A High Boost DC–DC Converter for Distributed Generation System

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Abstract*- High boost dc-dc converters are usually used as the front-end converters to step from low voltage to high voltage which re-quires a large conversion ratio, high efficiency and small volume. To improve the conversion efficiency and achieve a high step-up voltage gain, many step-up converters have been proposed. A high step-up voltage gain can achieved by the use of switched-capacitor and voltage-lift techniques. However, the switch will suffer high charge current and conduction loss. This paper proposes a novel high step-up ratio and clamp mode converter to achieve high step-up voltage gain and high efficiency. 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 the two capacitors in parallel during the switch-o period and discharge them in series during the switch-on period. However, the leakage inductor of the coupled inductor may cause high power loss and high voltage spike on the switch. Thus, a passive clamping circuit is needed to clamp the voltage level of the main switch and to recycle the energy of the leakage inductor. The switch with low resistance is adopted to reduce the conduction losses. Also, the reverse-recovery problems of the diodes are alleviated thus improving the efficiency further. The operating principle and the steady state analyses are discussed in detail. Finally, a prototype circuit with 24-V input voltage, 450-V output voltage and 200-W output power is implemented in the laboratary to verify the performance of the proposed converter. The experimental results have conformed that high efficiency and high step-up voltage gain can be achieved. The voltage on the main switch is clamped at 84-V.

Keywords—DistributionGeneration(DG),Leakage inductor,MagnetizingInductor

I. INTRODUCTION

In recent years, distributed generation (DG) systems based on renewable energy sources have rapidly developed. The DG systems are composed of microsource like fuel cells, photovoltaic (PV) cells, and wind power. However, fuel cells and PV source are low-voltage sources to provide enough dc voltage for generating ac utility voltage[1]. Although PV cells can connect in series to obtain sufficient dc voltage, it is difficult to avoid the shadow effect. Thus, high boost dc dc converters are usually used as the 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. Theoretically, the boost converter can provide a high stepup voltage gain with an extremely high duty cycle. In practice, the step-up voltage gain is limited by the effeect of the power switch, rectifer diode, and the equivalent series resistance of the inductors and capacitors.Also, the extreme duty cycle operation may result in serious reverse-recovery and electromagnetic interference problems. Some converters like the forward and flyback converters can adjust the turn ratio of the transformer to achieve a high stepup voltage gain. However, the main switch will suffer high voltage spike and high power dissipation caused by the leakage inductor of the transformer. Although the non dissipative snubber circuits and active-clamp circuits can be employed, the cost is increased due to the extra power switch and high side driver.To improve the conversion efficiency and achieve a high stepup voltage gain, many step-up converters have been proposed. A high step-up voltage gain can be achieved by the use of the switched-capacitor and voltage-lift techniques[2]. However, the switch will suffer high charged current and conduction loss. The converters use the coupled-inductor technique to achieve a high step-up gain. However, the leakage inductor leads to a voltage spike on the main switch and affect s the conversion efficiency. For this reason, the converters using a coupled inductor with an active-clamp circuit have been proposed. An integrated boost flyback converter is presented in which the secondary side of the coupled inductor is used as a flyback 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. Additionally, the voltage stress of the main switch can be adjusted by the turn ratio of the coupled inductor. To achieve a high step-up gain, it has been proposed that the secondary side of the coupled inductor can be used as flyback and forward converters.

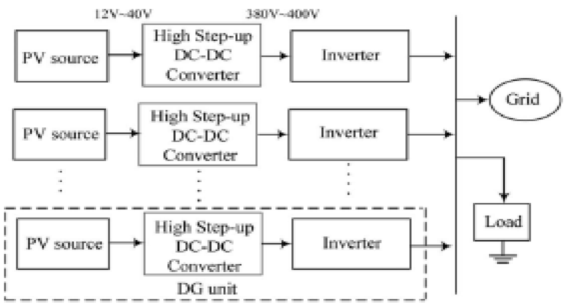

Figure 1.1: PV Distribured System

Also, several converters that combine output-voltage stacking to increase the voltage gain are proposed. Additionally, a high step-up boost converter that uses multiple coupled inductors with output stacking has been proposed

II. DC-DC CONVERTERS

The world is now habituated with the electronics devices without which it is very di cult for the mankind to keep going. So it is very important to develop the devices error free and fast response with high efficiency. Of the research field is dc-dc converters. The dc-dc converters means the input is dc and the output is also dc. The two basic dc-dc converters are buck converter and boost converter. Based on these two converters, all other converters are derived. The semiconductor devices are used as switching devices due to which the converters can operate at high frequencies. The different arrangement of inductors and capacitors in the converters operates as a filter circuit. The resistance act as a load in the circuit which can be varied to study the behavior during light load and heavy load

A. Classifcation of Converters

High voltage side and right hand side is used as low voltage side. Two capacitors with same rating are used in the high voltage side to maintain the half of normally, the converters are designed in the medium frequency range. The various types of converter are buck converter, boost converter, inverting and non-inverting buck-boost converter, Cuk-converter, SEPIC converter, full-bridge and half-bridge converter, forward converter, push-pull converter, flyback converter, resonant converter, bidirectional converter and so on. These converters can be classified based on various categories. These converters can be classified as isolated and non-isolated converters, unidirectional and bidirectional converters, step-up and step-down converters, single input and multi-input converters, Low power application and high power application converters, etc. There are different modes of operations comes into picture such as continuous conduction mode (CCM), discontinuous conduction mode (DCM), pseudo-continuous conduction mode (PCCM). There are three analysis studied in these converters. Those are steady state analysis, dynamic analysis and transient analysis. The converters are studied based on their efficiency, dynamic response, gain, switch stress, switching loss, robustness, voltage and current ripple, harmonics, wide operating range, etc .

B. Recent Converters

The recent converters are the modifications of the basic converter which increases the operating regions. The converters can be modified by adding inductor and capacitor which increases the order of the converters. Some examples are adaptive hysteresis control of 3rd order buck converter, predictive controller for fourth order buck converter etc. Multi-input converter can be obtained by adding more than one input sources in the converter.

C. Bidirectional Converter

One such type of converter is bidirectional buck-boost converters. In this type of converters, one direction is used to step-up the voltage and another direction is used to step-down the voltage. It is like the charging and discharging of the converter. It can be operated in CCM as well as DCM.The Fig shows one of the bidirectional dc-dc converter. It is using four controlled switching devices. The left side of the converter is used as the input voltage constant. A lot of work is done for designing the converter. But few work has been done for controlling this converter. The logic can be developed where the converter can operate buck or boost mode where the power is flowing from left to right.[3] Similarly, the logic can also be developed to operate the converter in buck as well as boost mode during right to left power flow. The converter is studied in CCM mode and DCM mode which can be extended to PCCM mode.[4]

III. DERIVATION OF THE PROPOSED CONVERTER

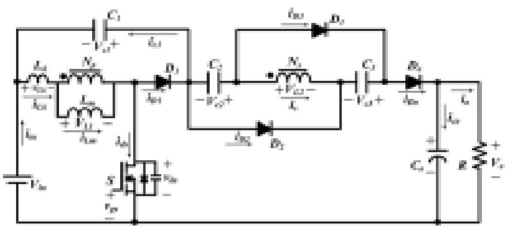

Figure 3.1: Circuit configuration of the proposed converter

Fig 2.1 shows the circuit topology of the proposed converter, which is composed of dc input voltage Vin, main switch S, coupled inductors Np and Ns, one clamp diode D1, clamp capacitor C1, two capacitors C2 and C3, two diodes D2 and D3, output diodeDo, and output capacitor Co. The equivalent circuit model of the coupled inductor includes magnetizing inductor Lm, leakage inductor Lk, and an ideal transformer. The leakage inductor energy of the coupled inductor is recycled to capacitor C1, 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. The original voltage-clamp circuit was first proposed in to recycle the energy stored in the leakage inductor. Based on the topology, the proposed converter combines the concept of switched-capacitor and coupled-inductor techniques. The switched-capacitor technique in has proposed that capacitors can be parallel charged and series discharged to achieve a high step-up gain. Based on the concept, the proposed converter puts capacitors C2 and C3 on the secondary side of the coupled inductor. Thus, capacitors C2 and C3 are charged in parallel and are discharged in series by the secondary side of the coupled inductor when the switch is turned o and turned on. Because the voltage across the capacitors can be adjusted by the turn ratio, the high step-up gain can be achieved significantly[5]. Also, the voltage stress of the switch can be reduced. Compared to earlier studies, the parallel-charged current is not in rush. Thus, the proposed converter has low conduction loss. Moreover, the secondary-side leakage inductor of the coupled inductor can alleviate the reverse-recovery problem of diodes, and the loss can be reduced. In addition, the proposed converter adds capacitors C2 and C3 to achieve a high step-up gain without an additional winding stage of the coupled inductor. The coil is less than that of other coupled inductor converters. The main operating principle is that, when the switch is turned on, the coupled-inductor-induced voltage on the secondary side and magnetic inductor Lm is charged by Vin[6]. The induced voltage makes Vin, VC1, VC2, and VC3 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 Lm is released via the secondary side of the coupled inductor to charge capacitors C2 and C3 in parallel.

The coupled inductor is used as a transformer in the flyback converter.

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

- Capacitors C1, C2, C3, and Co are large enough. Thus, VC1, VC2, VC3, and Vo are considered as constants in one switching period.
- The power devices are ideal, but the parasitic capacitor of the power switch is considered.
- The coupling coe cient of the coupled inductor k is equal to Lm/(Lm + Lk), and the turn ratio of the coupled inductor n is equal to Ns/Np.

The proposed converter operating in continuous conduction mode (CCM) and discontinuous conduction mode (DCM) is analyzed as follows

A. .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. Fig.2.2 to Fig.2.6 shows the current flow path of each mode of the circuit. The operating modes are described as following.

Mode I [t0, t1]: During this time interval, S is turned on. Diodes D1 and Do are turned off , and D2 and D3 are turned on. The current flow path is shown in Fig.2.2. The voltage equation on the leakage and magnetic inductors of the coupled inductor on the primary side is expressed as Vin = VLk + VLm. The leakage inductor Lk starts to charge by Vin. Due to the leakage inductor Lk,the secondary-side current is of the coupled inductor is decreased linearly. Output capacitor C0 provides its energy to load R. When current iD2 becomes zero at t=t1, this operating mode ends.

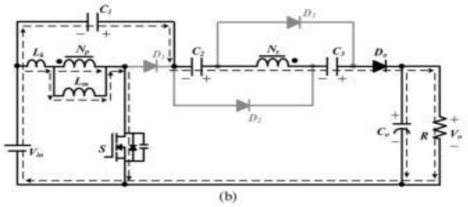

Figure 3.2: Mode-I

Mode II [t1, t2]: During this time interval, S remains turned on. Diodes D1, D2, and D3 are turned off , and Do is turned on. The current flow path is shown in Fig.2.3. Magnetizing inductor Lm stores energy generated by dc source Vin. Some of the energy of dc-source Vin transfers to the secondary side via the coupled inductor. Thus, the induced voltage VL2 on the secondary side of the coupled inductor makes Vin, Vc1, Vc2, and Vc3, which are connected in series, discharge to high-voltage output capacitor Co and load R. This operating mode ends when switch S is turned o at t = t2.

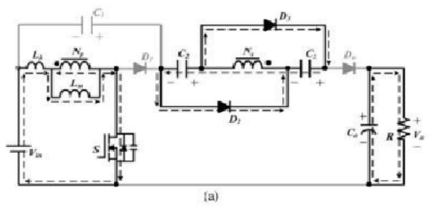

Figure 3.3: Mode-II

Mode III [t2, t3]: During this time interval, S is turned o . Diodes D1, D2, and D3 are turned o , and Do is turned on. The current flow path is shown in Fig.2.4. The energies of leakage inductor Lk and magnetizing inductor Lm charge the parasitic capacitor Cds of main switch S. Output capacitor Co provides its energy to load R. When the capacitor voltage Vc1 is equal to Vin + Vds at t = t3, diode D1 conducts, and this operating mode end

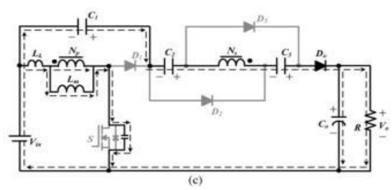

Figure 3.4: Mode-III

Mode IV [t3, t4]: During this time interval, S is turned off . Diodes D1 and Do are turned on, and D2 and D3 are turned off . The current flow path is shown in Fig.2.5. The energies of leakage inductor Lk and magnetizing inductor Lm charge clamp capacitor C1. The energy of leakage inductor Lk is recycled. Current iLk decreases quickly. Secondary-side voltage VL2 of the coupled inductor continues charging high-voltage output capacitor Co and load R in series until the secondary current of the coupled inductor is is equal to zero. Meanwhile, diodes D1 and D3 start to turn on. When iD0 is equal to zero at t = t4, this operating mode ends.

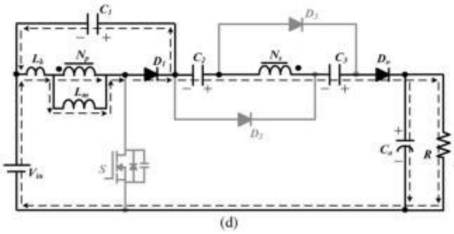

Figure 3.5: Mode-IV

Mode V [t4, t5]: During this time interval, S is turned off . Diodes D1, D2, and D3 are turned on, and D0 is turned off . The current flow path is shown in Fig.2.6. Output capacitor C0 is discharged to load R. The energies of leakage inductor Lk and magnetizing inductor Lm charge clamp capacitor C1. Magnetizing inductor Lm is released via the secondary side of the coupled inductor and charges capacitors C2 and C3. Thus, capacitors C2 and C3 are charged in parallel. As the energy of leakage inductor Lk charges capacitor C1, the current iLk decreases, and is increases gradually. This mode ends at t = t6 when S is turned on at the beginning of the next switching period

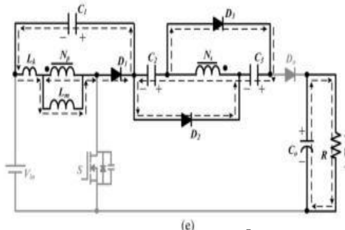

Figure 3.6: Mode-V

B. DCM Operation

To simplify the analysis of DCM operation, leakage inductor Lk of the coupled inductor is neglected. The Fig. showing the typical waveforms of the proposed converter operating in DCM, is shown.

Mode I [t0, t1]: During this time interval, S is turned on. The current flow path is shown in Fig.2.7 . The magnetizing inductor Lm stores the energy from dc source Vin. Thus, iLm increases linearly. Also, the energy of dc-source Vin is transferred to the secondary side of the coupled inductor, which is connected with capacitors C2 and C3 in series to provide their energies to output capacitor Co and load R. This mode ends when S is turned o at t = t1

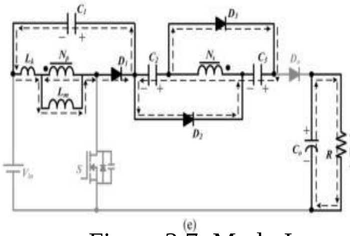

Figure 3.7: Mode-I

Mode II [t1, t2]: During this time interval, S is turned off . The current flow path is shown in Fig.2.8 . The energy of magnetizing inductor Lm transfers to capacitors C1, C2 and C3. Output capacitor Co provides its energy to load R. This mode ends when the energy stored in Lm is depleted at t = t2.

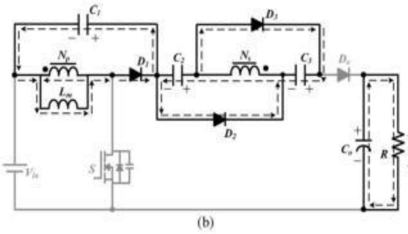

Figure 3.8: Mode-II

Mode III [t2, t3]: During this time interval, S remains turned off. The current-ow path is shown in Fig.2.9 . Since the energy stored in Lm is depleted, the energy stored in Co is discharged to load R. This mode ends when S is turned on at t = t3.

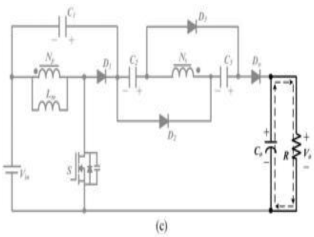

Figure 3.9: Mode-III

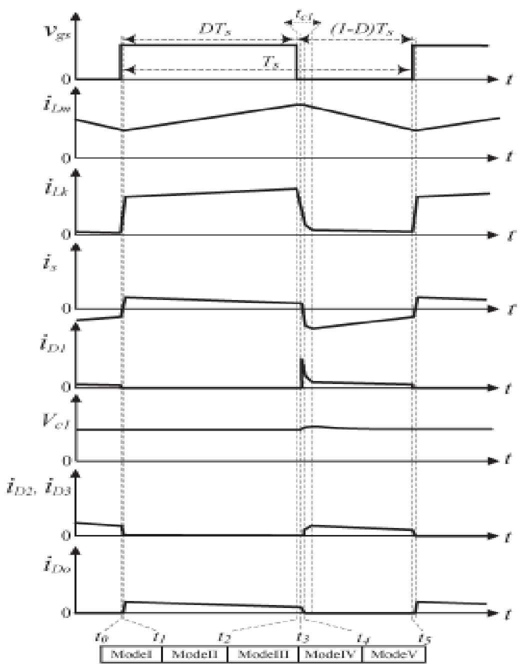

Figure 3.10 CCM Waveform

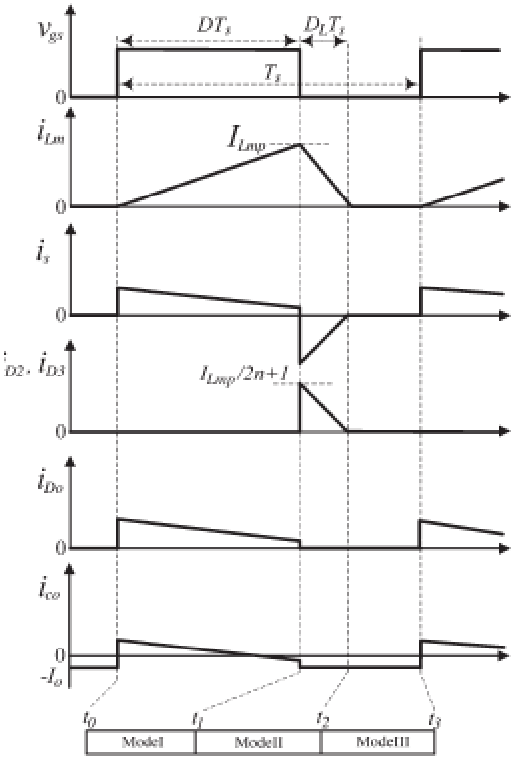

Figure 3.11. DCM operation

IV.STEADY STATE ANALYSIS

Voltage Gain in CCM mode

$$M_{CCM}=\frac{V_0}{V_{in}}=\frac{1+nK}{1-D}+\frac{D}{1-D}\frac{(K-1)+n(1+K)}{2} \qquad (1)$$

Voltage Gain in DCM mode

$$M_{DCM}=\frac{V_0}{V_{in}}=\frac{1+n}{2}+\sqrt{\frac{(1+n)^2}{4}+\frac{D^2}{2\tau L_M}} \qquad (2)$$

The normalized magnetizing-inductor time constant is defined as

$$\tau L_M = \frac{L_M}{RT_S} = \frac{L_M f_S}{R} \qquad (3)$$

Where fs is the switching frequency

In the boundary operation between CCM and DCM, the voltage gain of CCM is equal to the votage gain of DCM operation.

The boundary normalized magnetizing inductor time constant

$$\tau L_{MB} = \frac{D(1-D)^2}{2(1+2n)(1+n+nD)} \qquad (4)$$

A. Design Parameters

To verify the performance of the proposed converter, a prototype circuit is imple-mented in the laboratory. The speci cations are as follows:

1)input dc voltage Vin: 24 V;

2)output dc voltage Vo: 450 V;

3)maximum output power: 200 W;

4)switching frequency: 50 kHz;

5)MOSFET S: IRFB4410ZPBF;

6)diodesD1: SBR20A100CTFP, D2/D3: DESI30, andDo: BYR29;

7)coupled inductor: ETD-59, core pc40, Np : Ns = 1 : 4, Lm = 48 H, and Lk =0.25 H;

8)capacitors C1 : 56 F/100 V, C2/C3 : 22 F/200 V, and Co : 180 F/450 V.

The proposed converter is operated in CCM under the full-load condition. The steady-state analysiscan be demonstrated in the experimental results. In the measured waveforms, the voltage Vds across the main switch is clamped at approx-imately 84 V during the switch-o period. Therefore, a low-voltage-rated switch can be adopted to make the proposed converter reduce its conduction loss. In Fig. 2.10 the waveform of secondary current is of the coupled inductor shows that the proposed converter is operated in CCM because the current is not equal to zero when the switch is turned on. In Fig.2.11 the waveforms of iD2 and iD3 show that capacitors C2 and C3 are charged in parallel, which verify the concept of the proposed converter. Fig. 2.10.shows that the energy of leakage inductor Lk is released to capacitor C1 through diode D1. Fig.2.10 VC1 and VC2 satisfied. In addition, output voltage Vo is consistent.The out-put voltage is about 450 V, and the analysis of the DCM of the proposed converter is demonstrated.

V. SIMULATION OF PROPOSED CONVERTER

The simulation of the proposed converter is done by using SIMULINK/MATLAB software as shown .Here input voltage is 24V, output voltage is 450V, output power is 200W and load resistance can be 800 Ohms

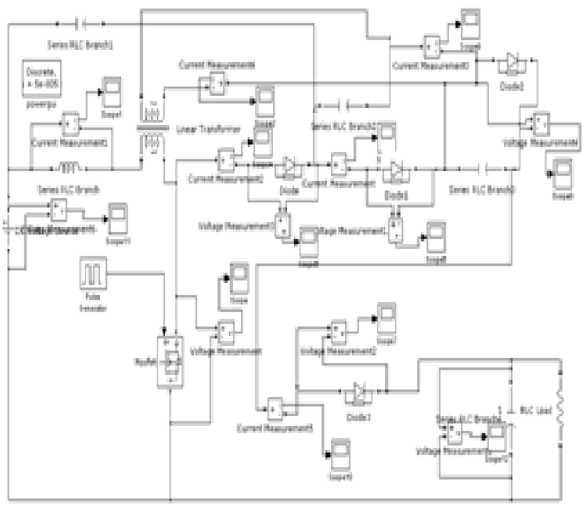

Figure 5.1 Simulation block

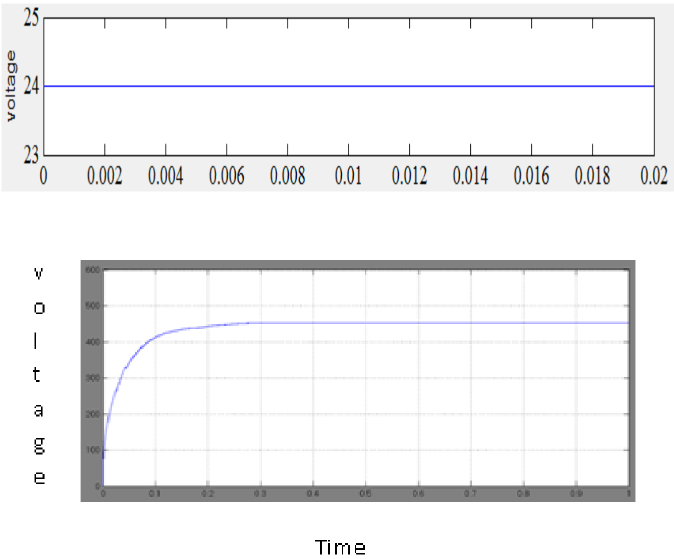

Figure 5.2 Input Output Waveform

VI. CONCLUSION

This paper has proposed a novel high step-up dc-dc converter for Distributed Generation systems. By using the capacitor charged in parallel and discharged in series by the coupled inductor, high step-up voltage gain and high efficiency are achieved. The steady-state analyses have been discussed in detail. Finally, a 24 to 450-V 200-W prototype circuit of the proposed converter is put into operation in the laboratory. The experimental results have conformed that high efficiency and high step-up volt-age gain can be achieved. Additionally, the voltage on the main switch is clamped at 84 V; thus, a switch with low voltage ratings and low ON-state resistance RDs(ON) can be selected.

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