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AN INTEGRATED AUTOTRANSFORMER AND COUPLED INDUCTOR BASED CLOSED LOOP CONTROL OF HIGH-STEP-UP DC-DC CONVERTER

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ABSTRACT:
In this paper, a coupled inductor andautotransformer based high step-up dc–dc converter is proposed. The converter utilizes an integrated autotransformer and a coupled inductor on the same core to achieve a high step-up voltage gain without extreme duty cycle. In addition, the energy stored in the coupled inductor is recycled; the voltage stress of the main switch is reduced. The switch with low resistance $R_{DS(ON)}$ can be adopted to reduce the conduction loss and the reverse-recovery problem of the diodes is alleviated. Not only lower conduction losses but also higher power conversion efficiency is benefited from lower turns ratios. The derivative circuit design and its implementation with closed loop control are given with operational results.

Key Words: dc-dc power conversion, coupled inductor, autotransformer, and distributed generation.

I. INTRODUCTION

Renewable energy sources (RES) have experienced a fast development in recent years. These systems employ with micro sources like PV, fuel cells etc. Though PV cells can be made into array and connected in series to produce high voltage there exist serious problems like shadowing effects, short circuit which drastically reduces its efficiency. In order to overcome such adverse effects this micro source energy is utilized by the high step up converter to produce high voltage and satisfy the demands. Conventional boost converters can't provide such a high DC voltage gain for extreme duty cycle. Thus high step up dc-dc converters are used as front end converters to step from low voltage to high voltage which are required to have a large conversion ratio, high efficiency and small volume [1].In some converters active clamp circuit is used to overcome voltage spikes caused by the leakage inductance of the coupled inductor. Though ZVS technique is employed for soft switching it can't sustain light loads [2].Different switching structures are formed either two capacitor or two inductor with two three diodes. Both the step up and step down operations can be performed in this topology, Performance of hybrid converters are better than classical converters but still its costlier to implement [3]. Low level voltage from the PV, fuel cells is connected to Kilo watt level using step up dc-dc converter and inverter circuits. Voltage spikes and switching losses are eliminated by active clamping. In dc-ac, inverter always tends to draw ac ripple current at twice the output frequency. Resonant inductors cost and circuit volume is high [4].
This converter requires a multi winding transformer which makes the circuit design complex [5]. This converter avoids extremely narrow turn off period, ripples and switching losses are eliminated by ZVS technique. It uses two coupled inductors which makes the circuit complex [6]. In this converter no additional

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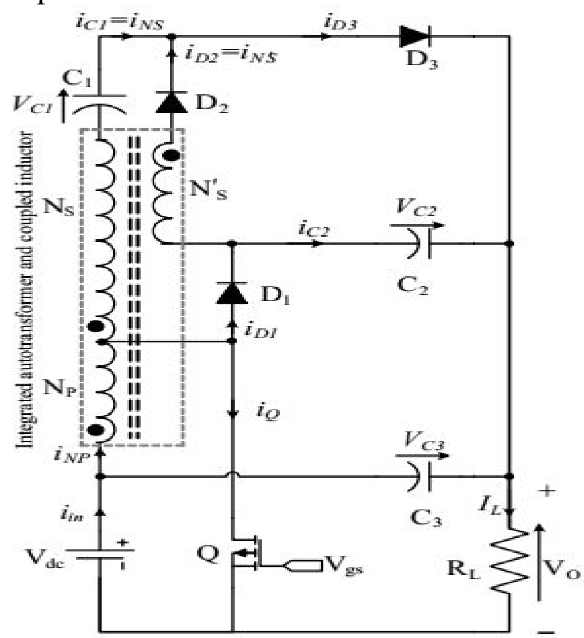
magnetic components used, switching losses are minimized by adopting a regenerative snubber circuit. As the circuit uses more switches controlling is complex [7]. In this converter high voltage gain is obtained but the circuit has more passive components [8]. It employees single ended scheme cost is reduced. Galvanic isolation is needed, but suitable only for low power and frequency applications [9], [10]. In this converter no need of extreme duty ratio but if conduction losses or switching losses occurs the efficiency is reduced [11]. It is possible to generate the non-isolated dc-dc converters but the major drawback is that switching frequency must be maintained constant and the turn ratio of the auto transformer must be unity [12]. Some converters operate at very high frequency with fast transient response.

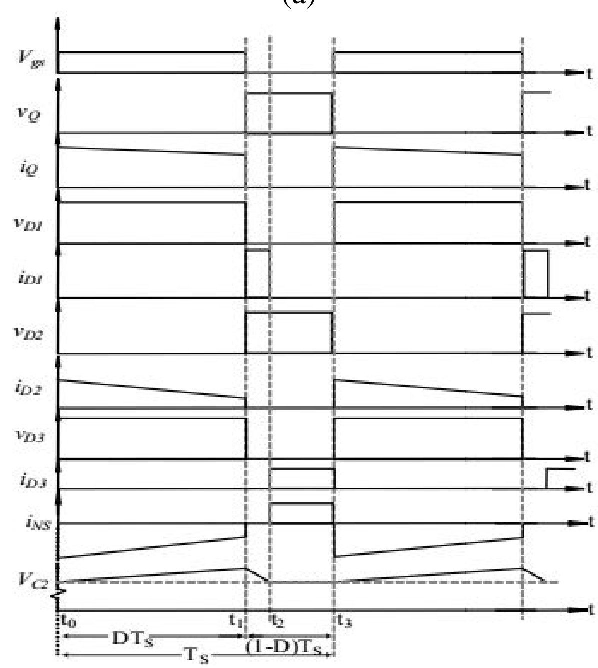
The main objective is to improve the Voltage Gain of the Step-up Converter and also to reduce Voltage stress of the circuit. Further the Voltage Drift problem is reduced using closed loop control of the proposed converter with PI controller. The output voltage from the converter is fed as feed back to the PI; there it compares the feedback voltage signal and the reference voltage signal to produce PWM pulse which triggers the main switch of the converter.

II. PROPOSED TOPOLOGY AND PRINCIPLE OF OPERATION

The proposed converter consists of an autotransformerand a coupled inductor wound on the same core and threediodes and the same number of capacitors as shown in Fig.1 (a). The advantage of the proposed topology are: (1) veryhigh voltage gain, which is particularly suitable for (a) lowvoltage output Fuel Cell (25 – 50 V) to stabilize the outputvoltage to 400 VDC and, (b) high voltage Light EmittingDiode (LED) lamps (which require 100– 600 V for aseries/parallel string of LED from a battery input of 12 – 24 V), (2) low voltage stresses on switch (Q), (3) no voltagespikes across the switch (diode D_1 and capacitor C_2 forms aregenerative snubber for the switch Q), and (3) only eightcomponents are required to design the converter. The windingdesign is simplified by winding the autotransformer andcoupled inductor on the same core that reduces the space andthe component count.



(a)



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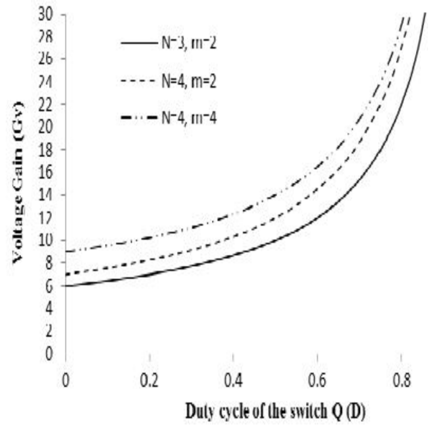
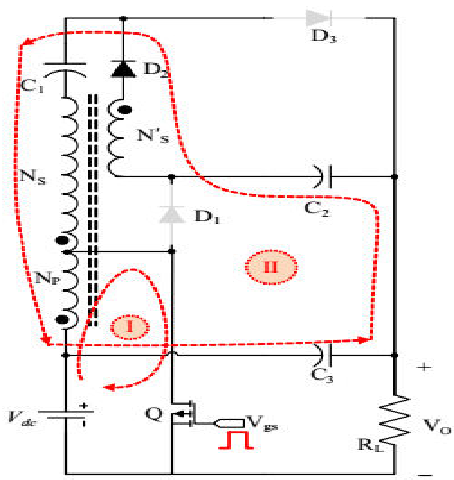
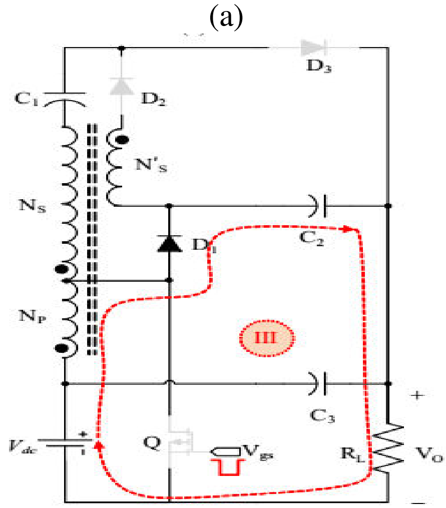


(c)

Fig.1 (a) Schematic of proposed ultra-step-up dc-dc converter and its (b)steady-state waveforms in Continuous Conduction Mode (CCM) operationand (c) theoretical voltage transfer characteristics



(a)



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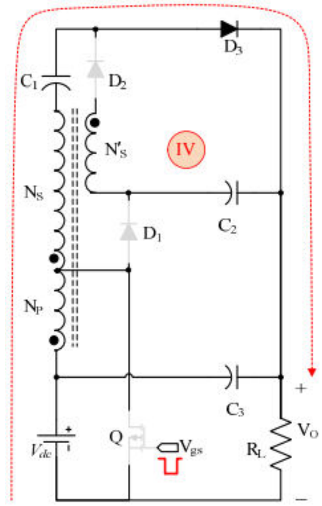

(c)

Fig.2. Equivalent circuit of the proposed converter during different operatingmodes: (a) Mode 1 [t_0-t_1], (b) Mode 2 [t_1-t_2], and (c) Mode 3 [t_2-t_3].

The steady-state waveforms of the proposed converteroperating in Continuous Conduction Mode (CCM) are depicted in Fig.1 (b). The converter has three operating modein a switching period. The equivalent circuit of the converterin each operating mode is shown in Fig.2 (a)-(c). Each modeis described briefly as follows:

Mode 1 ([t_0-t_1]): During this interval, the switch Qturns-on and current flows through the primary winding,secondary winding of the autotransformer and on the coupledinductor through diode D_2 and charge capacitor C_1 and C_2.Diode D_1 and D_3 are reversed biased. There are two closedloops for the current to flow as shown in Fig.2(a). Therelevant circuit expressions for this mode can then be written like in (1) and (2), where $V_L$is the voltage across the primary inductor winding (Np).

$$\frac{N_S}{N_P} v_L + V_O - V_{C2} + \frac{N_S'}{N_P} v_L - V_{C1} = 0$$

$$\Rightarrow \; v_L = (V_{C1} + V_{C2} - V_O)/((N_S + N_S')/N_P) \qquad (1)$$

$$\textbf{And } V_L = V_{dc} \qquad (2)$$

From (1) and (2)

$$V_{C1} + V_{C2} = \frac{N_S+N_S'}{N_P} V_{dc} + V_O \quad (3)$$

Mode 2 ([t_1-t_2],]): The switch is turned-off duringthis interval. Diode D_2 is reverse biased, whilst diode D_3continue its reverse biased until the end of this mode. Theload current flows through diode D_1 and primary winding ofan autotransformer, and discharge the capacitor C_2. Thecircuit expression for this mode can then be written as (4)

$$V_{dc} - v_L + V_{C2} - V_O = 0$$

$$\Rightarrow v_L = V_{dc} + V_{C2} - V_O \quad (4)$$

Mode 3 ([t_2-t_3]): The diode D_1 remains on in theprevious mode until capacitor C_2 is discharged to Vc_2. Thisreverse biasing the diode D_1 and the load current pathchanges to loop IV as shown in Fig.2 (c). The circuitexpression for this mode can then be written as (5)

$$V_{dc} - v_L - \frac{N_S}{N_P} v_L + V_{C1} - V_O = 0$$

$$\Rightarrow v_L = -\frac{V_{C1}-V_O-V_{dc}}{\frac{N_S+N_P}{N_P}} \quad (5)$$

Applying volt-sec balancing to (2) and (4) further resultsin (6), where D represents duty cycle of Q.

$$\int_0^{DT_s} v_L dt + \int_{DT_s}^{T_s} v_L dt = 0$$

$$\Rightarrow DV_{dc} + (1-D)(V_{dc} + V_{C2} - V_O)$$

$$\Rightarrow V_{C2} = (V_O(1-D) - V_{dc})/(1-D) \quad (6)$$

Applying volt-sec balancing to (1) and (5) further resultsin (7).

$$\int_0^{DT_s} v_L dt + \int_{DT_s}^{T_s} v_L dt = 0$$

$$\frac{(V_{C1}+V_{C2}-V_O)}{\frac{N_S+N_S'}{N_P}} D - \frac{(V_{C1}-V_O-V_{dc})}{\frac{N_S+N_P}{N_P}} (1-D) = 0 \quad (7)$$

The voltage gain (Gv)and hence the voltage transfercharacteristics equation of the converter is found by solving(3) and (7) as

$$G_v = \frac{V_O}{V_{dc}} = \left[\frac{1+N}{1-D} + m\right] \quad (8)$$

Where, $N = (N_P+N_S)/N_P$ is the autotransformer voltagetransfer constant and $m = N'_S/N_P$ is the turns ratio of thecoupled inductor. The voltage transfer characteristic of theproposed converter is shown in Fig.1 (c) with varying N, mand D.

III. CONTROL STRATEGY

In order to achieve good voltage regulation closed loop control methods are introduced. In pulse width modulation (PWM) control, the duty ratio is linearly modulated in a direction that reduces the error. When the input voltage is perturbed, that must be sensed as an output voltage change and error produced in the output voltage is used to change the duty ratio to keep the output voltage to the reference value.The main switch is fabricated from an integrated power process, the layouts can be changed to vary the parasitic, however design of switch layout is complex, fixed frequency and constant duty ratio must be maintained. This converter provides high voltage gain and can be employed for high power applications however the duty ratio is limited to 0.85. In this, the energy of the leakage inductor is recycled to the output load directly, limiting the voltage spike on the main switch. To achieve a high step-up gain, it has been proposed that the secondary side of the coupled inductor can be used as fly back and forward converters. In some converters voltage gain is improved through output voltage stacking.

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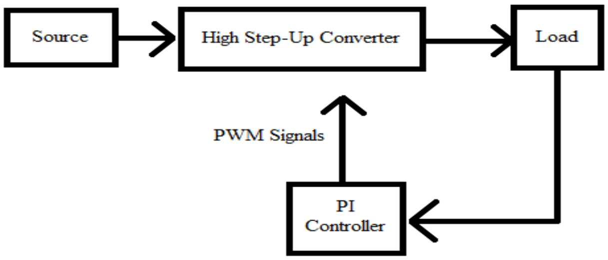
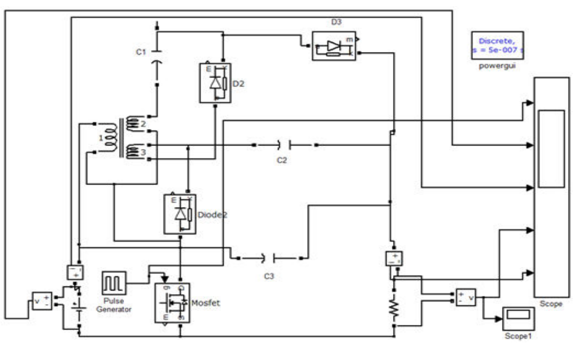
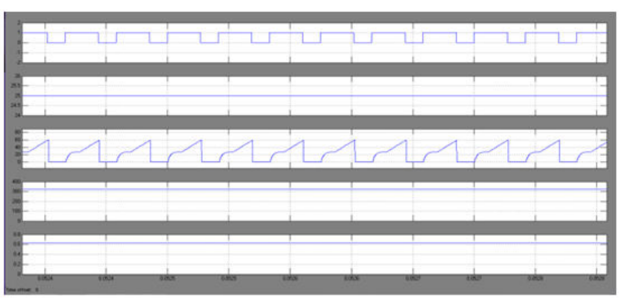


Fig.3 Block Diagram

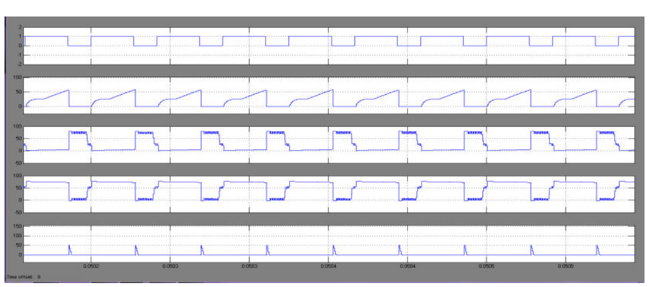
IV. MATLAB/SIMULINK RESULTS



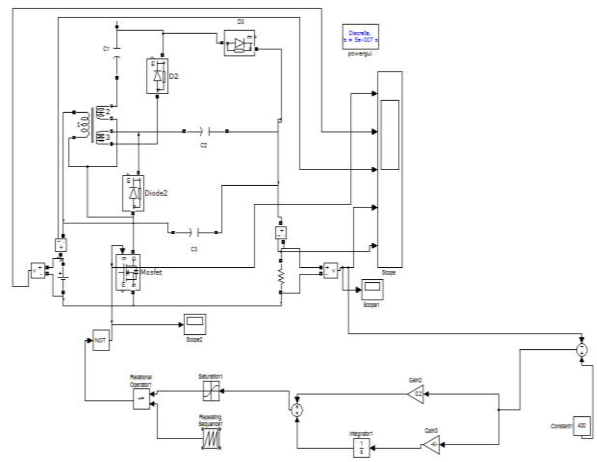
matlab/Simulink model of proposed converter in open-loop method



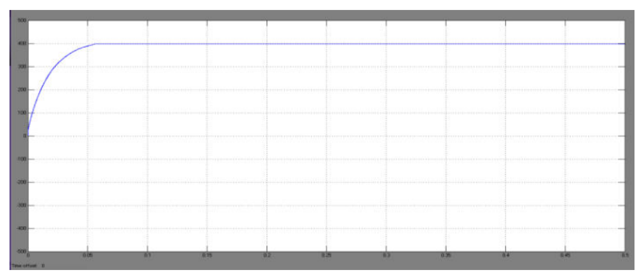
shows the simulation waveforms of proposed converter at N=4, m=2 conditions showing input voltage, current and output voltage, current



shows the simulation waveforms of proposed converter at N=4, m=2 conditions showing switch and diode voltage and current



matlab/Simulink model of proposed converter in closed-loop method



output voltage of the proposed converter in closed-loop Method

V. CONCLUSION

A high step-up dc/dc converter based on integrating coupled inductor and autotransformeris presented in this paper. The energy stored in the leakage inductance of the coupled inductor is recycled by using switched capacitors. The voltage stress across the main switch is reduced. Here the gate signals are generated using PWM control schemes. At last a same converter is controlled by closed loop PI control strategy with good dynamic response and low steady state error value with high stability factor.

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