages of MOSFETs and input inductor current and voltage respectively. Fig 15 shows proposed structure in parallel condition efficiency curve according to output power in comparison with conventional Boost converters.

Figure 13. Pulses generated by PIC to implement to IGBTs gates with different duty cycles, (a) Input voltage = 25VDC , (b) Input voltage = 15VDC

Figure 14. (a) Drain - source and gate - source voltages of MOSFETs, (b) Current and Voltage waveforms of input inductor
6. Conclusion

This paper is modeling a new structure for cascade DC DC boost converters by nonlinear PI control technique. It can expand to more than two controllers according to number of parallel structures. Simulation results has obtained in Matlab/SIMULINK and CADENCE and confirming theoretical designing. This technique is suitable for all low voltage and high voltage gain applications. Also it has all specifications of a good boost converter as no changing ability according to sudden changes in output loads or input voltages. Because of the power switch presence and switching, at the circuit start time we can have inrush current problem as it is a common problem in all kind of converters. There are many structures to limit and eliminate this problem by applying inrush current limiter circuits between input voltage source and circuit. We used from a relay and high power resistance for this purpose. At the start time input current passes from normally closed contact of relay and high power resistance and after a while current pass from normally closed contact and crosses to circuit. As mentioned above, one of advantages of this circuit is that's long life in comparison with normal boost converters because of smaller current values in inductors and all of circuit elements.

References