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SINGLE SWITCH HIGH STEPUP DC-DC CONVERTERS WITH VOLTAGE MULTIPLIER CELL

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***Abstract*—In this paper, a built-in voltage gain extension cell is Proposed to give a universal topology derivation on next-generation high step-up converters for large voltage gain conversion systems. Several improved single-switch high step-up converters with built in transformer voltage multiplier cell are derived with some advantageous performance, which includes extremely large voltage conversion ratio, minimized power device voltage stress, effective diode reverse-recovery alleviation, and soft-switching operation .The turns ratio of the built in transformer can be employed as another design freedom to extend the voltage gain, which shows great design flexibility. Compared with their active clamp counterpart, only one MOSFET is required to simplify the circuit configuration and improve the system reliability. The over resonance frequency and the below resonance frequency operation modes are studied to explore the circuit performance, and the key parameter design criterion is provided to show a valuable guidance for future industrial applications. Finally, the experimental results from a 500W 36–380V prototype are provided to validate the effectiveness of the main contributions in this paper.**

***Key words*—Built-in transformer, high step-up, voltage gain extension cell, voltage multiplier cell.**

NOMENCLATURE

V_{in} input voltage.
V_{out} output voltage.
L_f filter inductor current.
P_{out} output power.
f_s Switching frequency
L_{lk} leakage inductance.
C_b block capacitor.
C_m main capacitor.
C_o output capacitor.
D_C clamp diode.
D_r regenerative diode.
S switch (MOSFET).
D Dutycycle .
N Turns ratio of the transformer.

I. INTRODUCTION

The conventional single-switch boost converter is widely employed in the distributed front-end power factor correction applications, such as the server powers Systems due to its advantages of simple structure, low cost, and easy implementation. At ideal continuous current mode (CCM) operation, the voltage gain of the conventional boost Converter is only determined by the switch duty cycle, which means only one control freedom is available to regulate the output voltage. Therefore, its optimal voltage conversion ratio is limited to approximately four times with a relatively high efficiency .However, nearly or even over 10 times of voltage gain is expected in some high step-up applications. For example, the automobile high-intensity-discharge headlamps usually need to convert 12V onboard battery up to 100V at steady operation, even to 400V during the start-upstage . The 48V standard battery is required to be boosted to nearly 400V for back-up uninterruptable power systems .In these high step-up and high output voltage applications, the extremely large duty cycle is inevitable with the conventional boost converter, which increases the switch peak current, deteriorates the switching condition, and expands the conduction and switching losses. Furthermore, from the small-signal model analysis, How to realize high step-up dc/dc converters without extreme duty cycle to improve the system performance is becoming one of the most emergent technologies for power electrics researchers. In this paper, the active clamp switch in the single-phase high Step-up built-in transformer based converter presented in [4] is replaced by a passive diode by exploring its detailed operation analysis. These proposed single-switch high step-up converters have quite simple circuit configuration and can reduce the system cost. Furthermore, zero current switching (ZCS) turn-ON condition is provided for the switch, and the diode reverse-recovery problem that existed in the conventional boost converters can be alleviated effectively by the inherent leakage inductance of the built-in transformer. In addition, the turn's ratio of the transformer and the switch duty cycle can be both employed to achieve extremely large voltage conversion ratio with optimized circuit performance.

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II. CHARACTERISTICS OF VOLTAGE MULTIPLIER CELL

In order to extend the voltage gain, avoid the extreme duty cycle operation, and reduce the switch voltage stress, a built-in voltage gain extension cell can be inserted into the conventional boost converter, which is plotted in Fig. 1(b).With the proposed built-in voltage gain extension cell, another control variable can be provided to achieve extremely high step-up conversion.. By inserting the built-in voltage gain extension cell, the switch voltage stress is reduced, the switch peak current is minimized ,and the dynamic response may be enhanced because the turn-OFF period is greatly extended. A clear and advantageous circuit performance can be achieved in the high step-up applications. Therefore, how to realize the built-in voltage gain extension cell with simple but effective circuit components is an innovative and valuable solution to derive novel high step-up and high-efficiency converters. The diode-capacitor voltage multiplier can be inserted into the conventional boost, Cuk, Zeta, and Sepic converters to serve as the built-in voltage gain extension cell [3]–[5]. The voltage gain can be extended by making many diode-capacitor voltage multipliers in series. However, the circuit may be a little complex. A flexible and controllable variable is expected to appear on the voltage gain expression except the duty cycle to regulate the voltage conversion ratio. Generally, the turn's ratio of the coupled inductor is one of the selectable control freedom to implement the built-in voltage gain extension cell. Recently, some single-phase coupled-inductor-based converters have been published in literatures to offer another design freedom rather than the switch duty cycle to satisfy the stringently high step-up requirements. Some of them can be derived from the isolated fly back converters [2]. Some of them come from the composition of the conventional boost and fly back converter [4],and others can be taken as the integration of the coupled inductor and switched capacitor. Furthermore, some voltage doubler, tripler, and quadrupler are integrated with the conventional single-switch boost converter to achieve an extremely large voltage conversion ratio. Unfortunately, the input current ripple of most coupled-inductor-based converters is a little large because the input current is equal to the continuous magnetizing inductor current plus the reflected discontinuous secondary winding current. This makes the electrolytic capacitors in the input side indispensable. This has passive impact on the power density and circuit reliability improvements. The transformer existed in the isolated converters is a pretty good component to regulate the circuit voltage conversion ratio and optimize the switch duty cycle. The built-in transformer concept can be also employed in the non isolated converters to conduct as the voltage gain extension cell and achieve high voltage .

III. MODIFIED VOLTAGE MULTIPLIERCELL BOOST CONVERTER.

A. Basic block diagram of proposed circuit

The basic block diagram of boost converter with voltage multiplier cell is shown in the fig 3.1.

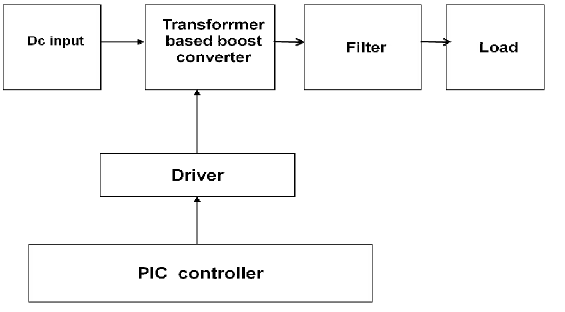

Fig 3.1 Basic block diagram of proposed converter

The DC source may be Battery or Solar Cell or fuel cell. It converts low voltage dc supply to high voltage DC supply, and the output voltage can be controlled by controlling the duty cycle of the converter. The voltage multiplier cell with built in transformer is used to reduce the voltage stress and switching losses. It is also used to improve the system performance. The DC output voltage can be used to run the pump motor of water springler for agricultural irrigation systems, power grid and also can be used for uninterrupted power system applications. Micro controller helps to generate necessary gating pulses for MOSFETS of main power circuit.

B. Boost Converter Circuit with voltage multiplier cell

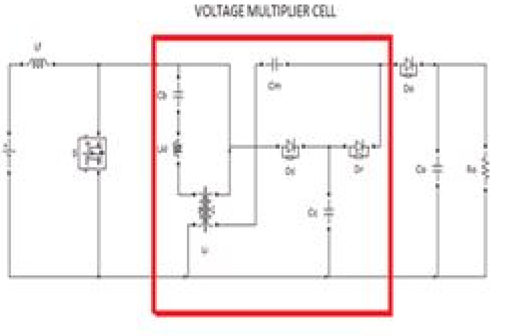

Fig 3.2 Boost converter circuit with voltage multiplier cell

The boost converter with voltage multiplier cell is shown in the fig 3.2. The voltage multiplier cell converter circuit is composed of an main switch (S_1), a block capacitor (C_b), a filter inductor (L_f), and clamp diode, regenerative diodes (D_c and D_r).

C. Modes of Operation

There are two typical operation modes. The first one is named as the over resonance frequency(ORF) operation and the other one is the below resonance frequency(BRF) operation. In ORF mode, the switch turn-ON time DT_s is longer than the resonance period T_r caused by leakage inductance and block capacitor. The leakage current i_{Lk} is continuous and its key steady-state waveforms are show ing. 3.8.On the contrary, in BRF mode, the switch turn-ON time DT_s is shorter than the resonance period T_r . The leakage current i_{Lk} keeps continuous and its corresponding key waveforms are described in Fig. 3.10

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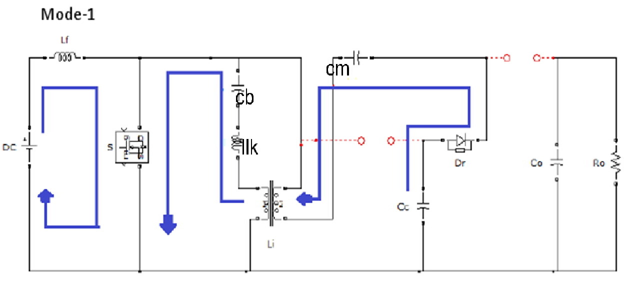
OVER RESONANCE FREQUENCY (ORF) operation

1) Mode 1: Operation.



$V_{if}=v_{in}$

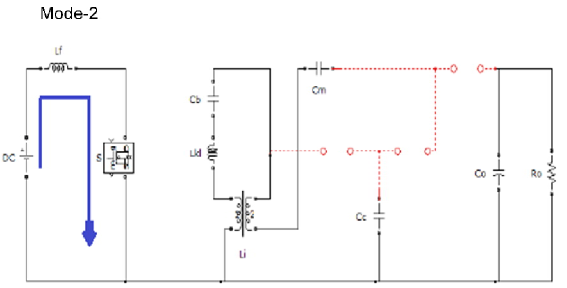
$V_{ts}=v_{cm}-v_{cc}$

$i_s(t)=I_{Lf}(t)+i_{Lk}(t)+i_{lk}(t)/N$

Fig 3.3: Mode 1 Operation 36V, 4.7uH ,3.7uF,470uF, 292 Ohm

The circuit diagram of Mode-1 is shown in the fig 3.3 *Stage 1 [t0, t1]:* Before *t1* , the switch *S* is in the turn-ON state and the voltage across the filter inductor *Lf* is the input voltage *Vin* . The clamp diode *Dc* and the output rectifier *Do* are reverse biased. And the energy stored in the clamp capacitor *Cc* is transferred to the switched capacitor *Cm* through the regenerative diode *Dr* and the secondary winding of the built-in transformer. The current of the switch is the summation of that of the filter inductor, leakage inductance, and secondary winding of the built-in transformer. The block capacitor *Cb* and the leakage inductance *LLk* begin to resonant

2) *Mode 2: Operation.*

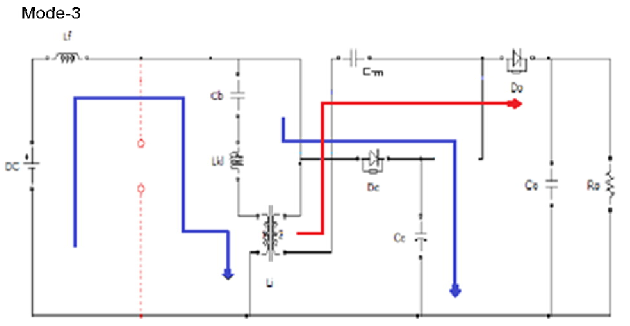


$i_s(t)=i_{Lf}(t)$

Fig 3.4: Mode 2 Operation 36V,4.7u H,1.6u H,292 ohm

The circuit diagram of Mode-2 is shown in the fig 3.4 *Stage 2 [t1, t2]:* At *t1* , the current of the leakage inductance *LLk* resonates to zero and the regenerative diode *Dr* turns OFF naturally, which minimizes the regenerative diode reverse-recovery losses. The filter inductor current is still increased linearly due to the input voltage.

3) Mode 3: Operation.



$i_{Do}(t)=i_{Lk}(t)/N$

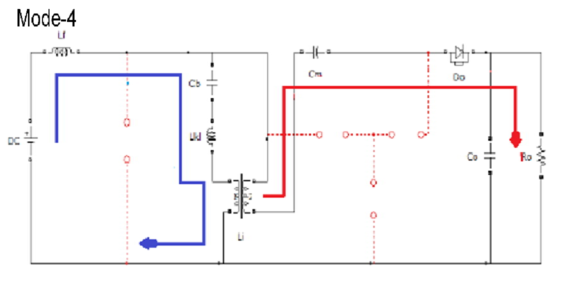
$i_{cc}(t)=i_{Lf}(t)-i_{Do}(t)-i_{Lk}(t)$

$v_{ts}=-v_{out}+v_{cm}$

Fig 3.5: Mode 3 Operation 292 Ohm 36V, 4.7uH 1.5uF 470uF

The circuit diagram of Mode-3 is shown in the fig 3.5. *Stage 3 [t2, t3]:* At *t2* , the switch *S* turns OFF and then the clamp diode *Dc* and the output rectifier *Do* turn ON to deliver the input energy to the output load. Part of another filter inductor energy transfers to the clamp capacitor *Cc*

4) Mode 4: Operation.



$i_{Lf}(t)=i_{Do}(t)+i_{lk}(t)$

Fig 3.6: Mode 4 Operation 292 Ohm 36V, 4.7uH 1.5uF 470uF

The circuit diagram of Mode-4 is shown in the fig 3.6 *Stage 4 [t3, t4]:* At *t3* , the clamp diode *Dc* turns OFF naturally, which alleviates the diode reverse-recovery problem. The filter inductor current is the summation of the leakage current and output diode current

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5) Mode 5: Operation.

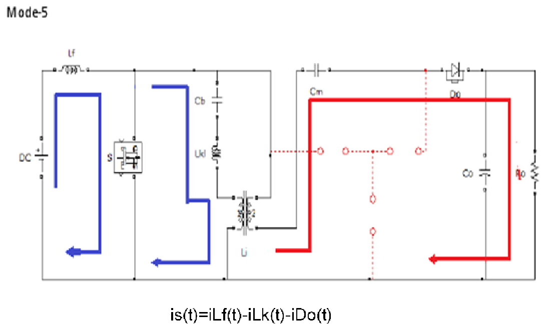

Fig 3.7: Mode 5 Operation 36V, 292 Ohm 4.7uH ,3.7uF, 470uF

The circuit diagram of Mode-5 is shown in the fig 3.7. *Stage 5 [t4, t5]:* At *t4* , the switch *S* turns ON with the ZCS soft switching performance because its turn-ON current is increased linearly from zero. The filter inductor current starts to increase again, and the current of the leakage inductance *L*Lk and that of the output diode *D*o decreases to zero at the end of this stage

The various modes of operation in ORF with equivalent circuit are explained. Corresponding waveforms are shown in Fig 3.8.

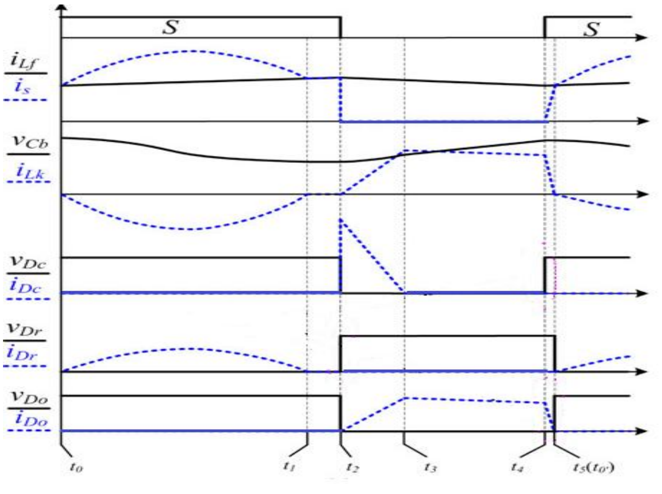

Fig 3.8: Waveform for ORF Operation

BELOW RESONANCEFREQUENCY(BRF)operation

6)Mode 6: operation

The circuit diagram of Mode-6 is shown in the fig 3.9. During BRF operation, the leakage current *i*Lk is still higher than zero when the switch *S* turns OFF.

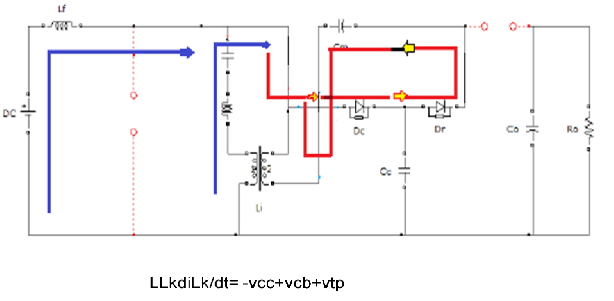

Fig 3.9: Mode 6 Operation 292Ohm 36V,16.3u F, 4.7 uH ,470uF

In this case, the operation of stage 2 has a small difference compared with the ORF operation whose equivalent circuit is plotted in Fig. 3.9. Once the switch *S* turns OFF, the clamp diode *D*c starts to conduct to make the voltage on the secondary winding equal to that of the switched capacitor *C*m. The leakage current *i*Lk decreases quickly in an approximately linear way. The other stages in the BRF operation are the same as those of the ORF operation

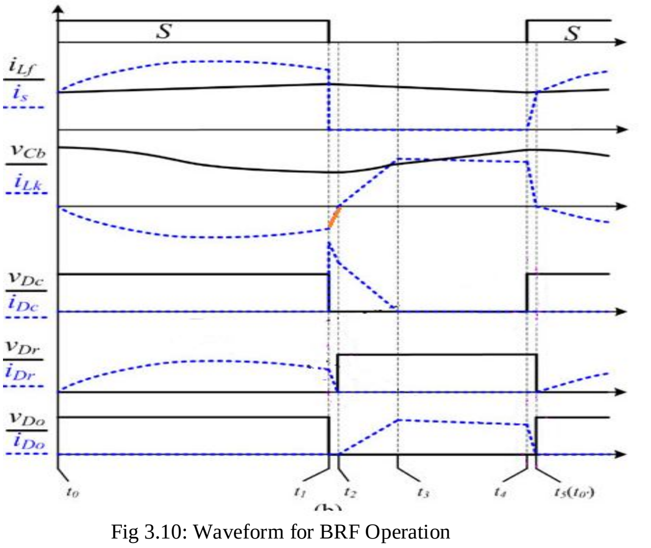

Fig 3.10: Waveform for BRF Operation

IV. DESIGN OF PROPOSED CIRCUIT

The design of voltage multiplier cell converter is presented below.

Input voltage V_{in} = 36V

Switching frequency f_s = 100 KHz

Output power P_o = 500W

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Design calculations for duty ratio:
The design calculations for duty ratio is presented below
N=Vout/Vin(1-D)-2
2.3=380/36(1-D)-2
D=0.6

Design calculations for output voltage:
The design calculations for output voltage is presented below
Vout=N+2/(1-D)
=2.3+2/(1-0.6)
=380v

Design calculations for output current:
The design calculations for output current is presented below
I_{0}=p/v
=500/380
=1.32A

Design calculations for output power:
The design calculations for output power is presented below
Pout=v*v/R
=380*380/292
=500w

Design calculations for Leakage Inductance:
The design calculations for Llk is presented below
di_{do}/dt= (N+1)Vout/N(N+2)Llk
10=(2.3+1)380/2.3(2.3+2)Llk
Llk=1.6*e-6H

V. SIMULATION OF VOLTAGE MULTIPLIER CELL

The simple auxiliary resonant converter circuit diagram are shown in the fig 5.1 the output results are obtained below.

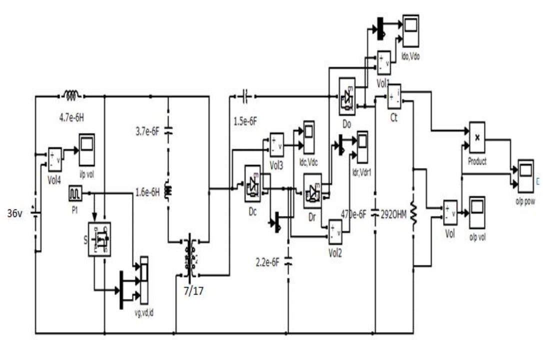

Fig 5.1 voltage multiplier cell converter simulation Diagram

A. voltage multiplier cell converter Circuit Performance Results

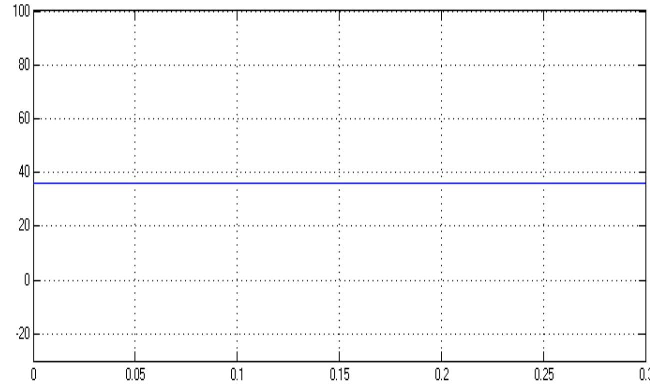

Fig5.2 DC input voltage waveform

The input voltage (36V) waveform of the proposed voltage multiplier circuit is shown in the fig 5.2.

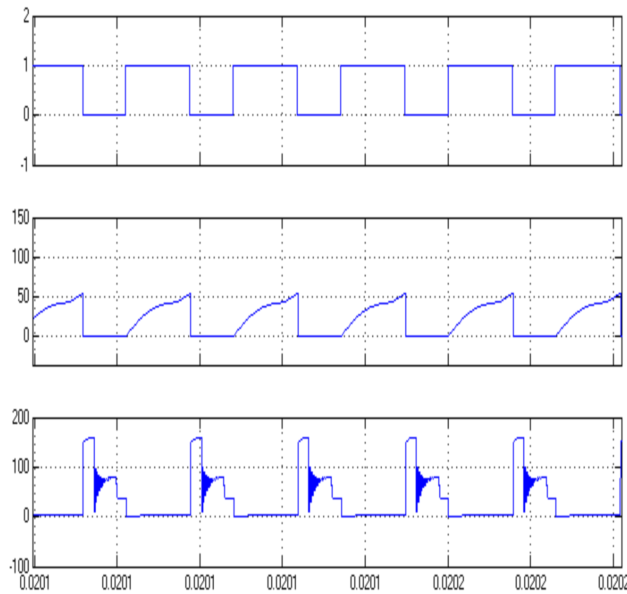

Fig5.3 DC waveform of V_{G}, I_{D} and V_{DS}

The waveform of V_{G},I_{D} and V_{DS} across switch S of the proposed circuit is shown in fig 5.3 and the output current waveform of the proposed circuit is 1.4A as shown in the fig 5.6.

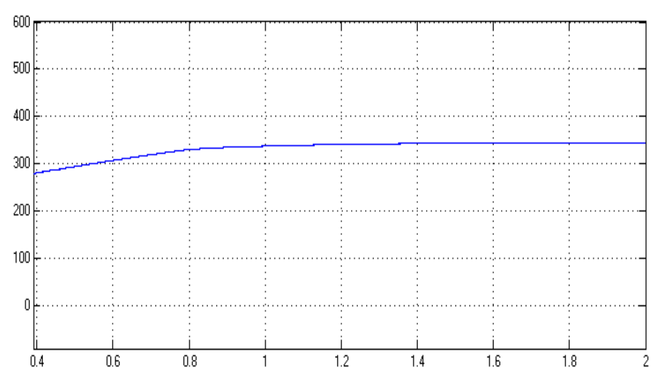

Fig5.4 DC output voltage waveform (380v)

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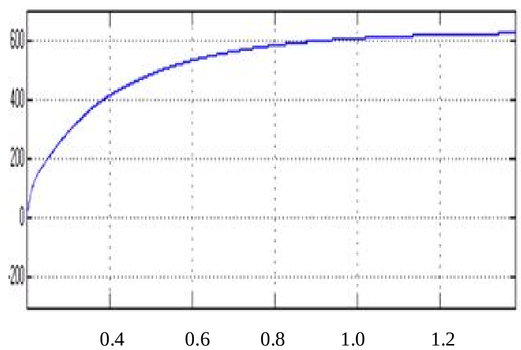

Fig5.5 DC output power waveform(500w)

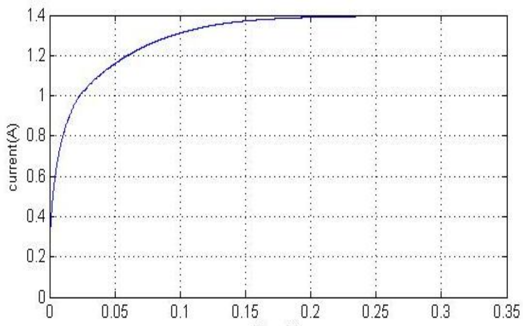

Fig5.6 DC output current waveform (1.4A)

VI. CONCLUSION

The transformer based voltage multiplier cell Boost Converter analysis and its implementation is suitable for energy output maximization in step up applications is presented in this paper. In this converter employ ZCS, which drastically minimizes the switching losses and optimize the duty cycle. The voltage multiplier circuit simulation has been carried out using SIMULINK of MATALAB 2010a Software. The results are comparable with the earlier approaches. Hence, this soft-switching boost converter can be used in a stand-alone and a grid-connected system using a voltage multiplier cell technique. The most commonly employable applications are uninterruptable power supplies system, battery charging DC motor etc. These improved converters contain the following clear advantages:1) The switch duty cycle and the turns ratio of the built-in transformer can be employed as two controllable variables to extend the voltage gain; 2) The power device voltage stress is far lower than the high output voltage; and 3) The diode reverse-recovery problem can be fully or partly solved based on the operation modes due to the leakage inductance. Experimental results have demonstrated that the proposed converters are The power device voltage stress is far lower than the high output voltage; and 3) The diode reverse- recovery problem can be fully or partly solved based on the operation modes due to the leakage inductance. Experimental results have demonstrated that the proposed converters are reverse -recovery problem can be fully or partly solved based on the operation modes due to the leakage inductance. Experimental results have demonstrated that the proposed converters are excellent topology candidates for high future high step-up conversion systems.

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