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MODIFIED STEP UP RESONANT CONVERTER FOR HIGH VOLTAGE APPLICATIONS

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Abstract—The improvement of renewable energy sources is essential to mitigate the pressures of exhaustion of the fossil fuel and environmental pollution. To connect large-scale renewable energy sources with HVDC grid we require a highly efficient high-power high-voltage step-up DC-DC converters . But most of the DC-DC converter has high switching losses and low efficiency. Voltage step up ratio is also limited in most of the converters. To overcome these problems a modified step up resonant converter is proposed for high voltage application. The converter can achieve high efficiency and low-cost with the help of an LC parallel resonant tank where soft switches are employed. High step up gain can be obtained using this converter.Simulation is performed and verified the result using MATLAB.

KeyWords - renewable energy sources,resonant con-verter,soft switching,step-up

I. Introduction

Renewable energy is a practical, affordable solution to our electricity needs.We can readily continue rapid expansion of renewable energy by utilizing existing tech-nologies and investing in improvements to our electricity system.The generation equipments of the renewable en-ergy sources and energy storage devices usually enclose DC conversion stages and the produced electrical energy is delivered to the power grid during DC/AC stages, ensuing in additional energy loss .These energy losses can be avoided with the help of DC-DC converter and DC grid. The large-scale renewable energy sources and HVDC grid is connected by a pure DC system where high-power high-voltage step-up DC-DC converters are the solution tools to transmit the electrical energy.Among DC DC converters several high-power high-voltage step-up converter topologies have been studied.Boost con-verter is adapted by researchers of Converteam company to transmit energy from 50kV to 200kV [3].But, the efficiency of Boost converter is relatively low due to large reverse recovery loss of diode and switching loss under high-voltage condition, and Boost converter is usually used for the application where voltage-ratio is less than six. [4] presented a brief outline on Electronic Devices and Circuits which forms the basis of the Clampers and Diodes.Wu Chen et al compared different types of high-power high voltage DC-DC converter topologies and proposed a resonant switched-capacitor converter, which can effectively avoid the reverse recovery loss of diode and realize softswitching for main switches, but the switched-capacitor converter has the shortage of poor output voltage regulation[6, 7].In [8] a new family of resonant transformerless modular DC-DC converters is proposed and the main feature of the proposed converters is that the unequal voltage stress on semiconductors of thyristor valve is avoided with the use of active switching network. Thyristors have large voltage and current ratings; however, the use of thyristor limits the switching frequency of the converter, and leads to use of bulky passive components.Several isolated DC-DC converters are compared in [6] and among them phase-shifted full-bridge converter is an optimal choice.But for isolated topologies the fabrication of high-power high-voltage medium-frequency transformer is very difficult and there is no report about the transformer prototype yet.

In this paper, a modified resonant step-up DC-DC converter is proposed, which can realize softswitching for main switches and diodes and large voltage gain. The operation principle of the converter is presented in the paper.

II. Operation Principle

Fig. 1 shows the proposed modified resonant step-up DC-DC converter and its key waveforms are depicted in Fig. 2. Q_2 and Q_3 are tuned on and off simultaneously, and Q_4 are tuned on and off simultaneously.There are 8 modes of operation.Equivalent circuits are illustrated in Fig. 3. The following assumptions are made before analysis, 1.All switches, diodes, inductor, and capacitor are ideal components; 2.

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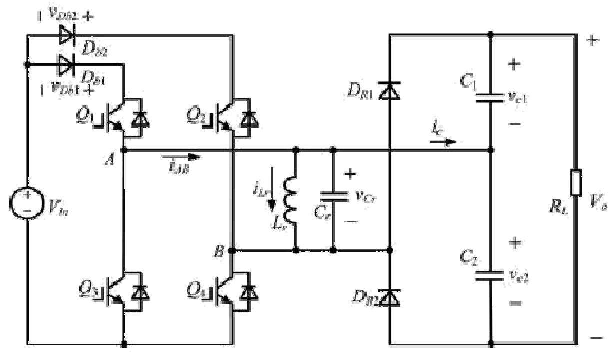

Fig. 1. Topology of the proposed step up resonant converter

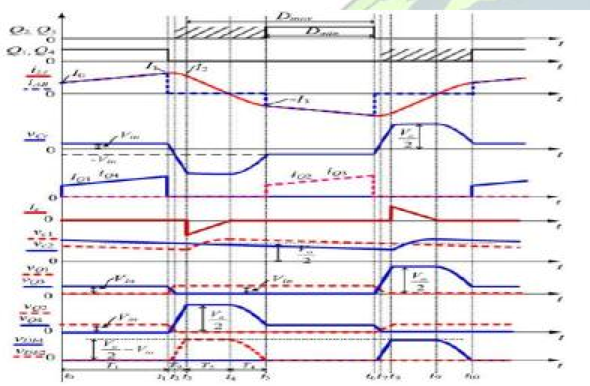

Fig. 2. Operating waveforms of the proposed converter

1) Mode 1[t_0; t_1]

At t_0, Q_1 and Q_4 are turned on.The resonant in-ductor L_r absorbs energy from V_{in}. The converter operates similar to a conventional boost converter and the resonant inductor $L_r$acts as the boost inductor with the current through it increasing linearly from I_0 .

$$I_1 = I_0 + \frac{V_{in} I_1}{L_r} \quad (1)$$

2) Mode 2 [t_1 ,t_3]

At t_1 , Q_1 and Q_4 are turned off and after that L_r resonates with C_r , v_{Cr} decreases from V_{in} , and i_{Lr} increases from I_1 in resonant form.Due to the parasitic capacitor of main switch is much smaller than C_r, the voltage increase of the parasitic capacitor is very small during the turn-off time of Q_1 and Q_4, hence, Q_1 and Q_4 are turned off with zero-voltage.during t_1 to t_3 , no power is transferred from the input source or to the load, and the whole energy stored in the LC resonant tank is unchanged.

$$i_{Lr}(t) = \frac{V_{in}}{Z_r}\sin[\omega_r(t-t_1)]+I_1\cos[\omega_r(t-t_1)] \quad (3)$$

$$v_{Cr}(t) = V_{in}\cos\omega_r(t-t_1)] - I_1 Z_r \sin\omega_r(t-t_1)] \quad (4)$$

where $Z_r = \sqrt{\frac{L_r}{C_r}}$,$\omega_r = \frac{1}{\sqrt{L_r C_r}}$

(3) Mode 3 [t_4, t_5]

At t_4, v_{Cr} = -V_o, D_{R1} and D_{R4} conduct naturally, C_o is charged by i_{Lr} through D_{R1} and D_{R4}, v_{Cr} keeps unchanged, i_{Lr}decreases linearly.

$$T_3 = \frac{2I_2L_r}{V_o} \quad (5)$$

The energy delivered to load side in this mode is

$$E_{out} = \frac{V_0 I_2 T_3}{2} \quad (6)$$

4) Mode 4 [t_4 ,t_5]

At t_4 , i_{Lr} decreases to zero and the current flow-ing through D_{R1}also decreases to zero, and D_{R1} is turned off with zerocurrentswitching (ZCS); therefore, there is no reverse recovery. After t_4 ,$L_r$resonates with C_r ,C_r is discharged through L_r , v_{Cr} increases from V_o/2 in positive direction, and i_{Lr} increases from zero in negative direction. During this mode whole energy stored in the LC resonant tank is unchanged,

$$\frac{1}{2}C_r\left(\frac{V_0}{2}\right)^2 = \frac{1}{2}L_r I_3^2 + \frac{1}{2}C_r V_{in}^2 \quad (7)$$

5) Mode 5 [t_5 ,t_6]

If Q_2 and Q_3 are turned on before t_5 , then after t_5, L_r is charged by V_{in} through Q_2 and Q_3 , i_{Lr} increases in negative direction, and the mode is similar to Mode 1.The other 4 operation modes are similar to Modes 2-4.

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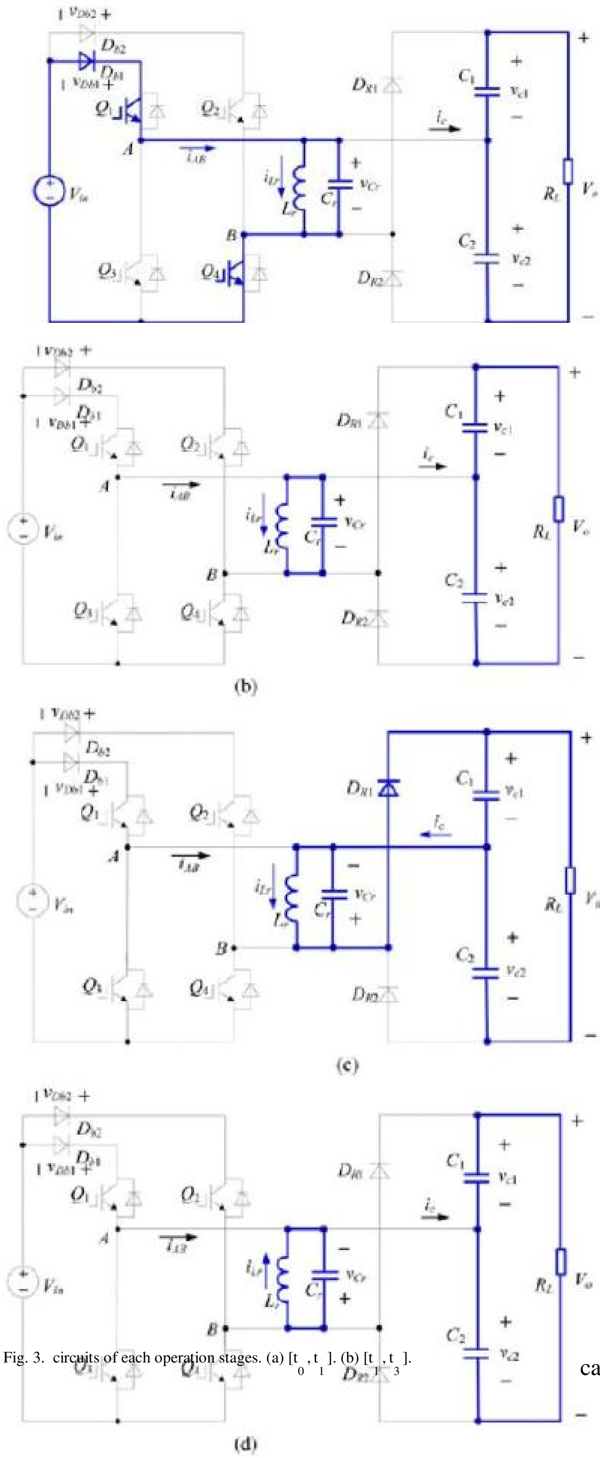

Fig. 3. circuits of each operation stages. (a) $[t_0, t_1]$. (b) $[t_1, t_3]$.

III. Analysis and design of the proposed converter

A. Analysis of the converter

$$\frac{V_o}{V_{in}} = \frac{2}{\cos(\omega_r T_4)} \quad (8)$$

From the above equation it can be seen that the gain is impacted by the resonant tank parameters and the time interval T_4,which is a part of switching period.Hence in another words gain is impacted by L_r,C_r and switching frequency.

under unloaded condition

$$f_s = f_r \quad (9)$$

where f_r is the resonant frequency and f_s is the switch-ing frequency.

$$f_r = \frac{1}{2\Pi\sqrt{L_r C_r}} \quad (10)$$

It can be seen that the switching frequency is equal to the resonant frequency under unloaded condition.the switch-ing frequency decreases with increase in load.Therefore, the maximum switching frequency of the converter is

$$f_{smax} = f_r \quad (11)$$

B. Design of the converter

A 5 MW,4kV/80kV step up converter is taken as an example to design the prameters.Insulated-gate bipolar transistors (IGBTs) are taken as the main switches and f_{smax} is set to be 5 kHz.

The switching frequency is associated with $L_r$under full load condition.With the help of mathematical anal-ysis software Maple, we can obtain the curves between L_r and T_s under different input voltages as shown in fig 4. from the figure it is clear that for given V_o and L_r , the lower the input voltage V_{in} , the lower the switch-ing frequency, and for given input voltage range, the smaller the L_r , the narrower the variation of switching frequency.from fig 3 it can be seen that the smaller the L_r , the shorter the T_s under full-load condition, which means that the converter has relatively narrower range of switching frequency because the maximum switching frequency is fixed, and it is beneficial to the design of input/output filters and resonant inductor. from fig 5,it can be seen that the peak current through switches and

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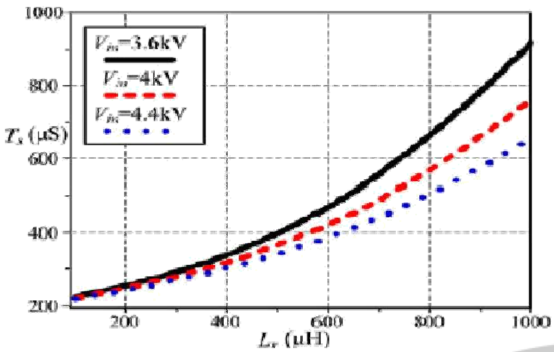


Fig. 4. Curves between L_r and T_S under different input voltages

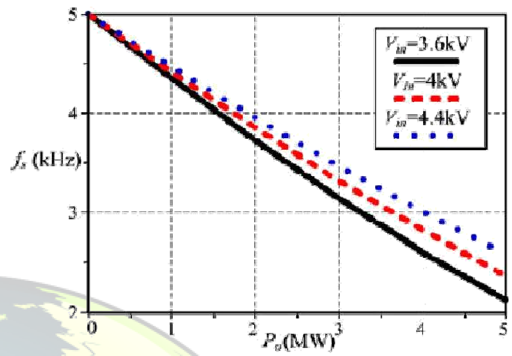


Fig. 6. Curves of switching frequency versus output power under different input voltages

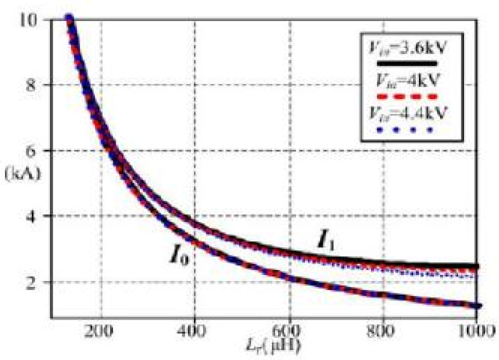
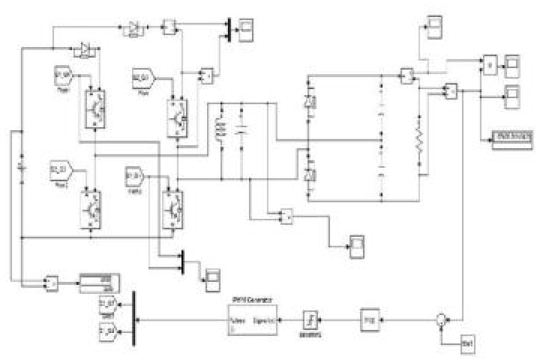


Fig. 5. Curves between L_r and I_0 , I_1 under different input voltages



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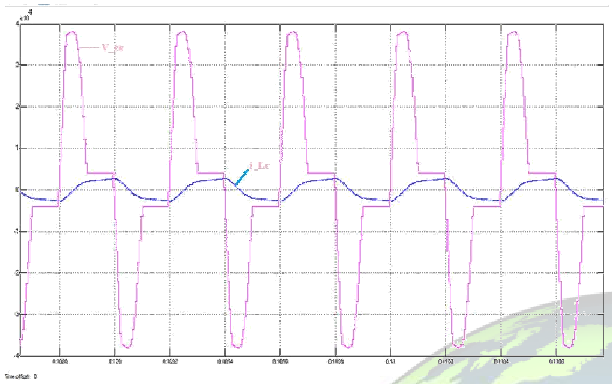

Fig. 9. v_{Cr} and i_{Lr} waveform

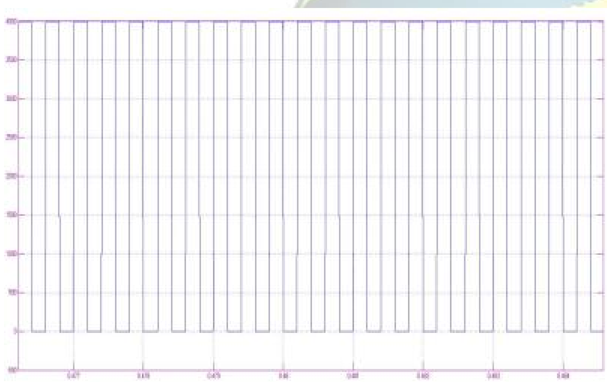

Fig. 10. voltage stress on Q_1

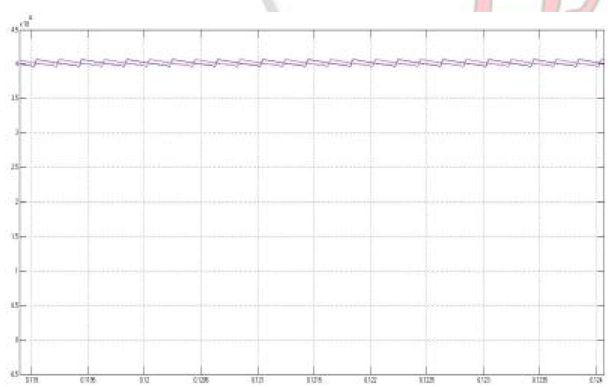

Fig. 11. voltage across filter capacitor

IV. Simulation Results

In order to verify the operation principle and the theo-retical analysis, a converter is simulated with MATLAB simulation software and the detailed parameters are listed in Table I .

Fig 6 shows the the input and output voltage wave-forms.The voltage across the resonant capacitor is 40 kV and it is shown in figure 8.The voltage stress of Q_1 is 40kV.Voltage across the filter capacitors are shown in fig 10.

V. Conclusion

A modified step up resonant converter is proposed in this paper,which can attain a high step up voltage gain and it can be used in high voltage high power applications.The gain value depends on the resonant tank parameter and gain can be varied by changing resonant inductance and capacitance value.soft switching can be for all the active switches during turn off.Simulation results verify the operation principle of the converter and parameters selection of the resonant tank.

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