A Step-up Resonant Converter For Renewable Energy Sources

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Abstract - With the rapid development of large-scale 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. A resonant converter which is suitable for grid-connected renewable energy sources. The converter can achieve high voltage gain using and LC parallel resonant tank. It is characterized by zero-voltage-switching (ZVS) turn-on and nearly ZVS turn-off of main switches as well as zero-current-switching turn-off of rectifier diodes; moreover, the equivalent voltage stress of the semiconductor devices is lower than other resonant step-up converters. The operation principle of the proposed converter has been successfully verified by simulation results.

***Key Words*:** HVDC, resonant, ZVC, LC parallel ,resonantank,,Grid Connected

1.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 equipments 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.

Moreover, 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. DC grid, as one of the solutions to the aforementioned issues, is an emerging and promising approach which has been drawn much attention recently.

At present, the voltages over the DC stages in the generation equipments of the renewable energy sources are relatively low, in the range of several hundred volts to several thousand volts, hence, high-power high-voltage step-up DC-DC converters are required to deliver the produced electrical energy to HVDC grid. Furthermore, as the connectors between the renewable energy sources and HVDC grid, the step-up DC-DC converters not only transmit electrical energy, but also isolate or buff kinds of fault conditions, they are one of the key equipments in the DC grid.

Recently, the high-power high-voltage step-up DC-DC converters have been studied extensively. The transformer is a convenient approach to realize voltage step-up. The classic full-bridge (FB) converter, single active bridge (SAB) converter and LCC resonant converter are studied and their performance is compared for the offshore wind farm application. The three phase topologies, such as three-phase SAB converter ,series resonant converter and dual active bridge (DAB)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 step-up applications.

2. PROPOSED STEP UP RESONANT CONVERTER

The proposed resonant step-up converter is shown in Fig2.1. The converter is composed of a full-bridge switch network, which is made up by $Q1$ through $Q4$, a 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. 3.4. 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.

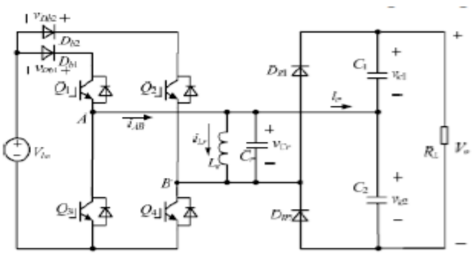

Fig:2.1 Proposed step up resonant converter

3.PRINCIPLE OF OPERATION AND ANALYSIS

3.1Mode 1 [$t0$, $t1$]

During this mode, $Q1$ and $Q4$ are turned on resulting in the positive input voltage Vin across the LC parallel resonant tank, i.e., $vLr=vCr=Vin$. 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 $I1$.

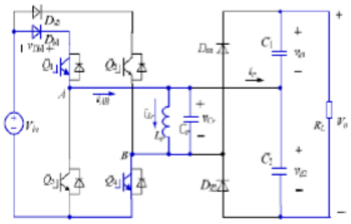

Fig:3.1Equivalent circuit of mode 1

3.2.Mode 2 [$t1$, $t3$]

At $t1$, $Q1$ and $Q4$ are turned off and after that Lr resonates with Cr, vCr decreases from Vin and iLr increases from $I1$ in resonant form. Taking into account the parasitic output capacitors of $Q1$ through $Q4$ and junction capacitor of $Db2$, the equivalent circuit of the converter after $t1$ is shown in Fig. 3.6(a), in which $CDb2$, $CQ1$ and $CQ4$are charged, $CQ2$ and $CQ3$ are discharged.

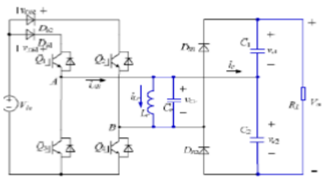

Fig:3.2 Equivalent circuit of mode 2

In order to realize zero-voltage-switching (ZVS) for $Q2$ and $Q3$, an additional capacitor, whose magnitude is about 10 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. Due to Cr is much larger than the parasitic capacitances, the voltages across $Q1$ and $Q4$ increase slowly. As a result, $Q1$ and $Q4$ are turned off at almost zero voltage in this mode. When vCr drops to zero, iLr reaches its maximum magnitude.

3.3.Mode 3 [$t3$, $t4$]

At $t3$, vCr =-Vo/2, $DR1$ conducts naturally, $C1$ is charged by iLr through $DR1$, vCr keeps unchanged, iLr decreases linearly. At $t4$, iLr =0.

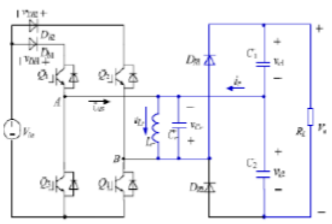

Fig:3.3Equivalent circuit of mode 1

At $t4$, iLr decreases to zero and the current flowing through $DR1$ also decreases to zero, and $DR1$ is turned off with zero-current-switching (ZCS), therefore, there is no reverse recovery.

3.4 Mode 4 [$t4$, $t5$]

After $t4$, Lr resonates with Cr, Cr is discharged through Lr, vCr increases from -Vo/2 in positive direction, iLr increases from zero in negative direction. Meanwhile, the voltage across $Q4$ declines from Vo/2. At $t5$, vCr = -Vin, iLr= -$I3$. In this mode, the whole energy stored in LC resonant tank is unchanged.

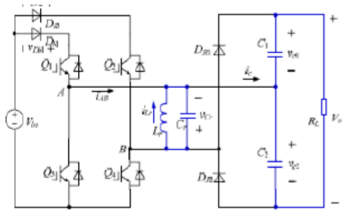

Fig:4 Equivalent circuit of mode 4

3.5 Mode 5 [$t5$, $t6$]

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, 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.

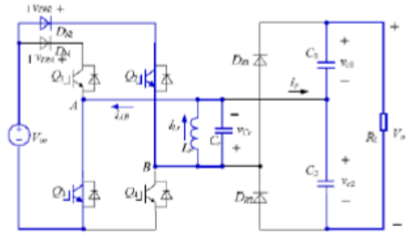

Fig:3.5 Equivalent circuit of mode 5

3.6 Mode 6 [t6,t8]

At $t6$, $Q2$ and $Q3$ are turned off and after that Lr resonates with Cr, vCr decreases from Vin and iLr increases from $I1$ in resonant form.
After that, vCr increases in negative direction and iLr declines in resonant form. At $t2$, vCr = -Vin, the voltages across $Q2$ and $Q3$ reach Vin, the voltages across $Q1$ and $Q4$ fall to zero and the two switches can be turned on under zero-voltage condition.

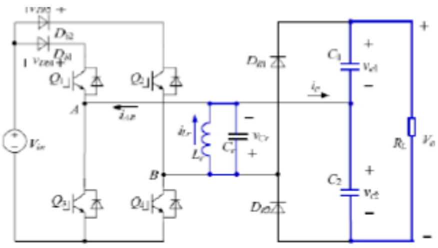

Fig:3.6 Equivalent circuit of mode 6

3.7. Mode 7 [t8, t9]

At $t8$, vCr =-Vo/2, $DR2$ conducts naturally, $C1$ is charged by iLr through $DR1$, vCr keeps unchanged, iLr decreases linearly. At $t9$, iLr =0.

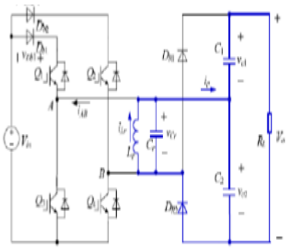

Fig:3.7 Equivalent circuit of mode 7

3.8 Mode 8 [t9, t10]

At $t9$, iLr decreases to zero and the current flowing through $DR2$ also decreases to zero, and $DR2$ is turned off with zero-current-switching (ZCS), therefore, there is no reverse recovery.

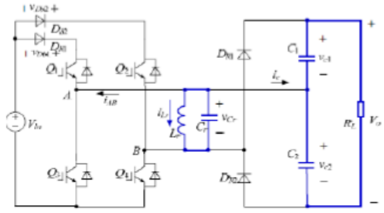

Fig:3.8 Equivalent circuit of mode 8

After $t9$, Lr resonates with Cr, Cr is discharged through Lr, vCr increases from $-Vo/2$ in positive direction, iLr increases from zero in negative direction. Meanwhile, the voltage across $Q3$ declines from $Vo/2$. At $t10$, $vCr = -Vin$, $iLr= -I3$. In this mode, the whole energy stored in LC resonant tank is unchanged.

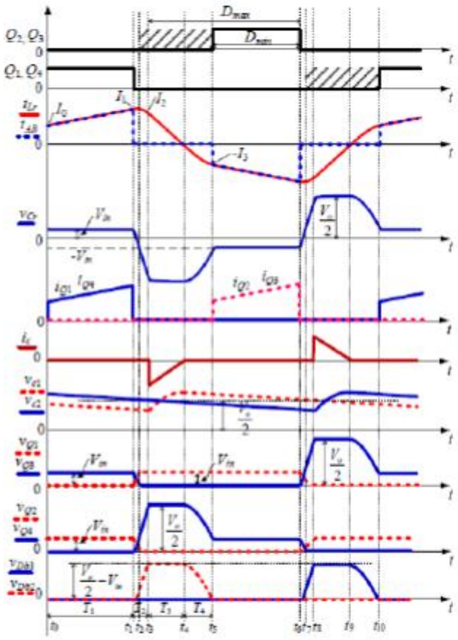

Fig:3.9 Operating waveforms of the proposed converter

4.PERFORMANCE ANALYSIS

MATLAB is a high-performance language for technical computing. It integrates computation, visualization and programming in an easy-to-use environment where problems and solutions are expressed in familiar mathematical notation. MATLAB is an interactive system whose basic data element is an array that does not require dimensioning. This allows you to solve many technical computing problems, especially those with matrix and vector formulations, in a fraction of the time.

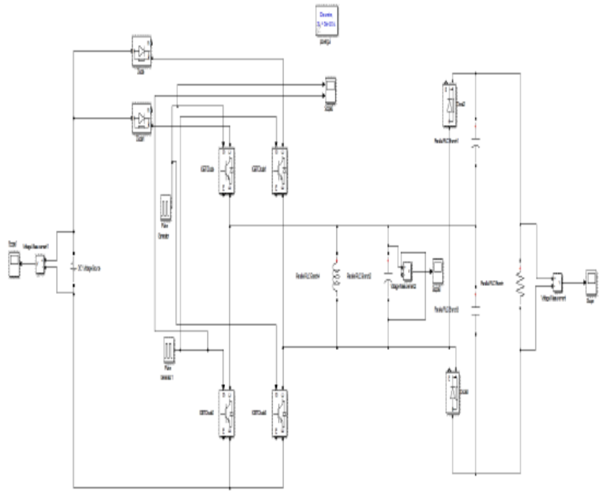

Fig:4.1 simulink diagram of step up resonant converter

Fig:4.1 shows the simulink diagram of step up resonant converter. The Fig4.2 shows the input voltage of step up resonant converter. The input voltage applied to the converter is 4000 V which can be seen from the input scope connected across the input source voltage.

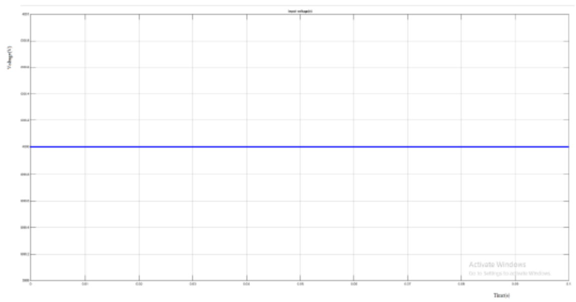

Fig:4.2 input voltage

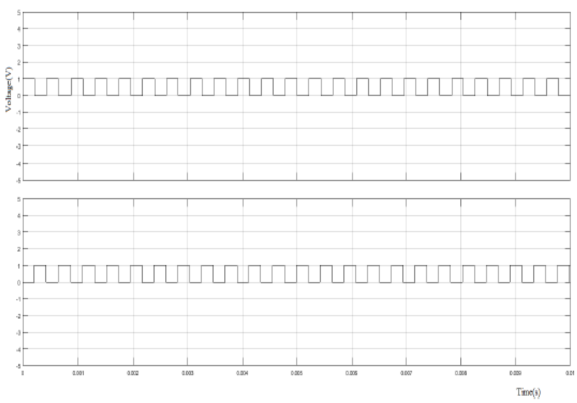

Fig 4. 2 pulses for switches Q1, Q4 and Q2, Q3.

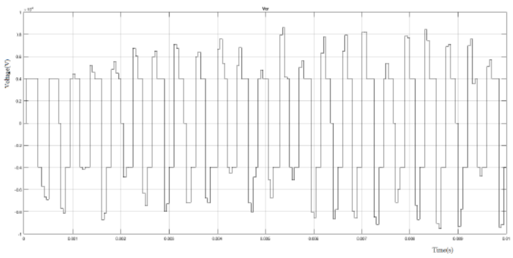

Fig:4.3Voltage across Capacitor of resonant converter

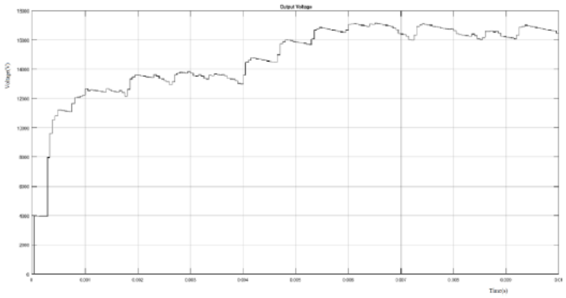

Fig:4.4 Output voltage

3. CONCLUSIONS

A novel resonant DC-DC converter is proposed, which can achieves very high step-up voltage gain and it is suitable for high-power high-voltage applications. The converter utilizes the resonant inductor to delivery power by charging from the input and discharging to 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, however, the parameters of the resonant tank determine the maximum switching frequency, the range of switching frequency and current ratings of active switches and diodes. The converter is controlled by the variable switching frequency. Simulation results verify the operation principle of the converter and parameters selection of the resonant tank.

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