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A Boost Resonant Converter for HVDC-Connected Renewable Energy Sources


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Abstract:

Rapid increasing of renewable energy sources and HVDC grid, it is a promising option to connect the renewable energy sources to the HVDC grid with a pure dc system, in which high-power high-voltage step-up dc–dc converters are the key equipment to transmit the electrical energy. This paper proposes a resonant converter which is suitable for grid-connected renewable energy sources. The converter can achieve high voltage gain using an LC parallel resonant tank. It is characterized by zero-voltage-switching turn-on and nearly ZVS turn-off of main switches as well as zero-current-switching turn-off of rectifier diodes.

The equivalent voltage stress of the semiconductor devices is lower than other resonant step-up converters.

Technologies used:

- Renewable energy.
- Resonant converter.
- Soft switching.
- Voltage step-up.
- Voltage Stress.

INTRODUCTION:

The development of renewable energy sources is crucial to relieve the pressures of exhaustion of the fossil fuel and environmental pollution. At present, most of the renewable energy sources are utilized with the form of ac power. The generation equipment's of the renewable energy sources and energy storage devices usually contain dc conversion stages and the produced electrical energy is delivered to the power grid through dc/ac stages, resulting in additional energy loss. The common problem of the renewable energy sources, such as wind and solar, is the large variations of output power, and the connection of large scale of the renewable sources to the power grid is a huge challenge for the traditional electrical equipment, grid structure, and operation.

Exciting:

The voltages over the dc stages in the generation equipment's of the renewable energy sources are low, High-power high-voltage step-up dc–dc converters are required to deliver the produced electrical energy to the HVDC grid. The converter between the renewable energy sources and HVDC lines, the step-up dc–dc converters not only transmit electrical energy, but also isolate of fault conditions.In resent days, the high-power high-voltage step-up dc–dc converters have been extensively used. The transformer is a convenient approach to realize voltage step-up. The classic full-bridge (FB) converter, and LCC resonant converter are implemented wind farm application. The three-phase topologies, such as three-phase SAB converter, series resonant converter, and dual active bridge converter, which are more suitable for high-power applications due to alleviated current stress of each bridge, are also studied and designed for high-power high-voltage

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step-up applications. The emerging modular dc–dc converter, which uses two modular multilevel converters linked by a medium frequency transformer, is well suited for the application in the HVDC grid. For isolated topologies, the main obstacle is the fabrication of the high-power high-voltage medium-frequency transformer and there is no report about the transformer prototype yet. Multiple small-capacity isolated converters connected in series and/or parallel to form a high-power high-voltage converter is an effective means to avoid the use of single large-capacity transformer.

Proposed:

For the application where galvanic isolation is not mandatory, the use of a transformer would only increase the cost, volume, and losses, especially for high-power high-voltage applications [21]. Several non-isolated topologies for high-power high-voltage applications have recently been proposed and studied in the literature. To obtain the higher voltage gain. proposed a multiple-module structure, which consists of a boost converter and a buck/boost converter connected in input-parallel output-series. The output power and voltage are shared by the two converters and the voltage and current ratings of switches and diodes are correspondingly reduced. However, the efficiency of a boost or buck/boost converter is relatively low due to the hard switching of the active switch and the large reverse recovery loss of the diode.

The soft-switching technology is critical to improve the conversion efficiency, especially for high-voltage applications [31]–[37]. Recently, several soft-switching topologies for high power high-voltage applications have been proposed. In [24] and [25], the converter topologies based on resonant switched capacitor (RSC) are proposed with reduced switching loss and modular structure. The shortage of the RSC-based converter is the poor voltage regulation and the requirement of a large number of capacitors. Jovcic et al. proposed a novel type of resonant step-up converter with potentially soft-switching operation, which utilizes thyristors as switches and does not suffer from excessive switch stresses and reverse recovery problems; moreover, a large voltage gain is easily obtained [26]–[28]. Similarly, in [29], 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, which is composed of anc capacitor and four identical active switches.

Working principle:

The proposed resonant step-up converter is shown in Fig. 1. The converter is composed of an FB switch network, which comprises Q1 through Q4 , an LC parallel resonant tank, a voltage doubler rectifier, and two input blocking diodes, Db1 and Db2 . The steady-state operating waveforms are shown in Fig. 2 and detailed operation modes of the proposed converter are shown in Fig. 3. For the proposed converter, Q2 and Q3 are tuned on and off simultaneously; Q1 and Q4 are tuned on and off simultaneously. In order to simplify the analysis of the converter, the following assumptions are made:

1) All switches, diodes, inductor, and capacitor are ideal components;

2) Output filter capacitors C1 and C2 are equal and large enough so that the output voltage Vo is considered constant in a switching period Ts .

Mode of the operation:

Mode 1:

During this mode, Q1 and Q4 are turned on resulting in the positive input voltage Vin across the LC parallel resonant tank, i.e., vLr = vC r = Vin . The converter operates similar to a conventional boost converter and the resonant inductor Lr acts as the boost inductor with the current through it increasing linearly from I0 . The load is powered by C1 and C2 . At t1 , the resonant inductor current iLr reaches I1.

$$I_1 = I_0 + \frac{V_{\text{in}} T_1}{L_r}$$

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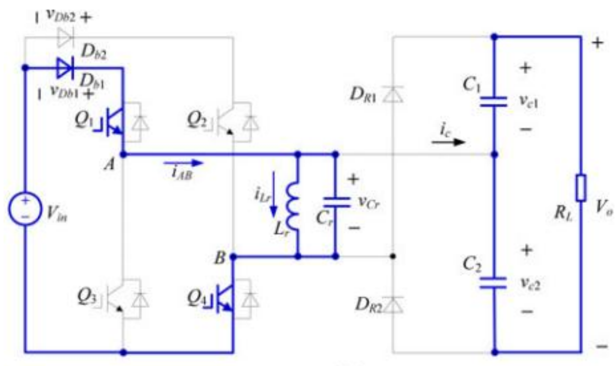
Where T1 is the time interval of t0 to t1 .

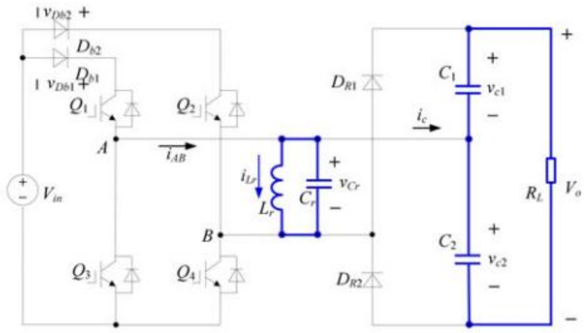


(a)

Mode 2:

At t1 , Q1 and Q4 are turned off and after that Lr resonates with Cr , vC r decreases from Vin , and iLr increases from I1 in resonant form. Taking into account the parasitic outputcapacitors of Q1 through Q4 and junction capacitor of Db2 , the equivalent circuit of the converter after t1 is shown in Fig. 4(a), in which CDb2 , CQ1 , and CQ4 are charged, CQ2 and CQ3 are discharged. In order to realize zero-voltage switching (ZVS) for Q2 and Q3 , an additional capacitor, whose magnitude is about ten times with respect to CQ2 , is connected in parallel with Db2 . Hence, the voltage across Db2 is considered unchanged during the charging/discharging process and Db2 is equivalent to be shorted.

When vC r drops to zero,iLr reaches its maximum magnitude. After that, vC r increases in negative direction and iLr declines in resonant form. At t2 , vC r = −Vin , the voltages across Q1 and Q4 reach Vin , the voltages across Q2 and Q3 fall to zero and the two switches can be turned on under zero-voltage condition. It should be noted that although Q2 and Q3 could be turned on after t2 , there are no currents flowing through them. After t2 ,Lr continues to resonate with Cr , vC r increases in negative direction from −Vin , iLr declines in resonant form. Db2 will hold reversed-bias voltage and the voltage across Q4 continues to increase from Vin .



(b)

Mode 3:

At t3 ,vC r = −Vo/2, DR1 conducts naturally, C1 is charged by iLr through DR1 , vC r keeps unchanged, and iLr decreases linearly. At t4 ,iLr = 0. The time interval of t3 to t4 is

$$T_3 = \frac{2I_2L_r}{V_o}.$$

The energy delivered to load side in this mode is

$$E_{\text{out}} = \frac{V_oI_2T_3}{4}.$$

The energy consumed by the load in half-switching period is

$$E_R = \frac{V_oI_oT_s}{2}.$$

Assuming 100% conversion efficiency of the converter and according to the energy conversation rule, in half-switching period

$$E_{\text{in}} = E_{\text{out}} = E_{\text{R}}.$$

Combining above equations, we get:

$$I_2 = V_o\sqrt{\frac{I_oT_s}{V_oL_r}}$$

$$T_3 = 2\sqrt{\frac{T_sI_oL_r}{V_o}}.$$

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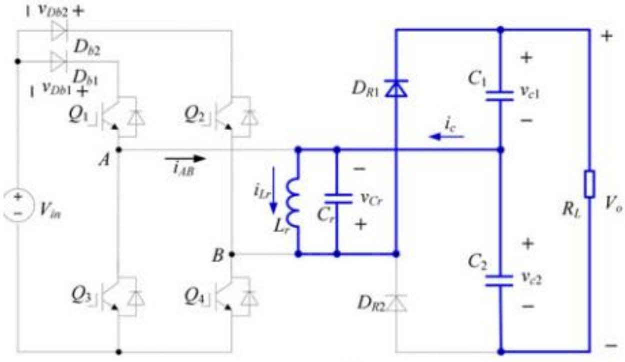


(c)

Mode 4:

At t4 ,iLr decreases to zero and the current flowing through DR1 also decreases to zero, and DR1 is turned off with zerocurrent switching (ZCS); therefore, there is no reverse recovery. Aftert4, Lr resonates with Cr, Cr is discharged throughLr ,vC r increases from −Vo/2 in positive direction, and iLr increases from zero in negative direction. Meanwhile, the voltage across Q4 declines from Vo/2. At t5 ,vC r = −Vin , and iLr = −I3 . In this mode, the whole energy stored in the LC resonant tank is unchanged, i.e.,

$$\frac{1}{2}C_r\left(\frac{V_o}{2}\right)^2 = \frac{1}{2}L_r I_3^2 + \frac{1}{2}C_r V_{\text{in}}^2.$$

We have

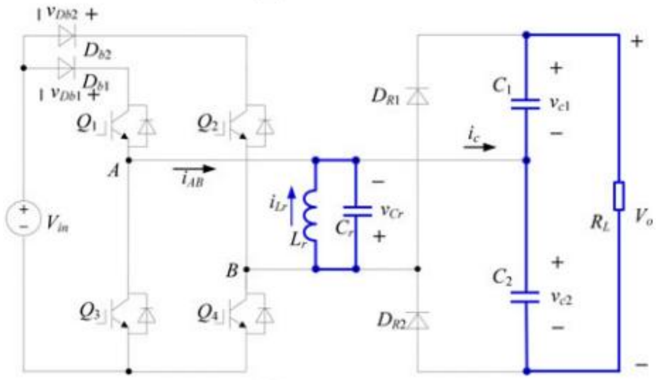
$$I_0 = I_3 = \frac{1}{2}\sqrt{\frac{C_r(V_o^2 - 4V_{\text{in}}^2)}{L_r}}$$

$$i_{Lr}(t) = -\frac{V_o}{2\omega_r L_r}\sin\left[\omega_r(t-t_5)\right]$$

$$v_{Cr}(t) = \frac{-V_o\cos\left[\omega_r(t-t_5)\right]}{2}$$

$$T_4 = \frac{1}{\omega_r}\arccos\left(\frac{2V_{\text{in}}}{V_o}\right)$$

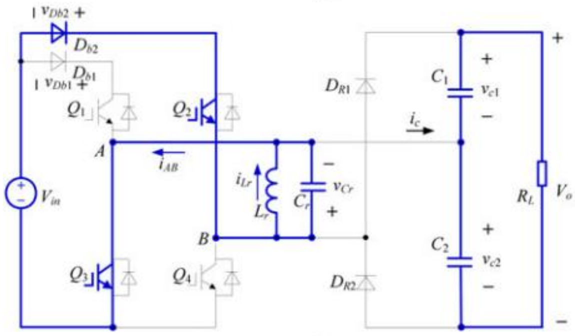
Where T4 is the time interval of t4 to t5.



(d)

Mode 5:

If Q2 and Q3 are turned on before t5 , then after t5 , Lr is charged by Vin through Q2 and Q3 , iLr increases in negative direction, and the mode is similar to Mode 1. If Q2 and Q3 are not turned on before t5 , then after t5 , Lr will resonate with Cr , the voltage of node A vA will increase from zero and the voltage of node B vB will decay from Vin ; zero-voltage condition will be lost if Q2 and Q3 are turned on at the moment. Therefore, Q2 and Q3 must be turned on before t5 to reduce switching loss.



(e)

ANALYSIS:

A. Voltage Rating and DC Fault Response:

The voltage stresses of Q1 and Q2 are the input voltage Vin , the voltage stresses of Q3 and Q4 are half of the output voltage, i.e., Vo/2, the voltage stresses of Db1 and Db2 are Vo/2 − Vin . The total voltage stress of the primary semiconductor devices is 2Vo , which is half of that in [26]–[29]. It implies that much less semiconductor devices are required in the

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proposed step-up converter, resulting in low conduction and switching losses and low cost. Moreover, the peak voltages across the resonant inductor and resonant capacitor are Vo/2, which is also half of that in [26]– [29]. Lower peak voltage indicates that the insulation is easy to be implemented, leading to the reduction of the size of the resonant tank

B. Voltage Balance between C1 and C2

The previous analysis is based on the assumption that voltages across C1 and C2 are, respectively, half of output voltage. Provided that Vc1 = Vc2 , for example, Vc1 > Vo/2 > Vc2 , according to the operation principle of Fig. 2, the peak current of ic at t3 will be smaller than that at t8 , which means that the average current flowing into C1 will be smaller than the average current flowing into C2 . Due to C1 and C2 power the same load, therefore, Vc1 decreases and Vc2 increases, and finally they share the same output voltage. Vice versa, i.e., Vc1 increases and Vc2 decreases under the presumption that Vc1 < Vo/2 <Vc2 .

SOFTWARE TOOLS:

(Matlab Simulation)

- **Simulink**
- It is a commercial tool for modeling, simulating and analyzing multi domain dynamic systems.
- Its primary interface is a graphical block diagramming tool and a customizable set of block libraries.
- Simulink is widely used in control theory and digital signal processing for multi domain simulation and Model based design.

APPLICATIONS

1. Technical computing
2. Engineering and sciences applications
   - Electrical Engineering
   - Automation
   - Communication purpose
   - Aeronautical
   - Pharmaceutical
   - Financial services.

Other Features

- 2-D and 3-D graphics functions for visualizing data
- Tools for building custom graphical user interfaces
- Functions for integrating MATLAB based algorithms with external applications and languages, such as C, C++, Fortran, Java, COM, and Microsoft Excel .

ADVANTAGES:

In the proposed converters, all the power switches are operated at fixed 50% duty cycle, and the output voltage regulation is achieved by adopting phase shift control between the primary and secondary-side switches. ZVS performance has been achieved for both the primary- and secondary-side switches in a wide voltage and load range. Furthermore, the reverse-recovery problems associated with the rectifier diodes are alleviated.

APPLICATION:

Developments of renewable energy, smart grid, and electric vehicles, isolated dc–dc converters have been widely used in a number of applications to meet the requirements of galvanic isolation and/or voltage conversion ratio. For further improvements on performance of efficiency, power density, and electromagnetic noise,

SIMULINK RESULTS AND OUTPUTS:

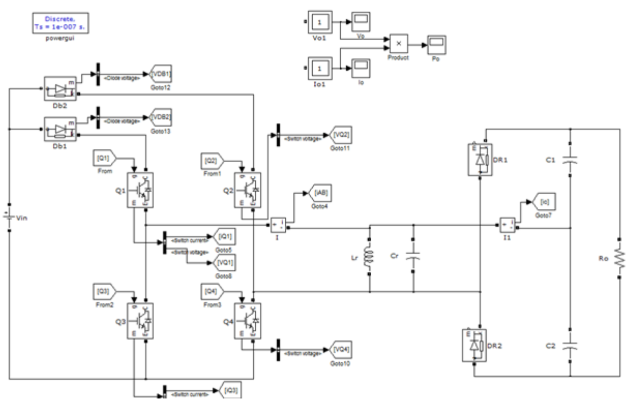

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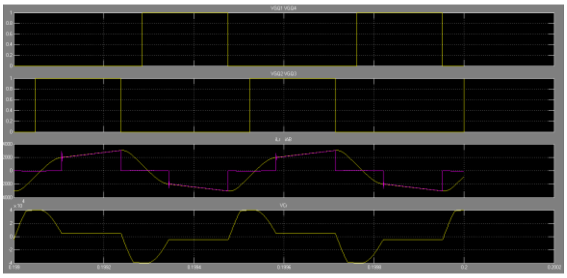
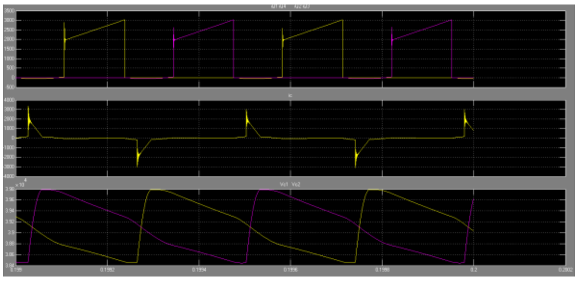
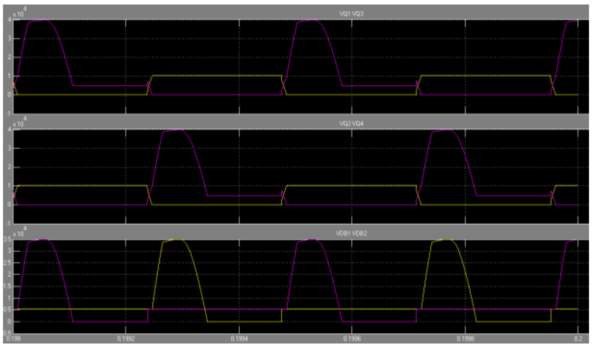
Figure: simulation block diagram of the A Stepup Resonant Converter for Grid Connected.

Simulation waveforms:

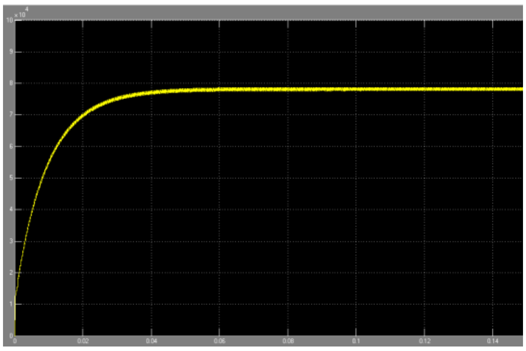


Pulses and respected Resonant tank outputs.

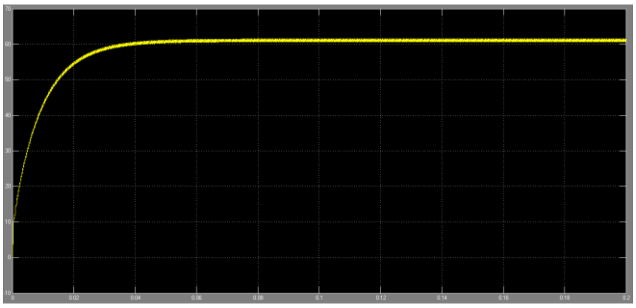




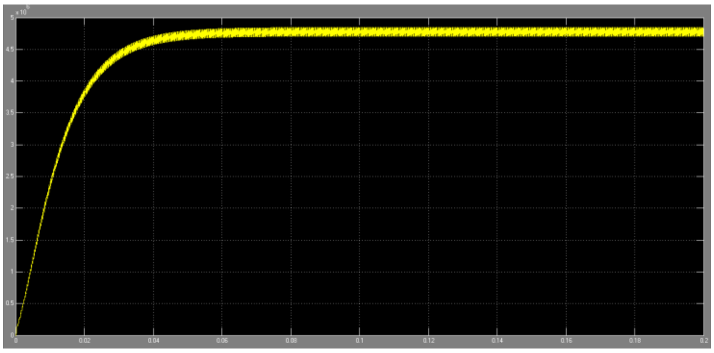
Switching voltage of Q1,2,3 and 4 And diode VDb1,b2



Output voltage



Output current



V. CONCLUSION:

A New resonant dc–dc converter is shown in this project, which can achieve very high step-up voltage gain and it is suitable for high-power high-voltage applications.

- The converter utilizes the resonant inductor to deliver power by charging from the input and discharging at the output.
- The resonant capacitor is employed to achieve zero-voltage turn-on and turn-off for the active switches and ZCS for the rectifier diodes.
- The analysis demonstrates that the converter can operate at any gain value (> 2) with proper control.

The resonant tank determines the maximum switching frequency, the range of switching frequency, and current ratings of active switches and diodes.

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