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Research Paper

A NEW STEP-UP DC-DC CONVERTER FOR ISOLATED POWER SYSTEM

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In this paper, a new step up dc-dc converter with a coupled inductor for isolated power system. Theoretically the conventional boost converter provides high step up voltage gain but in practical it is limited by reverse recovery problem of diode, effective series impedance of inductors and capacitors and switching losses. High charged current and conduction losses occur in the switch when voltage lift and switched capacitor techniques are used. In the proposed strategy a coupled-inductor and two capacitors is utilized to achieve high step-up voltage gain. High power loss and voltage spike on the switch is avoided using passive clamp circuit that recycles the leakage inductor energy. The operating principle and steady-state analysis are discussed. The Proposed topology was simulated using Matlab/Simulink environment and the following results were obtained. For an input voltage of 24 V, an output of 393 V was obtained.

Keywords: High step-up, Coupled inductor, Distributed Generation (DG), Reverse-recovery, Gain

INTRODUCTION

Driven by economical, technical, and environmental reasons, the energy sector is moving into an era where large portions of increases in electrical energy demand will be met through widespread installation of distributed resources or what is known as Distributed Generation (DG) [1]. Distributed Generation (DG) systems based on renewable energy sources have rapidly developed. The DG systems are powered by micro sources such as fuel cells, photovoltaic cells, batteries, and micro turbines, etc., and have already been used to share peak generation during peak load hours when energy cost is high and to provide standby generation during system outages.

Being a systematic organization of DG systems, a micro grid has larger power capacity and more control flexibilities to fulfill system reliability and power quality requirements, in addition to all the inherited advantages of a single DG system [2].

This boost converter theoretically can provide a high step-up voltage gain with an

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extremely high duty cycle but in practice, the step-up voltage gain is limited by the effect of the power switch, rectifier diode, and the equivalent series resistance of the inductors and capacitors.

Conventional boost converters cannot provide such a high voltage gain, even for an extreme duty cycle. It may also result in serious reverse-recovery problems and increase the ratings of all devices [3]. As a result, the conversion efficiency is degraded, and the electromagnetic interference (EMI) problem is severe under this situation. To increase the conversion efficiency and voltage gain, many modified boost converter topologies have been investigated in the last decade.

The dc-to-dc converters comprising high-frequency transformers can provide a high voltage gain, but their efficiency is drastically degraded by losses associated with the leakage inductors, which induce high voltage stress, large switching losses and serious electromagnetic interference (EMI) problems [4].

The converters using a coupled inductor with an active-clamp circuit have been proposed. An integrated boost-fly back converter is presented in which the secondary side of the coupled inductor is used as a fly back converter. Thus, it can increase the voltage gain. Also, the energy of the leakage inductor is recycled to the output load directly, limiting the voltage spike on the main switch. Furthermore, the voltage stress of the main switch can be adjusted by the turn ratio of the coupled inductor [5].

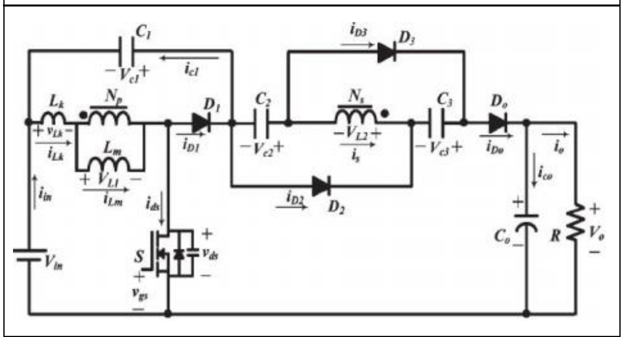
To attain a high step-up gain, it has been proposed that the secondary side of the coupled inductor can be used as fly back and forward converters. Also, several converters that combine output-voltage stacking to increase the voltage gain are proposed. To achieve high step-up voltage gain and high efficiency, this paper proposes a new step-up ratio and clamp-mode converter. The proposed converter adds two capacitors and two diodes on the secondary side of the coupled inductor to achieve a high step-up voltage gain. The coupled inductor can charge two capacitors in parallel and discharge in series. Though, the leakage inductor of the coupled inductor may cause high power loss and a high voltage spike on the switch. Therefore, a passive clamping circuit is needed to clamp the voltage level of the main switch and to recycle the energy of the leakage inductor [6].

OPERATING PRINCIPLE OF THE PROPOSED CONVERTER

Derivation of the Proposed Converter

Figure 1 shows the circuit topology of the proposed converter, which is composed of main switch *S*, *dc* input voltage V_{in}, coupled inductors N_p and N_s, one clamp diode D_1, clamp capacitor C_1, two diodes D_2 and D_3, two

Figure 1: Circuit Configuration of the Proposed Converter



capacitors C_2 and C_3, output diode D_o, and output capacitor C_o. The equivalent circuit model of the coupled inductor includes leakage inductor L_k, magnetizing inductor L_m, and an ideal transformer. The leakage inductor energy of the coupled inductor is recycled to capacitor C_1, and thus, the voltage across the switch S can be clamped. The voltage stress on the switch is reduced significantly. Thus, low conducting resistance RDS (ON) of the switch can be used. This proposed converter has low conduction loss. Also, the secondary-side leakage inductor of the coupled inductor can improve the reverse-recovery problem of diodes, and the loss can be reduced. In addition, the proposed converter adds capacitors C_2 and C_3 to attain a high step-up gain without an extra winding stage of the coupled inductor. The coil is less than that of other coupled inductor converters.

The main working principle is that, when the switch is turned on, the coupled-inductor-induced voltage on the secondary side and magnetic inductor L_m is charged by V_{in}. The induced voltage makes V_{in}, V_{C1}, V_{C2}, and V_{C3} release energy to the output in series. The coupled inductor is used as a transformer in the forward converter. When the switch is turned off, the energy of magnetic inductor L_m is released via the secondary side of the coupled inductor to charge capacitors C_2 and C_3 in parallel.

To simplify the circuit analysis, the following conditions are assumed.

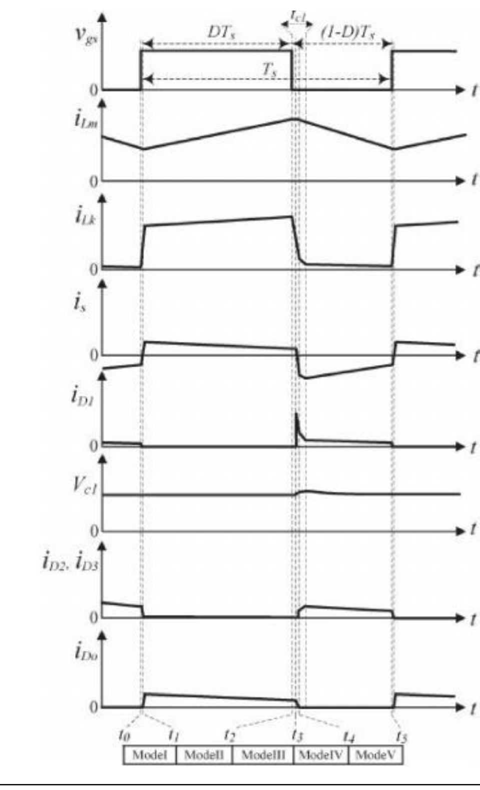
1. Capacitors C_2, C_3, and C_0 are large enough that V_{c2}, V_{c3}, and V_0 are considered to be constant in one switching period.
2. The power MOSFET and diodes are treated as ideal, but the parasitic capacitor of the power switch is considered.
3. The coupling coefficient of coupled inductor k is equal to $L_m/(L_m + L_k)$ and the turns ratio of coupled inductor n is equal to N_s/N_p.

The proposed converter operating in Continuous Conduction Mode (CCM) and Discontinuous Conduction Mode (DCM) I analyzed as follows [6].

CCM Operation

This section presents the operation principle of the proposed converter. The following analysis contains the explanation of the power flow direction of each mode. In CCM operation, there are five operating modes in one switching period. Figure 2 shows the typical waveforms.

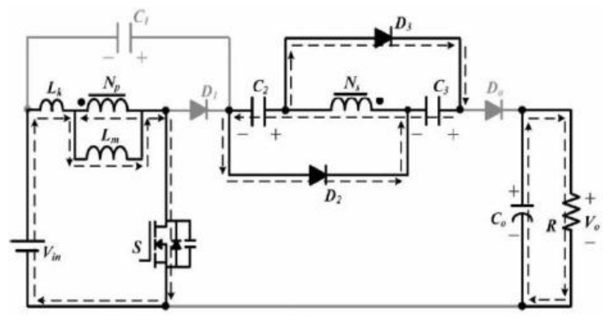
Figure 2: Some Typical Waveforms of the Proposed Converter at CCM Operation



The operating modes are described as follows.

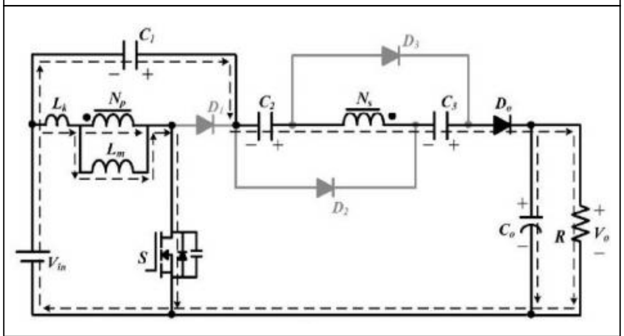
Mode I [t_0, t_1]: Switch is turned on. Diodes D_1, D_o are off, D_2, D_3 are on. The leakage inductor starts charging C_1. C_o discharges through R. Mode ends when D_2 current becomes zero. This mode is of very short duration.

Figure 3: Current Flowing Path of Mode-I During One Switching Period



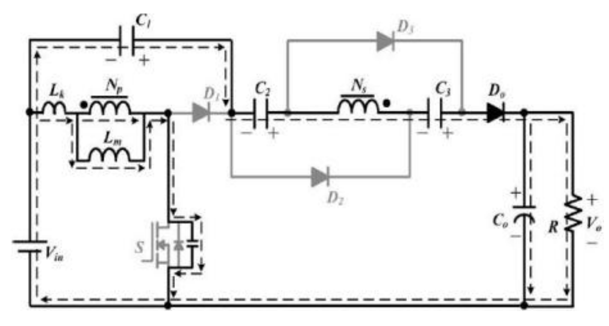
Mode II [t_1, t_2]: Switch remains on. D_1, D_2, D_3 turned off. D_o is turned on. Energy from DC source is stored by the magnetizing inductor. This mode continues till the switch is off.

Figure 4: Current Flowing Path of Mode-II During one Switching Period



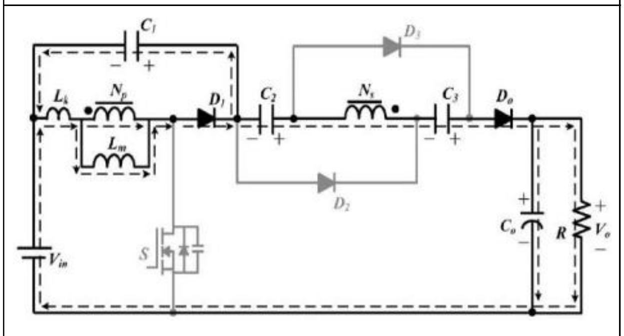
Mode III [t_2, t_3]: Switch remains turns off. Diodes D_1, D_2 and D_3 remains turned off. D_o turns on. The parasitic capacitor of the switch is charged by the energies of leakage and magnetizing inductor. C_o provides energy to load. Mode ends at the instant when D_1 conducts.

Figure 5: Current Flowing Path of Mode-III During One Switching Period



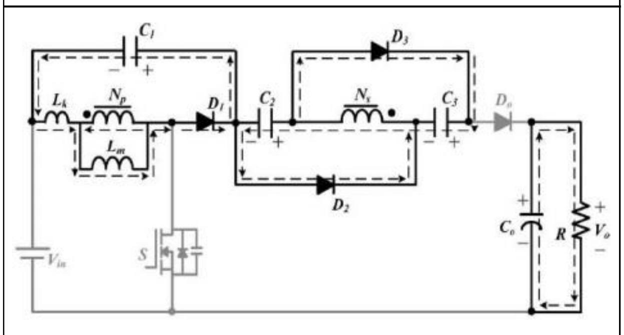
Mode IV [t_3, t_4]: Switch remains off. D_1 and D_o are on and D_2 and D_3 are off. Leakage inductor energy is recycled. Coupled inductor continues charging C_o and load. Mode ends when current through D_o becomes zero.

Figure 6: Current Flowing Path of Mode-IV During One Switching Period



Mode V [t4, t5]: Switch remains off. D_1, D_2 and D_3 are on. D_o is turned off. Leakage inductor L_k energy and magnetizing inductor

Figure 7: Current Flowing Path of Mode-V During One Switching Period



L_m charge C_1. C_2 and C_3 are charged in parallel. Mode ends when switch is turned on and cycle repeats.

DESIGN AND SIMULATION OF THE PROPOSED CONVERTER

The simulation of this proposed topology is carried out to verify the validity of the circuit. The simulation is done using Matlab/Simulink with the following specifications:

Input Voltage	24 v dc
Coupled Inductor	L_m = 48 µH
	L_k = 0.25 µH
	N_p:N_s = 1:4
Switching Frequency	50 kHz
Capacitors	C_1 = 56 µF
	C_2 = C_3 = 22 µF
	C_0 = 180 µF
MOSFET	IRF 540
Diode	MUR 150
Output Voltage	393 v dc

Figure 8: MATLAB/SIMULINK Circuit of the Converter

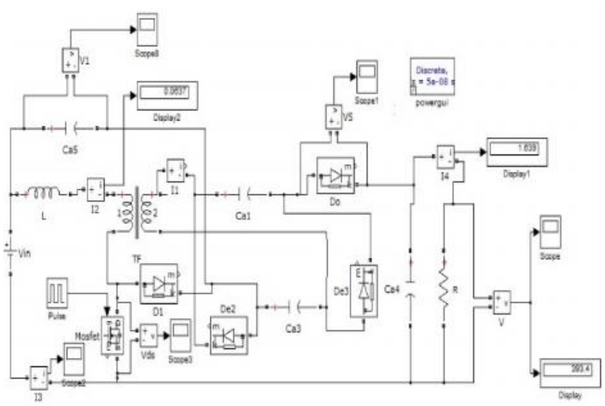


Figure 9: Shows the Proposed Converter Output Waveforms of Proposed Converter V_{DS}, I_{LK}, I_S

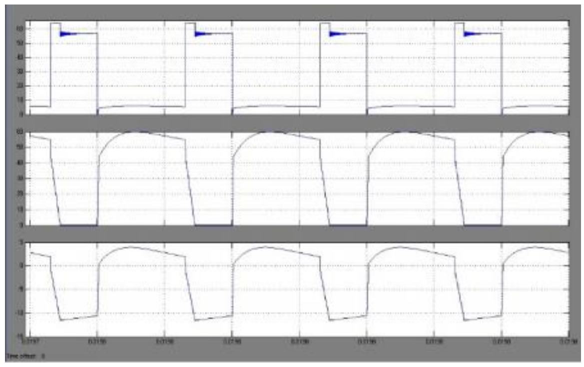


Figure 10: Waveforms of V_{DS}, I_{D2}, I_{D3}

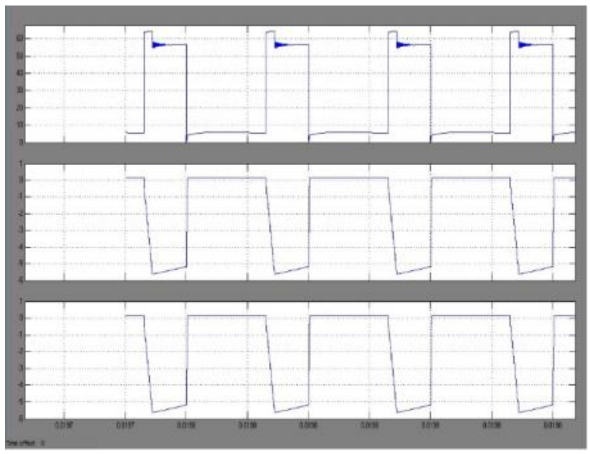


Figure 11: Waveforms of V_{DS}, V_{D1}, V_{D2}, V_{D0}

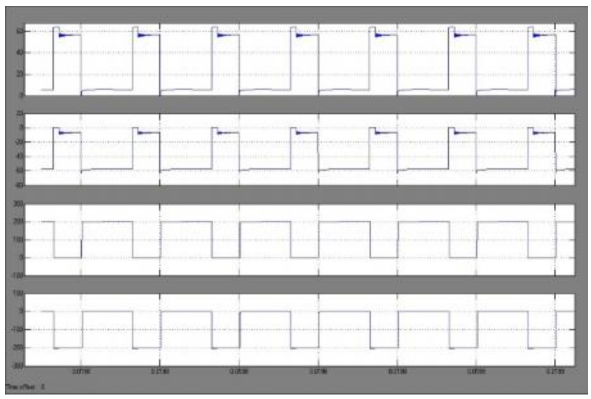
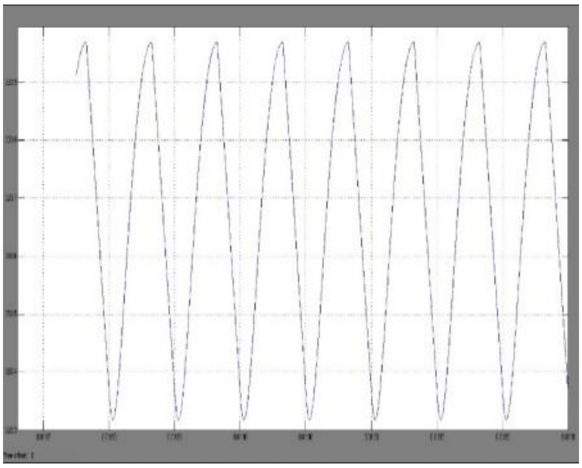


Figure 12: Output Voltage



The proposed converter is simulated using MATLAB Software as shown in Figure 8. The output wave form is shown in Figures 9-12. The input voltage of 24 V is applied to the converter and the output of 393 V is obtained.

CONCLUSION

A new step-up dc-dc converter with high voltage gain for isolated power system has been proposed in this study. By using coupled inductor high gain was obtained. Using passive clamp circuit the leakage inductor energy was recycled. Henceforth reverse-recovery problem is alleviated. It provides a continuous input current and the ripple in the output voltage is also very low. The different modes of operation and steady state analysis were discussed. The setup was validated by simulation using MATLAB software.

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