A New High Step-Up DC/DC Converter for Renewable Energy Applications

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Abstract: In this paper, a coupled inductor based high step-up dc–dc converter for high step-up applications is proposed. The concept is to utilize two capacitors and one coupled inductor. The two capacitors are charged in parallel during the switch-off period and are discharged in series during the switch-on period by the energy stored in the coupled inductor to achieve a high step-up voltage gain. 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 $R_D$ (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 operating principle and steady-state analyses are discussed in detail. Finally, a 200W Converter Operating at 50KHZ with 12V input and 120V output simulation is presented to demonstrate the performance. The results are verified through MATLAB Software.

Keywords: Coupled Inductor, DC/DC Converters, High Step-Up, And Switched Capacitor.

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. 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. 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. In some converters high voltage conversion is obtained by changing transformer turns ratio which will increase the overall efficiency but still the operation of main switch involves hard switching and also EMI noise gets raised. Impacts of SiC (silicon carbide) MOSFETS on converter, switching and conduction losses are reduced even though fast switching is done. Si diodes have ideal, but sil SiC devices processes large amount of ringing current at turn OFF relatively to other devices. Package of external diode and the diode itself have more parasitic capacitances that are added to the devices parasitic aggravating the ringing. Here, the voltage step is done without a transformer and a high voltage gain is achieved without an extremely high duty ratio but still the circuit becomes more bulky as more number of passive components is used. Though this converter provides a non-pulsating current by using an auto transformer, duty ratio is limited by 0.5 and not suitable for non-linear loads. Here voltage stress of the active switch is reduced thereby the conversion efficiency is improved. This converter requires a multi winding transformer which makes the circuit design complex. 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.

In this converter no additional magnetic components used, switching losses are minimized by adopting a regenerative snubber circuit. As the circuit uses more switches controlling is complex. In this converter high voltage gain is obtained but the circuit has more passive components. It employees single ended scheme cost is reduced. Galvanic isolation is needed, but suitable only for low power and frequency applications. In this converter no need of extreme duty ratio but if conduction losses or switching losses occurs the efficiency is reduced. 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. Some converters operate at very high frequency with fast transient response. 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 this Converter leakage inductance and parasitic capacitance are neglected only magnetizing inductance considered.

II. LITERATURE REVIEW

A conventional boost converter can achieve high voltage gain only with a higher duty ratio. At high duty cycle low conversion efficiency, reverse recovery and EMI problems occur resulting in the deterioration of the performance of the system. Some transformer based converters can achieve high voltage gain by adjusting the turn’s ratio of the transformer. However, the leakage inductance of the transformer will cause serious problems such as voltage spikes on the main switch and high power dissipation switched capacitors and voltage lift techniques have been used to achieve high voltage gain. High charging current through the switches increases conduction losses in these structures. Coupled inductors based converters can achieve high step up voltage gain by adjusting the turn’s ratios. However, the energy stored in the leakage inductor causes voltage spikes in the main switches and deteriorates the conversion efficiency. As a solution for this problem coupled inductor with active clamp circuit was presented. However, the conversion ratio was not large enough. As a solution for the above mentioned problems this paper presents a new topology.

Fig.1.Circuit configuration of proposed converter.

III. OPERATING PRINCIPLE

The circuit configuration of the proposed converter is shown in Fig1. The proposed converter comprises a DC input voltage (Vi), active power switch (S), coupled inductor, four diodes and four capacitors. Capacitor C1 and diode D1 are employed as clamp circuit respectively. The capacitor C3 is employed as the capacitor of the extended voltage multiplier cell. The capacitor C2 and diode D2 are the circuit elements of the voltage multiplier which increase the voltage of clamping capacitor C1. The coupled inductor is modeled as an ideal transformer with a turn ratio N (NP/NS), a magnetizing inductor Lm and leakage inductor Lk. Assumptions considered are:

- All capacitors are large, therefore VC1, VC2, VC3 and Vo are considered to be constant during the switching period
- All components are ideal but the leakage inductance of the coupled inductor is considered.

According to the above mentioned assumptions, the Continuous Conduction Mode (CCM) operation of the proposed converter is presented below. It includes five stages of operation in one switching period. Conducting elements in each stage is shown in the corresponding explanation.

Stage I: [Fig.2 (a):]: In this stage, switch S is turned on. Also, diodes D2 and D4 are turned on and diodes D1, D3 are turned off. The DC source (Vi) magnetizes Lm through S. The secondary-side of the coupled inductor is in parallel with capacitor C2 using diode D2. As the current of the leakage inductor Lk increases linearly, the secondary-side current of the coupled inductor (iS) decreases linearly. The required energy of load (RL) is supplied by the output capacitor Co. This interval ends when the secondary-side current of the coupled inductor becomes zero.

Stage II [Fig. 2(b):]: In this stage, switch S and diode D3 are turned on and diodes D1, D2 and D4 are turned off. The DC source V1 magnetizes Lm through switch S. So, the current of the leakage inductor Lk and magnetizing inductor Lm increase linearly. The capacitor C3 is charged by dc source VI, clamp capacitor and the secondary-side of the coupled inductor. Output capacitor Co supplies the demanded energy of the load RL. This interval ends when switch (S) is turned off.
A New High Step-Up DC/DC Converter for Renewable Energy Applications

Stage III [Fig. 2(c)]: In this stage, switch S is turned off. Diodes D₁ and D₃ are turned on and diodes D₂ and D₄ are turned off. The clamp capacitor C₁ is charged by the stored energy in capacitor C₂ and the energies of leakage inductor Lₖ and magnetizing inductor Lₘ. The currents of the secondary-side of the coupled inductor (iS) and the leakage inductor are increased and decreased respectively. The capacitor C₃ is still charged through D₃. Output capacitor Cₒ supplies the energy to load RL. This interval ends when iₖ is equal to iₘ.

Stage IV [Fig. 2(d)]: In this stage, S is turned off. Diodes D₁ and D₄ are turned on and diodes D₂ and D₃ are turned off. The clamp capacitor C₁ is charged by the capacitor C₂ and the energies of leakage inductor Lₖ and magnetizing inductor Lₘ. The currents of the leakage inductor Lₖ and magnetizing inductor Lₘ decrease linearly. A part of stored energy in Lₘ is transferred to the secondary side of the coupled inductor in order to charge the capacitor C₁ through diode D₁. In this interval the DC input voltage V₁ and stored energy in the capacitor C₃ and inductances of both sides of the coupled inductor charge the output capacitor Cₒ and provide the demand energy of the load RL. This interval ends when switch S is turned on.

Stage V [Fig. 2(e)]: In this stage, S is turned off. Diodes D₂ and D₄ are turned on and diodes D₁ and D₃ are turned off. The currents of the leakage inductor Lₖ and magnetizing inductor Lₘ decrease linearly. Apart of stored energy in Lₘ is transferred to the secondary side of the coupled inductor in order to charge the capacitor C₁ through diode D₁. In this interval the DC input voltage V₁ and stored energy in the capacitor C₃ and inductances of both sides of the coupled inductor charge the output capacitor Cₒ and provide the demand energy of the load RL. This interval ends when switch S is turned on.

IV. EXPERIMENTAL RESULTS

The performance of the presented converter is assessed using the prototype circuit implemented in the laboratory. The specifications of the implemented circuit are given in Table I. The experimental results are shown in Fig. 3 under load 300 W. The results verify the analysis of the steady-state operation. The voltage on the switch (VDS) during the turn-off state is clamped to about 80V. Therefore, a low-voltage-rated switch can be used to improve the efficiency of the presented converter. Fig. 3(a) shows that the energy stored in the leakage inductance is recycled to capacitor C₁ through diode D₁. Fig. 3(e) and (f) depicts the voltage stresses on the main switch and diodes. Also, Fig. 3(d) shows the voltages on capacitors C₁, C₂, C₃, and Cₒ, which are in consistency. The current waveforms of the diodes, switches, and the coupled inductor (iₖ) shown in Fig. 3(a)–(c) validate the analysis and the feasibility of the proposed converter. The input current waveform with and without an input filter is also shown in Fig. 3(g). The input current ripple is as much as other proposed high-step-up converters such as the converters. However, as it is shown in Fig. 3(g) (iSource), a low-pass filter can be used to reduce the input current ripple. The experimental conversion efficiency of the presented converter is given in Fig. 4. The peak value of efficiency is 96.9% which is achieved at PO = 200 W. The efficiency of the presented converter at full load PO = 300 W is 96%. The results show the high conversion efficiency of the presented converter. The experimental conversion efficiency of the presented converter is given in Fig. 4. The peak value of efficiency is 96.9%, which is achieved at PO = 200 W. The efficiency of the presented converter at full load PO = 300 W is 96%. The results show the high conversion efficiency of the presented converter.
KAPPETA RAGHUNATHA REDDY, J. NAGARAJUNA BABU

The proposed converter successfully enlarges the voltage conversion ratio without a high turn’s ratio of the coupled inductor. The voltage gain is 10 when the turn’s ratio of the coupled inductor is two. The efficiency of the proposed converter is 97.9%. Moreover, the diodes can be replaced with switches to form a bidirectional switched-coupled inductor converter.

VI. REFERENCES

Fig.3. Experimental results under load 300 W.

Fig.4. Experimental conversion efficiency.

V. CONCLUSION
The proposed coupled-inductor based DC-DC converter is a simple dc–dc step-up converter with a high voltage conversion ratio inherent in this converter. By adopting coupled-inductor and switched-capacitor techniques, the

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