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FULL SOFT-SWITCHING HIGH STEP-UP CASCADED BOOST CONVERTER WITH THREE-WINDING COUPLED-INDUCTOR

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ABSTRACT

The importance of transformers is highlighted in many applications, including industrial applications and renewable energies. Among the types that can be highlighted are a series soft-switching transformer with a voltage multiplier in addition to a double-threaded inductor. The series transformer is considered better than a regular transformer as it is possible to achieve a voltage gain greater than Ordinary transformers. Tests can also be performed using electronic switches in addition to a coupled inductor in the process of building a model of a cascade DC/DC converter. The results of the proposed simulation and tests are being verified to show the increase in gain due to the effect of a double-type, three-coil inductor. Tests were conducted using the ORCAD program by proposing an electronic power transformer to raise the voltage from 24 V to the input voltage. Work is underway to verify the possibility of raising the voltage to 200 V. Some electronic elements are added to the transformer to assist in the process of distributing voltages and branching currents. The passive elements include the coil and the capacitor, as well as the presence of the basic and active elements such as the diode and the transistor. All problems of electronic transformers can be overcome as a result of changing operating conditions with time and the occurrence of any disturbances such as lost energy during opening and closing. Electronic keys in addition to the problem of reverse recovery. Therefore, the effectiveness of the proposed circuit can be investigated to provide the required gain to represent a higher voltage than the low input voltage with a relatively high efficiency. The current study also discussed the behavior analysis of the proposed system to include the steady state, justifying the theoretical analysis and design considerations in detail.

KEYWORDS

full soft switching; high step-up DC-DC cascaded boost converter; three-winding coupled inductor; voltage multiplier (VM); zero current switching (ZCS).

1. INTRODUCTION

Developments in the field of modern technology include applications in various fields, including transformers. Transformers according to modern technologies include electronic power transformers using electronic power devices such as diodes, transistors, thyristors, and MOSFET. Transformers are classified into step-up transformers and step-down transformers, and there is a third type called step-down transformers.

Studies have shown that using a step-up converter can obtain a gain in the value of the Voutput of the converter compared to other converters' Vinput of traditional converters, as these converters are distinguished by their simple composition and structure. It is possible to obtain a double gain by using more than one amplification stage, but the problem of power loss will appear as a result of closing and opening the switches of the MOSFET. (Liu et al., 2016) to solve this problem using a single switch to obtain a high voltage surge. A description of the traditional cascade transformer or step-up converter can be constructed consisting of a coupled inductor, a diode, and a capacitor for charging and discharging with the output resistance, and thus it obtains a higher voltage gain while addressing the problem of stress and pressure that causes it during open operation. Some techniques are used to increase the efficiency in the cascade converter such as voltage lift, Voltage Multipliers, Switched Capacitors, and Switched Inductors, which are used in the traditional step-upconverters, but these suffer from the problem of difficulty switching within turn-on and off (Lee et al., 2018, Forouzesh et al., 2017, Hosseini et al., 2012- zhao et al., 2003).

DC-DC converters obtain the necessary voltage level from the photovoltaic (PV) system. One of the challenges of DC-DC converters is determining the optimum converter because it impacts the behavior of the PV system. This research reviews several step-up converters that have been presented in the literature recently. It also analyzes and compares various converter topologies in various situations, including conventional boost converter (CBC) (Abdul et al., 2022).

Although DC-to-DC converters might be considered the most widely used circuits in power electronics, where a specific DC output voltage must be stabilized to a specific desired level (Hadi, et al., 2024).

Voltage step-up transformers were designed using a new technology, namely, double inductors consisting of two coils (primary and secondary). They have become commonly used and important in power electronics applications because they achieve high voltage gains. By specifying the number of windings turns for the inductors while connecting the active-passive clamp networks, the problem was overcome. Leakage inductance during circuit operation (hu et al., 2020- Hasan pour et al., 2020).

To solve this problem, a new topology of a no-isolated boost converter with zero-voltage-switching to achieve ZVS conditions in this circuit used a coupled inductor (CI), a diode that operates with a zero current-switching ZCS and ZVS condition, from that can the reverse recovery problem of MOSFET antiparallel diodes can be resolved, and the voltage and also reduced the current stresses on the switch (Zhang et al., 2013).

In (Xian et al., 2019- he et al., 2018-Hassan et al., 2019- Nardi et al., 2017- Pourjafar et al., 2019), Step-up converters can include step-up converters that step up the output voltage using a single-switch step-up, CI-based step-up converter presented in VMs, three-winding-coupled-inductor and an output capacitor in series. The first is the single switch, this type is linked to regenerative negative clamp circuits. The second type is linked to step-up based on a type of voltage rectifier that increases as a result of the soft switching process. The other is based on double inductors, through which the required and appropriate performance can be obtained, in addition to the possibility of achieving the highest gain by using three-winding. By operating the switches in an effective switching method to solve the problem of reverse recovery occurring in the valves, relying on the leakage inductor, which leads to raising efficiency improving performance, and saving energy, capacitors are placed in series with the output. It is worth noting that there are coils connected from the source side that can be charged during repeated cycles, which saves Gain during the converter duty cycle.

In (Deng et al., 2012- Babu et al., 2020), in this type of converter quasi-resonant performance is obtained, which in turn helps to mitigate losses and reduce the pressure on the switch significantly, as a soft switching condition occurs. In (Hasanpour et al., 2020), another type of converter is used, called quasi-quadratic. Its characteristic gives a very high gain, but it uses two switches for operation with a hard switching condition and this is considered one of the disadvantages of these types of converters.

In (khalilzadeh et al., 2015- eskandarpour et al., 2020) a new type of converter is presented. It is possible to obtain a high voltage gain with an appropriate duty cycle by adjusting the rotation ratios of the secondary and tertiary windings of the converter. However, one of the disadvantages of this transformer is the occurrence of high ripple in the input current due to connecting these windings to the input source DC. Another type of converter has been proposed to solve this problem, it is based on three-step-up converters (3WCI), which makes the input current continuous and at the same time gives a high voltage gain, as in (moradpour et al., 2021 -farakhor et al., 2020- radmanesh et al., 2021). To improve the performance of these transformers, a negative clamp circuit is connected, as it reduces the recovery loss. Reverse by recycling (3WCI), but one of the disadvantages of these transformers is the limited voltage gain at low rotation ratios, (Hasanpour et al., 2021) These converters were improved by using an inductor with the addition of a voltage multiplier (3WCI) and a clamp circuit where the stress condition is treated via operating switches, and to obtaining zero-current- switching. (3WCI) Based on the quasi-resonance occurring between the leakage inductor and the intermediate capacitors, which are connected in series with the inductors.

Work is underway to verify the cases based on the simulation model, it has been proposed to operate the system according to conditions suitable for the electronic switch using the Z is technology, in addition to the leakage inductance and testing the performance of a tank by adopting an auxiliary capacitor and providing resonant storage with the switch turned off due to this effect of the reduced current value during the shutdown to solve the problem of reverse recovery for all diodes, as they deal with power losses during the process of switching electronic switches. The research was organized on a theoretical basis to know the step-up transformer, test the operating conditions through the mathematical representation of the transformer, build a model with suggested specifications that suit some real-time applications, conduct simulations of the proposed tests, and analyze the simulation results. The behavior of the system is in the transient and stable state. It is possible to develop a suitable design for a transformer and conduct preliminary tests of the model by adopting the computer system or the computer and some of the system behaviors are verified to reach the goals and some appropriate conclusions.

2. ANALYSES AND DESCRIPTION OF THE SYSTEM FOR 3WCI

In this section, many parts are included in this circuit, the first is the input side, the second is the boost converter, and the third side is for load.

1-The input side contains the DC power source, DC macro grid, PV, and the input inductor L_{inp}.

2-The second side contains:

- A boost converter using a single-stage structure for conventional cascaded with a common switch that is shown in Fig. 1. (Lee et al., 2018) D_1, D_2, C_3,

Three-Winding Coupled-Inductor 3WCI shown in Fig. 2. (Hasanpour et al., 2021), the primary windings, secondary, and third L_1, L_2, L_3.

- C_1, C_2, C_{clamp} with diodes D_3, and D_4 in the form of VMs, as the passive clam C_{clamp}, D_{clamp}.

- Other compounds of the circuit: L_S, L_4, C_4.

3-The third side contains load C_{out}, D_{out}, and the resistance R_0, Fig. 3. shows the proposed circuit, and three-winding-coupled (3WCI).

The analysis of all the stages in the circuit works in the condition of Continuous Conduction

Mode (CCM). The currents of the parameters S_{switch} and the diodes D_3, and D_{out} vary like the shape of sinusoidal waves, due to the Quasi-Resonance (QR) operation between the inductor L_{K1} of the 3WCI and the capacitors, C_1, and C_{clamp}. The 3WCI is considered a perfect transformer with a parallel magnetizing inductor L_{M1} and a series leakage inductor L_{K1}, from the primary, secondary, and tertiary with the turn ratios of:

$(n_{21} = N_2/N_1)$

$(n_{31} = N_3/N_1)$

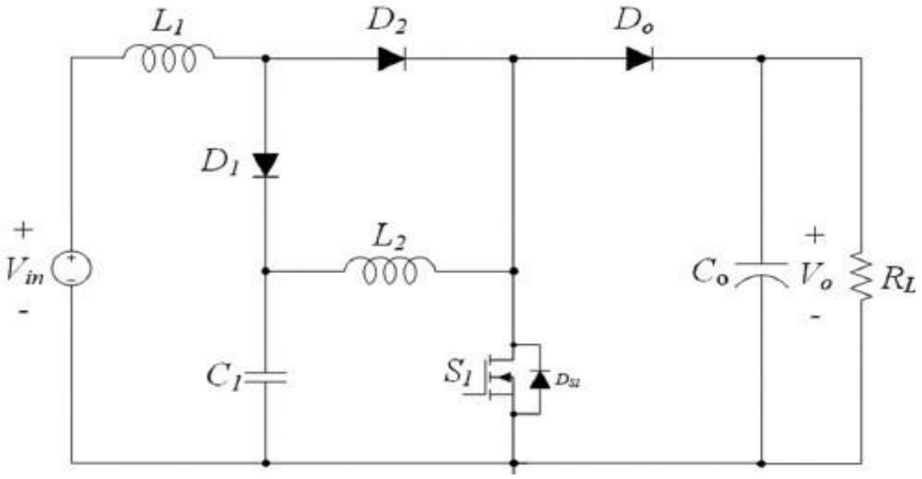


Fig. 1. Boost converter using a common switch. (Lee et al., 2018)

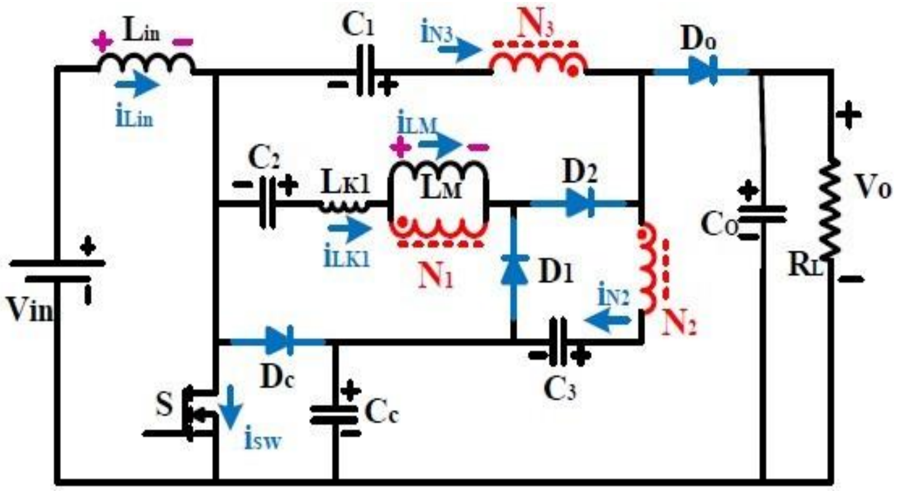


Fig. 2. Converter Based on 3WCI. (Hasanpour et al., 2021)

3. THE PRINCIPAL OPERATING STAGES

there are seven stages to the soft-switched boost converter are explained, the key waveforms are shown in Fig. 4, and the equivalent circuits for each operating stage are shown in Fig. 5.

Stage 1: from [t_0 to t_1]: at $t= t_0$, the S_{switch} is on at ZCS condition, diode D_2 is forward-biased, diode D_l is reverse-biased, at the turn-on instant, the leakage in the inductance which happens of the 3WCI will be removed *di/dt* in the MOSFET, in this period all the diodes are reverse-biased only the Diode D_4 is forward-biased. The inductor of the input L_{inp} begins to be charged by V_{inp}. The capacitors C_{clamp} and C_2 took the energy from i_{L2} of the 3WCI. That is because the current i_{LK1} and i_{L3} are positive, and the two capacitors C_1 and C_4 are discharging the energy. In the time transition, the current of L_{K1} will decline linearly, also, the current of the L_{M1}, the leakage inductor of the first part of the 3WCI leads to a decline current slope through D_4. When time at ($t = t_1$), it can be seen the current of the D_4 arrives at zero in the Zero Current Switching Condition, and recovery loss is e minimum.

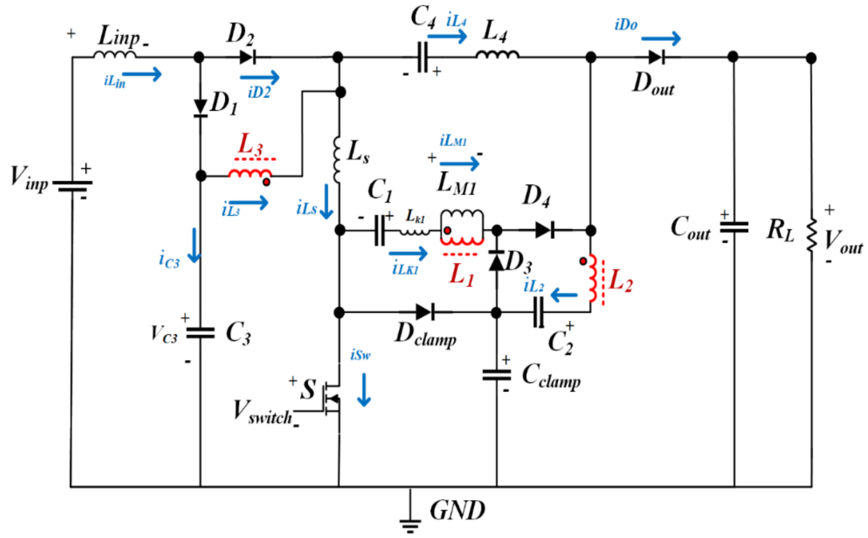


Fig. 3. The Proposed Cascaded Boost Converter with Three-Winding Coupled.

Stage 2: from [t1 to t 2]:, the Sswitch remains on, under the effect of ZCS conditions the D3 begins to turn on, and Dout is still off The iLinp takes energy from Vinput, because the voltage applied to the magnetic inductor (VC1 - VCclamp), is positive, the current of the iLinp rises linearly with a positive slope. In this stage, the leakage inductor of LK1 and the capacitor Cclamp will form a resonant tank, the capacitor C1 appears in the form of QR and discharges the energy of the capacitor Cclamp. This QR performance will change the waveform of the current switch, diode D3, also the leakage inductor will change into a quasi-sinusoidal current, in this stage, the current of Dout will be still zero.

Stage 3: from [t2 to t 3]: the stage starts when the current of the Dout turns on. The values of the current of the secondary winding and tertiary winding of the 3WCI will match. Capacitors C3 and C1 are charged by the primary and tertiary sides current of the coupled inductor. The current of output diode Dout will take the shape of sinusoidal, and the problem of the losses and reverse recovery disappears. Also, the energy stored in capacitors Cclamp and C2 is discharged, and the output capacitor Cout takes this energy from two capacitors Cclamp and C2. In this state, the current of iLinp is magnetized by the Vinp. Because the positive voltage is applied to the magnetizing inductor (VC1 - VCclamp), the current starts to rise slopingly. The inductors Linp and LM1 are also charged in the operating of stage 2, the current of Sswitch will decrease and that will reduce operating losses.

Due to the QR, the diode Dout current will reach zero under the effects of the condition ZCS. By using Kirchhoff's Voltage Law and assuming the voltage of the magnetizing inductor LM1 is constant, it can calculate resonant frequency fR from the equation:

$$f_R = \frac{1}{T_R} = \frac{1}{2\pi\sqrt{L_{K1}\left[C_1 \| \frac{C_{clamp}}{2+\frac{1+n_{21}}{n_{31}-n_{21}}}\right]}} \quad (1)$$

From the stage, it can see these equations below:

$$\mathrm{V_{Linp}} = \mathrm{V_{inp}} - (\mathrm{V_{L3}} + \mathrm{V_{C3}}) \quad (2)$$

$$\mathrm{V_{LM1}} = \mathrm{V_{c1}} - \mathrm{V_{C_{clamp}}} \quad (3)$$

$$\mathrm{V_{LM1}} = \frac{\mathrm{V_{C2}}+\mathrm{V_{C1}}-\mathrm{V_{C4}}}{1-\mathrm{n_{21}}+\mathrm{n_{31}}} \quad (4)$$

$$\mathrm{V_{LM1}} = \frac{\mathrm{V_{out}}-\mathrm{V_{c4}}}{\mathrm{n_{31}}} \quad (5)$$

$$\mathrm{V_{out}} = \mathrm{V_{Cc}} + \mathrm{V_{C2}}+\mathrm{n_{21}}\mathrm{V_{LM1}} \quad (6)$$

$$\mathrm{V_{out}} = \mathrm{V_{C1}}+\mathrm{n_{31}}\mathrm{V_{LM1}} \quad (7)$$

The current of the switch can calculated from the equation:

$$i_{switch} = (i_{inp} - i_{C3}) - i_{LK1} - I_{L4} \quad (8)$$

The iL3, is the current of the tertiary inductor of the coupled inductor. Before the stage ends, the current of the diode Dout decreases and becomes zero at the ZCS condition.

Stage 4: from [t3 to t 4]: the power Sswitch stays on, and theD3 is on, the current of Dout is still zero, it can be noted that the currents of iL1 and iLM1 of the 3WCI are matched, and the capacitor C4 takes the energy from the capacitors Cclamp and C2, the equation of the current of i_{switch} as below:

$$i_{switch} = \left(i_{inp} - i_{L3}\right) + \frac{i_{LM1}}{n_{31}-n_{21}} \quad (9)$$

Stage 5: from [t4 to t 5]: at t = t4, the Sswitch is turned off, and at the same time the diode Dclamp is conducted, the current of the diode D4 still turns off because existence of the leakage inductor. The effect of the performance and operation of the clamp capacitor Cclamp will reduce the voltage surge on the operating switch, thus reducing

the stress and pressure on the switch. Also, the capacitor C3 begins to charge from the energy stored in the magnetizing inductor and capacitors C1 and C2, and the capacitor Cclamp takes energies from the input inductor current. The iLinp and iLM1 decline linearly, which can be noted in the following equations:

$$V_{Linp} = V_{inp} - \left(V_{Ls} + V_{Cclamp}\right) \quad (10)$$

$$V_{Linp} = V_{inp} - V_{L3} \quad (11)$$

$$V_{LM1} = \frac{V_{c1}-V_{c2}}{1+n_{21}} \quad (12)$$

$$V_M = \frac{V_{C1}-V_{c3}}{1+n_{31}} \quad (13)$$

Stage 6: from [t5 to t 6]: at, t = t5, in this stage, the clamp diode Dclamp stays on, and the D4 turns on. It can be seen the energy stored in the Linp is moving around both of the capacitors Cclamp and C2.

Stage 7: from [t6 to t 7]: this stage begins when the current of Dclamp becomes zero, this happens at the ZCS, and reverse recovery is decreased.

The current of D4 remains on, in this stage both the current of Linp and the iL3 of the 3WCI are identical, it can write the equation as:

$$V_{LM1} = \frac{V_{C1}-V_{c4}}{1+n_{31}} \quad (14)$$

3.1. ANALYSIS PROCEDURES FOR THE CONVERTER WHEN IT IS IN THE STEADY STATE

3.1.1. THE GAIN OF VOLTAGE

To calculate the voltage of the parameters, the volt-second balance law is applied to Linp, the average value of capacitor Cclamp from this equation:

$$V_{Cclamp} = \frac{V_{inp}}{1-Dy} \quad (15)$$

D_y is the duty cycle of S_{switch}. By using The Volt-Second Balance within the magnetizing inductor L_{M1}, the equation between the voltage C_4 and the C_1 can be taken from the equations:

$$(1 - D_y)n_{31}V_{C1} - V_{C4}(D_y + n_{31}) = -V_{out}D_y(1 + n_{31}) \quad (16)$$

from (3), (16), and (5), the voltage of C_4 is obtained:

$$V_{C4} = \frac{V_{out}(1 + D_y\, n_{31}) + n_{31}(1-D_y).V_{Cclamp}}{1+n_{31}} \quad (17)$$

from (16) and (17), it can calculate the V_{C1} from the equation:

$$V_{C1} = \frac{-D_y V_{out}(1 + n_{31}) + V_{C4}(1+D_y)}{n_{31}(1-D_y)} \quad (18)$$

About the operating stage 3, take the equations (3) and (6), it can obtain the voltage C_3:

$$V_{C3} = V_{out} + V_{Cclamp}.(n_{21} - 1) - n_{21}.V_{C1} \quad (19)$$

from (3), (4), (12), (13), and (7), (6), the voltage of all gain of the converter in the condition of CCM is calculated:

$$\mathrm{M} = \frac{\mathrm{V_{out}}}{\mathrm{V_{inp}}} = \mathrm{G_1}.\frac{1}{(1-\mathrm{D_y})} \quad (20)$$

the parameter G_1 is known:

$$G_1 = \frac{1+n_{31}+Y}{Y} \tag{21}$$

the parameter Y is known:

$$\mathbf{Y} = \boldsymbol{n_{31-}n_{21}} \tag{22}$$

From (20), The voltage gain ratio as equation of *Dy*, duty cycle, and many values of n_{31}, Y is expressed, the gain ratio will increase by selecting the suitable three elements including n_{31}, Y, and *Dy*. It is getting more by increasing *Dy*, n_{31}, and reducing the parameter Y, by selecting Y, it can obtain a higher voltage gain at a lower winding turns ratio [n_{21} +n_{31}]. Table 1. shows the different values of the parameters Y, n_{21}, and, n_{31} to achieve the suitable voltage gain, when choosing low values for Y, with lower turns of the 3WCI, Fig.6. shows the value of voltage gains with a duty cycle D_y.

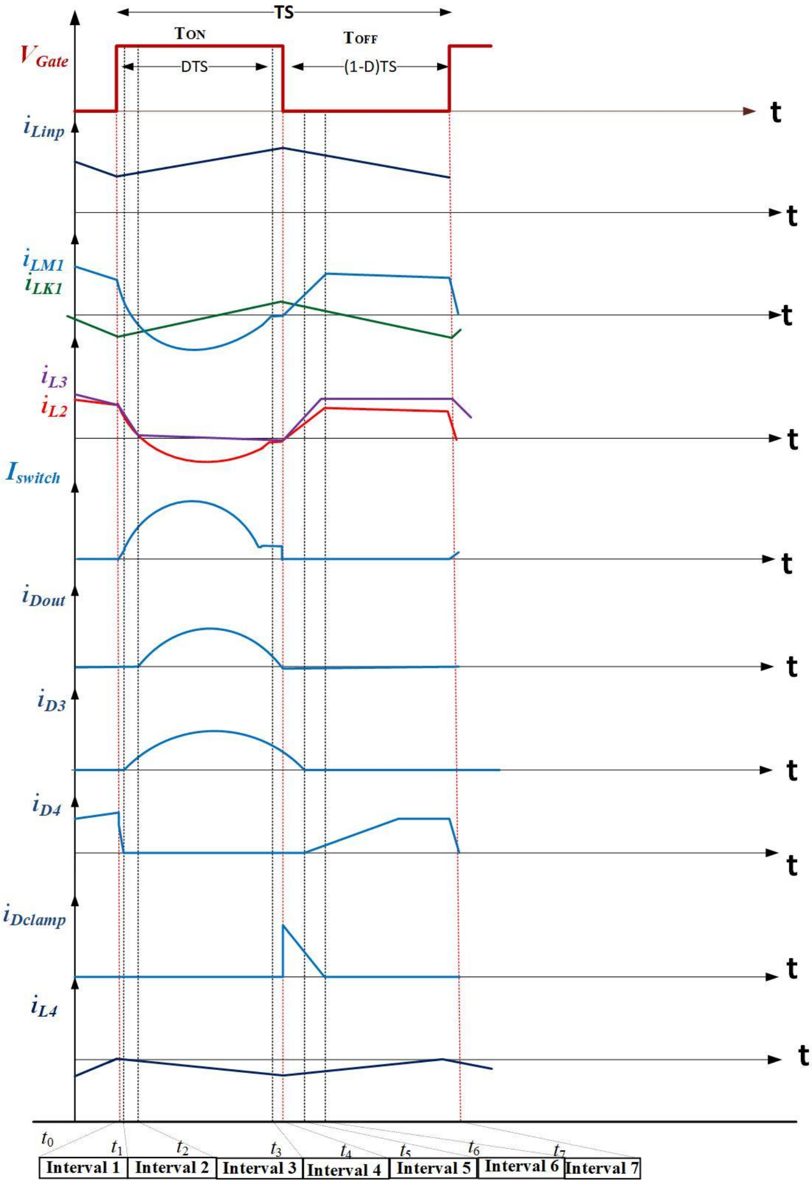
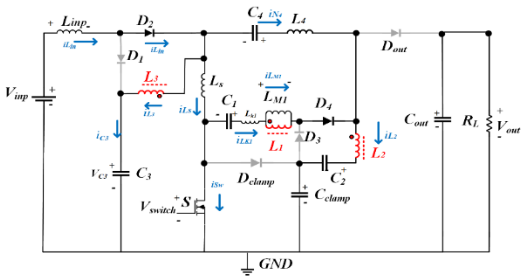
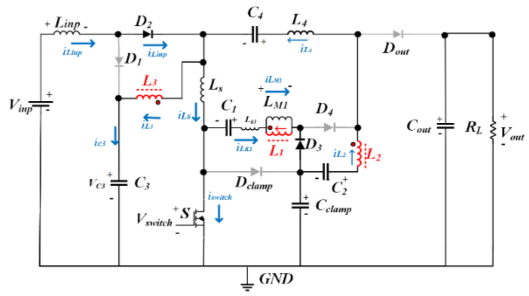


Fig. 4. Key Waveforms for a Switching Period



Mode1



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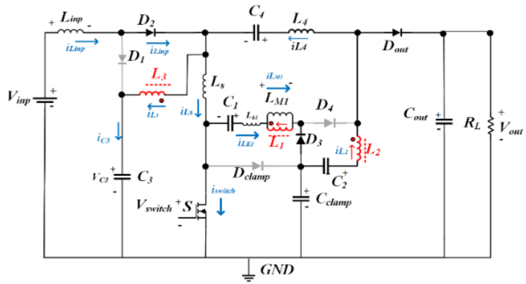

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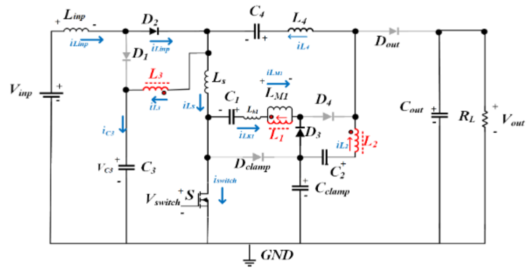

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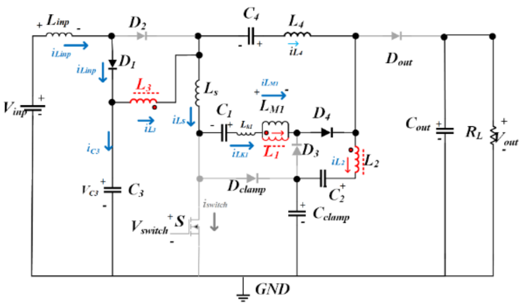
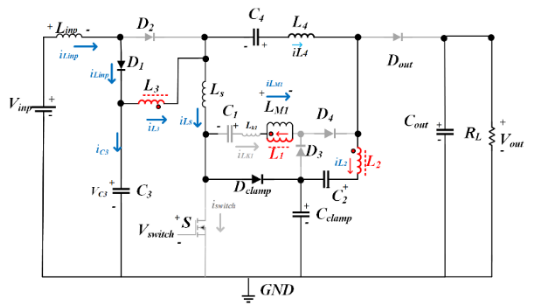
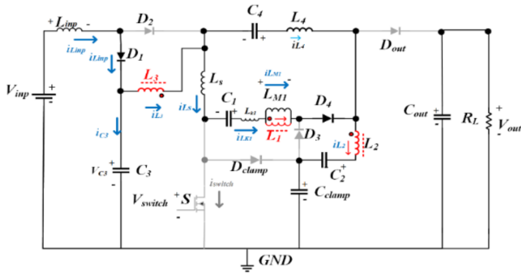


Mode5



Mode6



Mode7

Fig. 5. Equivalent circuit of each operation mode

Table 1. Variable Values of Dy, n31 with Y to calculate Gain.

Test no.	Dy	Y	n31	n21	G_1	M
1	0	0.625	1.5	0.875	5	5
2	0.1	0.55	1.2	0.65	5	5.556
3	0.2	0.5	1	0.5	5	6.25
4	0.3	0.475	0.9	0.425	5	7.143
5	0.4	0.455	0.91	0.455	5.198	8.66
6	0.53	0.447	0.827	0.38	5.087	10.824
7	0.6	0.2	0.5	0.3	8.5	21.25
8	0.7	0.12	0.35	0.23	12.25	40
9	0.8	0.11	0.322	0.212	13.018	65.091
10	0.9	0.1	0.3	0.2	14	140

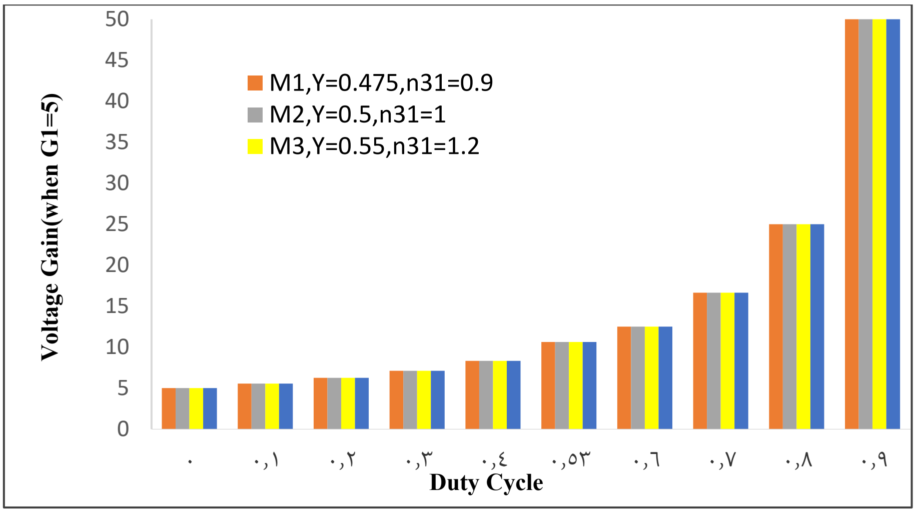


Fig. 6. The value of voltage gains with a duty cycle, Variable Values of n31, and Y.

Table 2 and Fig.7 show the value of voltage gains with a duty cycle Dy when n31 is variable and, Y is constant, also Table 3. and Fig.8 show the value of voltage gains with a duty cycle Dy, when Y is variable and n31 is constant.

Table 2. (a) when n31=0.7, (b) n31=0.9, (c) n31=1.1, (d) n31=1.3

Dy	Y	$n31$	$n21$	G_1	M
0	0.55	0.7	0.15	4.091	4.091
0.1	0.55	0.7	0.15	4.091	4.545
0.2	0.55	0.7	0.15	4.091	5.114
0.3	0.55	0.7	0.15	4.091	5.844
0.4	0.55	0.7	0.15	4.091	6.818
0.53	0.55	0.7	0.15	4.091	8.181
0.6	0.55	0.7	0.15	4.091	10.227
0.7	0.55	0.7	0.15	4.091	13.636
0.8	0.55	0.7	0.15	4.091	20.455
0.9	0.55	0.7	0.15	4.091	40.91

(a)

Dy	Y	$n31$	$n21$	G_1	M
0	0.55	0.9	0.35	4.455	4.46
0.1	0.55	0.9	0.35	4.455	4.95
0.2	0.55	0.9	0.35	4.455	5.57
0.3	0.55	0.9	0.35	4.455	6.36
0.4	0.55	0.9	0.35	4.455	7.42
0.5	0.55	0.9	0.35	4.455	8.91
0.6	0.55	0.9	0.35	4.455	11.14
0.7	0.55	0.9	0.35	4.455	14.85
0.8	0.55	0.9	0.35	4.455	22.27
0.9	0.55	0.9	0.35	4.455	44.55

(b)

Dy	Y	$n31$	$n21$	G_1	M
0	0.55	1.1	0.55	4.818	4.82
0.1	0.55	1.1	0.55	4.818	5.35
0.2	0.55	1.1	0.55	4.818	6.023
0.3	0.55	1.1	0.55	4.818	6.88
0.4	0.55	1.1	0.55	4.818	8.03
0.5	0.55	1.1	0.55	4.818	9.64
0.6	0.55	1.1	0.55	4.818	12.05
0.7	0.55	1.1	0.55	4.818	16.06
0.8	0.55	1.1	0.55	4.818	24.09
0.9	0.55	1.1	0.55	4.818	48.18

(c)

Dy	Y	$n31$	$n21$	G_1	M
0	0.55	1.3	0.75	5.182	5.18
0.1	0.55	1.3	0.75	5.182	5.76
0.2	0.55	1.3	0.75	5.182	6.48
0.3	0.55	1.3	0.75	5.182	7.40
0.4	0.55	1.3	0.75	5.182	8.64
0.5	0.55	1.3	0.75	5.182	10.37
0.6	0.55	1.3	0.75	5.182	12.96
0.7	0.55	1.3	0.75	5.182	17.27
0.8	0.55	1.3	0.75	5.182	25.91
0.9	0.55	1.3	0.75	5.182	51.82

(d)

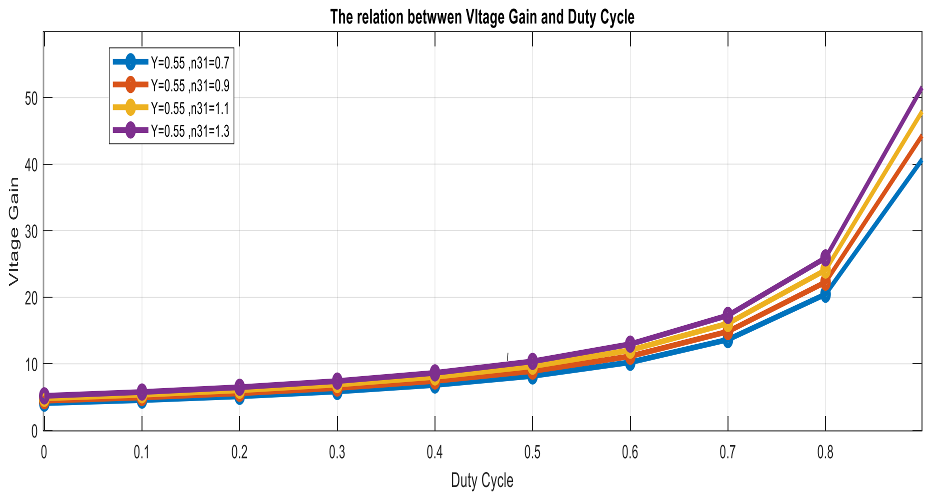


Fig. 7. The value of voltage gains with a duty cycle when n31 is variable and, Y is constant.

Table 3. (a) when Y=0.3, (b) Y=0.4, (c) Y=0.5, (d) Y=0.6

Dy	Y	$n31$	$n21$	G_1	M
0	0.3	1	0.7	7.667	7.67
0.1	0.3	1	0.7	7.667	8.52
0.2	0.3	1	0.7	7.667	9.58
0.3	0.3	1	0.7	7.667	10.95
0.4	0.3	1	0.7	7.667	12.78
0.53	0.3	1	0.7	7.667	16.31
0.6	0.3	1	0.7	7.667	19.168
0.7	0.3	1	0.7	7.667	25.56
0.8	0.3	1	0.7	7.667	38.34
0	0.3	1	0.7	7.667	7.67

(a)

Dy	Y	$n31$	$n21$	G_1	M
0	0.4	1	0.6	6	6
0.1	0.4	1	0.6	6	6.67
0.2	0.4	1	0.6	6	7.5
0.3	0.4	1	0.6	6	8.57
0.4	0.4	1	0.6	6	10
0.53	0.4	1	0.6	6	12.77
0.6	0.4	1	0.6	6	15
0.7	0.4	1	0.6	6	20
0.8	0.4	1	0.6	6	30
0.9	0.4	1	0.6	6	60

(b)

Dy	Y	$n31$	$n21$	G_1	M
0	0.5	1	0.5	5	5
0.1	0.5	1	0.5	5	5.556
0.2	0.5	1	0.5	5	6.25
0.3	0.5	1	0.5	5	7.143
0.4	0.5	1	0.5	5	8.33
0.53	0.5	1	0.5	5	10.638
0.6	0.5	1	0.5	5	12.5
0.7	0.5	1	0.5	5	16.667
0.8	0.5	1	0.5	5	25
0.9	0.5	1	0.5	5	50

(c)

Dy	Y	$n31$	$n21$	G_1	M
0	0.6	1	0.4	4.333	4.333
0.1	0.6	1	0.4	4.333	4.8144
0.2	0.6	1	0.4	4.333	5.416
0.3	0.6	1	0.4	4.333	6.19
0.4	0.6	1	0.4	4.333	7.2217
0.53	0.6	1	0.4	4.333	9.219
0.6	0.6	1	0.4	4.333	10.8325
0.7	0.6	1	0.4	4.333	14.443
0.8	0.6	1	0.4	4.333	21.665
0.9	0.6	1	0.4	4.333	43.33

(d)

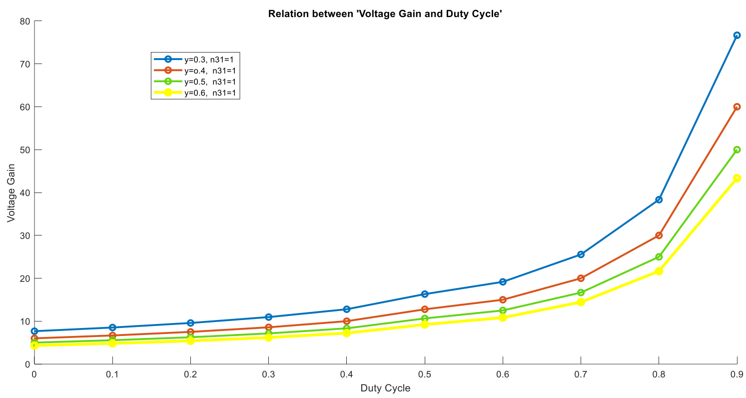


Fig. 8 The value of voltage gains with a duty cycle when Y is variable and n_{31} is constant.

3.1.2. DESIGN OF IMPORTANT ITEMS

a. DUTY CYCLE

The values of the basic parameters, which include D_y, n31, and Y, affect the performance of the proposal converter and, therefore, the least stress that occurs on the switch current at a value. D_y between (0.4-0.7) (Hasanpour et al., 2021), and obtain a high voltage gain, the smallest value of Y was chosen, at a lower turn ratio. It can be seen in Table 1 that any change in or increase in the value of Y will lead to a change in the D3, and an increase in it will occur.

b. DESIGN OF THE INPUT INDUCTOR AND MAGNETIZING

When designing L_{inp}, it must consider how to restrict the fluctuations that occur in the input current, at (CCM)condition the equation is calculated to obtain the required value. (Hasanpour et al., 2021):

$$L_{inp} = \frac{V_{inp}.D_y}{\Delta I_{inp}.f_{Sw}} \tag{23}$$

Where ΔI inp, the value of the ripple current represents the permissible ripple current, and the f_{Sw} switching frequency, the design of the magnetizing inductor of the 3WCI can be obtained from:

$$L_{inp} > \frac{V_{inp}.D_y}{\Delta I_{LM1}.f_{Sw}} \tag{24}$$

Whereas ΔI_{LM1} represents the best ripple that occurs in the current, and if a very small value is used for the ripple, it will lead to an increase in the value of I_{LM1}, and this will lead to an increase in conduction loss.

b. CAPACITORS SELECTION

We can calculate the output capacity mathematically, and design the appropriate value that works to reduce or eliminate the ripple that happens in the V_{out}, as in the equation below: (Hasanpour et al., 2021).

$$C_{out} = \frac{D_y V_{out}}{R_L.\Delta V_{Cout}.f_{SW}} \quad (25)$$

ΔV_{Cout} is allowed the highest value, the suitable value for which voltage ripple is 1 % of the output DC voltage. The values of the capacitors C_3, C_1, C_2, C_{clamp} can be calculated from the equations:

$$C_3 = \frac{i_{L3}.(1-D_y)}{\Delta V_{C3}.f_{SW}} > \frac{(1+n_{31})V_{out}}{\Delta V_{C3}.R_L.Y f_{SW}} \quad (26)$$

$$C_1 = \frac{i_{D2}.(1-D_y)}{\Delta V_{C2}.f_{SW}} > \frac{V_{out}}{\Delta V_{C1}.f_{SW}} \quad (26)$$

$$C_2 = \frac{i_{in}.(1-D_y)}{\Delta V_{C3}.f_{SW}} > \frac{(1-D_y).M.V_{out}}{\Delta V_{C2}.R_L.f_{SW}} \quad (28)$$

$$C_{Clamp} = \frac{i_{inp}.(1-D_y)}{\Delta V_{Cclamp}.f_{SW}} > \frac{(1-D_y).M.V_{out}}{\Delta V_{Cclamp}.R_L.f_{SW}} \quad (29)$$

Where ΔV_{C3} and ΔV_{C2} represent acceptable the voltage ripple, that operates in stage .3, queso - resonate which happens duration is a function of capacitors C_3 and C_{clamp}, it is possible to determine the values of these capacitors:

$$\pi\sqrt{L_{K2}\left[C_3 \| \frac{C_{clamp}}{2+\frac{1+n_{21}}{Y}}\right]} = D_y T_S \quad (30)$$

Through the above equation, we conclude that using small values of these capacitors C_3 and C_{clamp} will not affect the operation of the circuit, and therefore will not affect the result of the output voltage. Therefore, it is possible to use any appropriate values of C_3 and C_{clamp} for the circuit to work in an acceptable.

3.1.3. THE RESULTS OF THE SIMULATION

Fig. 9 shows the results of an implemented 160W to the prototype converter. The cascaded boost converter using soft switching technique simulation in ORCAD software. The V_{inp} equal 24V, and the V_{out} 200V of the converter, the frequency for the switching of 50 kHz, IRFB4310 as the converter S_{switch}, MUR 860 is used as the diode D_{out} and the diodes, D_1, D_2. Table 4. Shows the values of the parameters that are used in the circuit. The RDS (on) is chosen very small in the MOSFET to obtain low stress In Fig. 10. when the S_{switch} is connected to the condition of zero current switches, it can be seen the stress is very low to the voltage, and the QR performance, and when the S_{switch} is disconnected the decreases, making to decreased switching dissipation. Fig. 11,12,13,14 show the ZCS condition at the current of diodes D_{out}, D_{clamp}, D_3, and D_4, when the S_{switch} is turned -off which helps to solve the problem of the diode reverse recovery. In Fig. 15, the current of L_{inp} in the steady state is continuous which improves the current ripple. Experimental results of I_{L1}, I_{L2}, and I_{L3} of the primary, secondary, and tertiary sides of the 3WCI are shown in Fig. 16,17,18, and Fig. 19,21 show the inductors' current L_4, L_S.

Due to the QR performance in Fig 20, it can be seen the voltage of the output is still constant there is no change in waves and no spike or noise when the switching turns on and turns off.

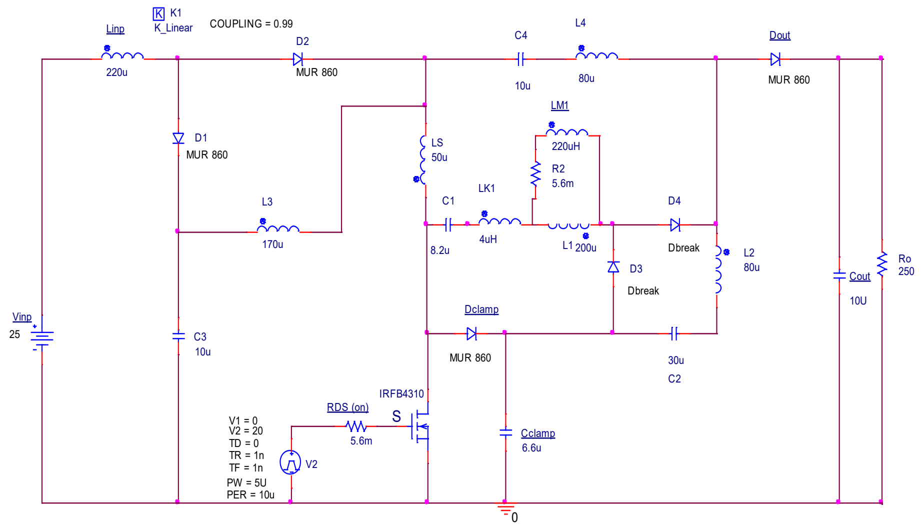


Fig.9. The Circuit Proposed using soft switching technique simulation in ORCAD software.

Table 4. Parameters of The Implemented Converter.

Parameters	Value
Switching Frequency f_{sw}	50khz
output resistance R_L	250Ω
Input Inductor *Linp*	220µH
Diodes Of the Cascaded Boost Converter D_1, D_2	MUR 860
Capacitor Of Cascaded Boost Converter C_3	10µ F
Capacitors C_1, C_2	8.2 µ F,30 µ F
Capacitor C_4	10 µ F
The Coupled Inductor L_1, L_2, L_3	200 µH, 80 µH,170 µH
Diode D_{Clamp}	MUR420
Capacitor C_{Clamp}	6.6µF
Output Capacitor C_{out}	10µF
Output Diode D_{out}	MUR 860
Leakage Inductor L_{K1}, L_{K2}, L_{K3}	3.96,065,0.68 µH
Inductor L_4	80 µH
Inductor L_S	50 µH
Power Switch S_{Switch}	IRFB4310
$R_{DS\ (on)}$	5.6mΩ
Coupling Coef. K_1	0.99
Duty Cycle D_y	0.51

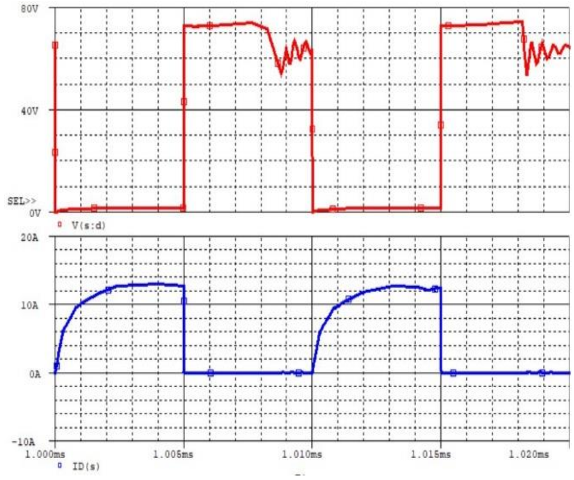


Fig.10. V_{switch}**,** I_{switch} **waveform**

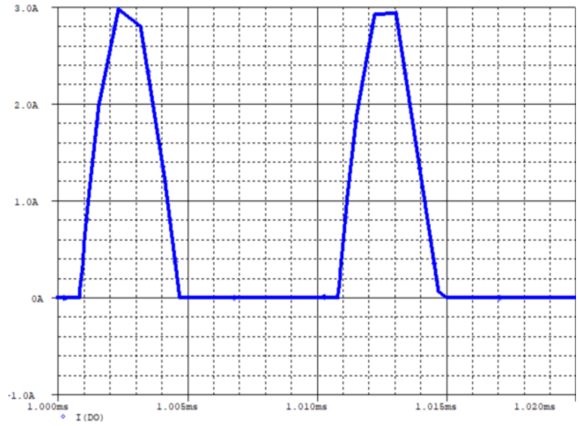


Fig. 11. I_{Dout} **waveform**

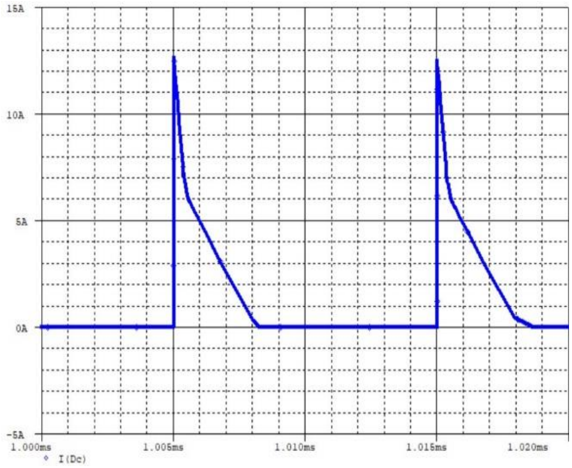


Fig. 12. I_{Dclamp} **waveforms**

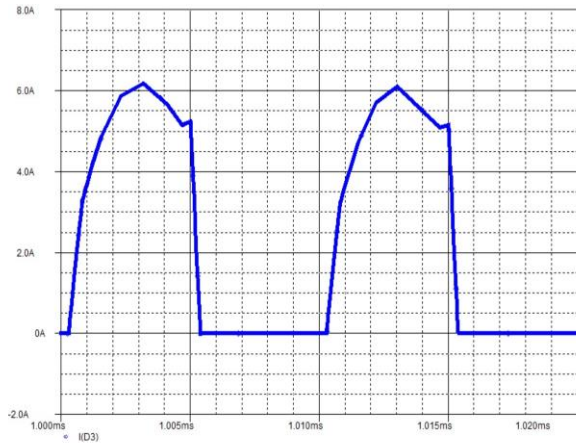


Fig.13. I_{D3} **waveforms**

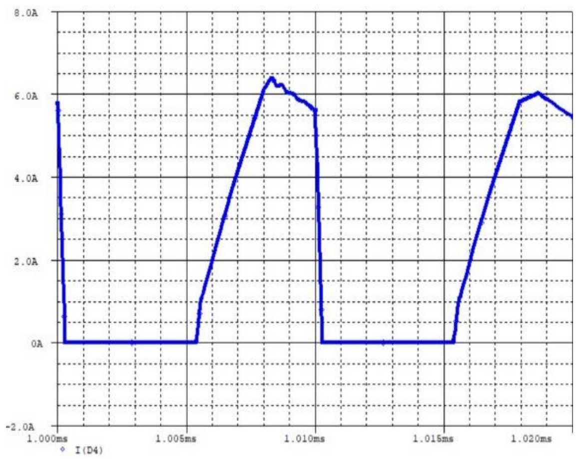


Fig. 14. I_{D4} **waveform**

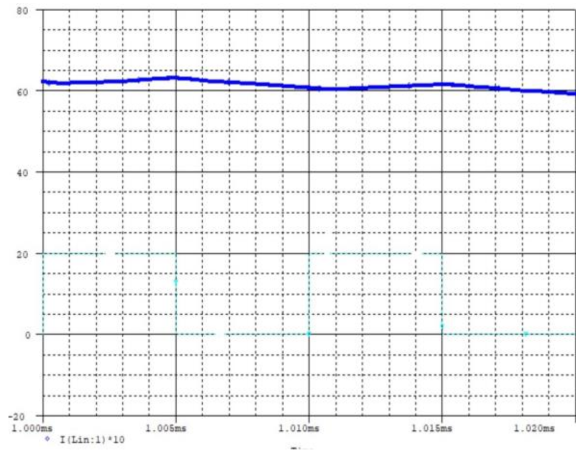


Fig. 15. I_{Linp} **waveform**

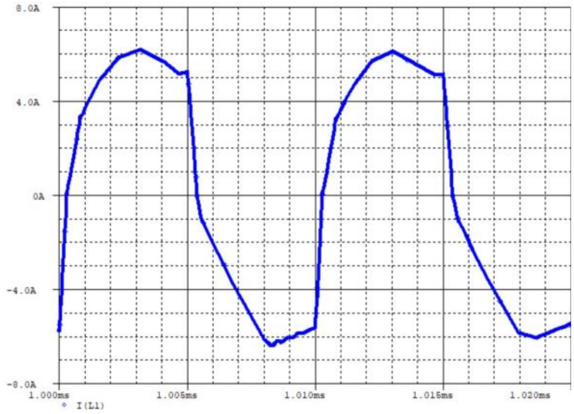


Fig. 16. I_{L1} **waveform**

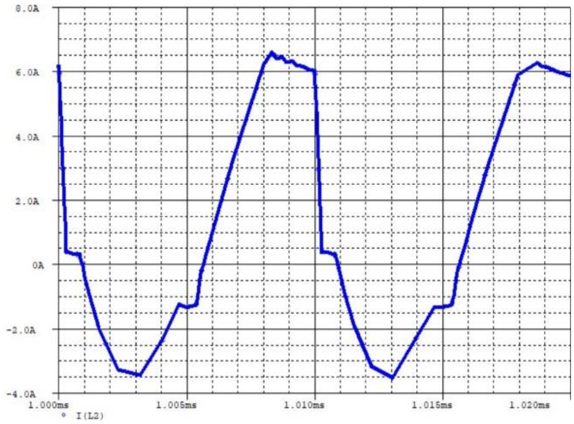


Fig. 17. I_{L2} **waveform**

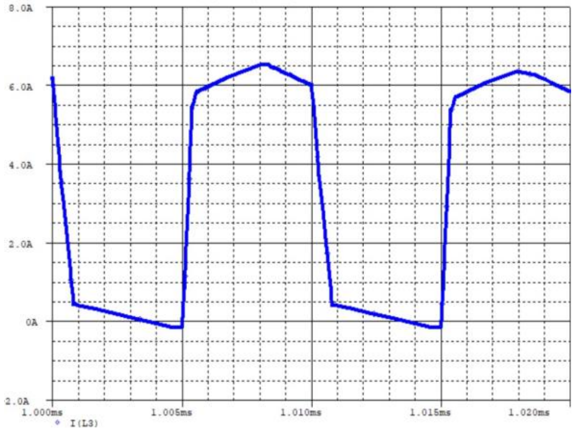


Fig. 18. I_{L3} **waveform**

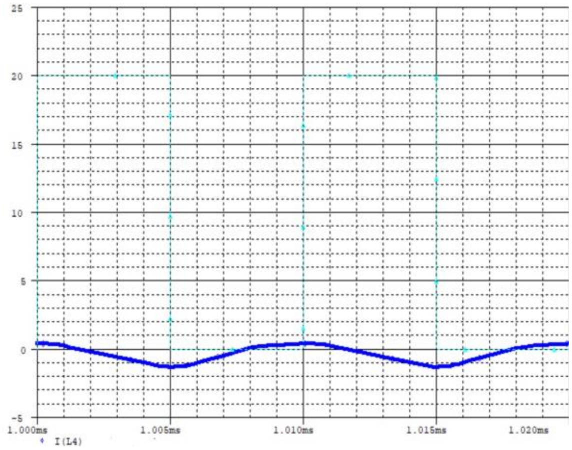


Fig. 19. I_{L4} **waveform**

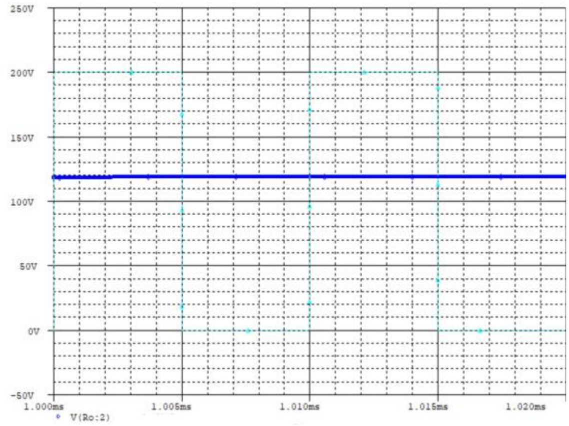


Fig. 20. V_{out} **waveform**

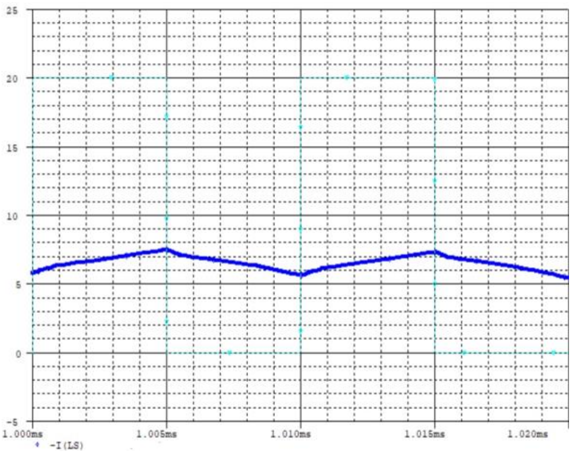


Fig. 21. I_{Ls} **waveform**

4. CONCLUSIONS

A new full soft-switching with cascaded boost DC-DC converter and high step-up has been proposed by using Three-Winding CI for renewable energy applications and photovoltaic arrays. Cascaded boost converters improve the voltage gain and increase efficiency with a coupled inductor. To reduce the stress and pressure on the start switch, a capacitor with a diode is used that connects with the switch circuit and forms what is called a regenerative negative clamp circuit, which improves the performance and operation of the transformer. One of the advantages of this circuit is that it is possible to obtain a complete soft switch state for the start switch with soft switching of the diodes during the operating period. Extinguishing employing achieving its waveform with a small ripple in the input current and thus high efficiency by displaying the steady state of the circuit to achieve it continuously, in addition to high voltage gain and higher efficiency than its counterpart transformers, and the loss of reverse recovery is reduced, an indication of the features of this circuit, which makes it suitable for many applications in power electronics.

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