The Circuits of Resonant Inverters with Limited Voltage across the Commutating Inductors

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Abstract – **The paper presents a review of resonant inverters circuits with limited voltage across the commutating inductors. In the paper are shown the priority, which it has over the classical resonant inverters. Some of the circuits can work in both regimes – with natural commutation and with forced commutation (current source inverter).**

Keywords – **limited voltage across the commutating inductors, resonant inverters, current source inverter, improved output characteristics.**

I. Introduction

For the resonant inverters (RI) with limited voltage across the commutating inductors (LVCI), there is no matter if they operate in natural or forced commutation mode, a lot of performances working with non-constant load can be reached as they possess better characteristics. Usually these loads are typical for various technologies as: induction heating, melting, hardening, switching power supplies, electronic ballast for fluorescent lamps etc**.**

II. The review of voltage limited circuits

The one of the circuits that improves resonant inverters output characteristics is shown on figure 1. In these circuits there is additional device that limits voltage across the commutating inductors [1]. This is the half-bridge resonant inverter with divided power supply. To the classical circuit there are added additional devices C_F, L_F, VD1 and VD2, witch improve the resonant inverters output characteristics. When the value of the coefficient of hesitation k [2] is 1<k<1.5, the diodes VD1 and VD2 have not conditions for turning-on. In this case the circuit from figure 1 works as classical resonant inverters (CRI). If at the technology process by any reasons the voltages across the devices increases (increment of the voltage across the commutating inductor Lk1 over 0,5Ud), that the diodes VD_1 and VD_2 are turned-on and limits the voltage across the commutating inductors to the 0,5Ud level. The level 0,5Ud is the voltage level to which the capacitors C_F are charged. At these conditions the voltage across the switching devices are not higher than 1,5Ud. The limitation of the voltage level can be regulated by dividing the commutating inductors Lk in two parts and connecting a part of Lk in series with load Z and commutating capacitor Ck. This circuit (fig.1) has a “harder” output characteristic.

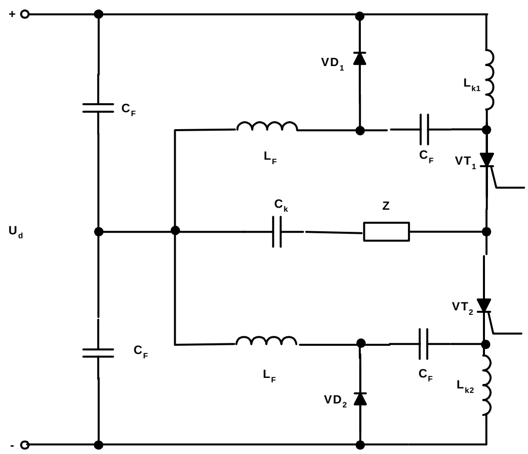

Figure 1. - Half-bridge resonant inverter

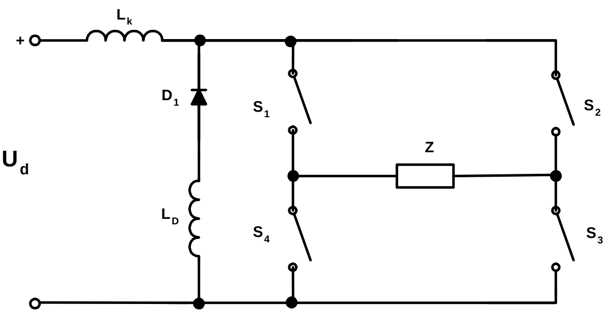

Figure 2. Full-bridge inverter

The priority of this circuit is that it keeps the voltage across the switches at significant load changes without complicate the converters driving, regulation and protection system. The disadvantage of this RI is the increased the number of devices and installed power.

The method of the VLCI [3,4] is characterized with the fact that for a part of the semi period of output current, the power circuit configuration changes by including the group (or groups) witch contain from diode and inductor. In some cases the inductors can be in absence. By including the additional inductance the level of limit could be changed. As result of

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this the current that flows through the load consists of two currents. The first current is due to the storage energy from the equivalent commutating capacitors, and the second is due to the power supply. The first current can be resonant or non-periodical. They flow to the moment when the difference between them becomes zero. After that, only the current due to the power supply flows. The priority of this method is that it can be used for RI and CSI.

The fundamental circuit, realizing this method (VLCI) is shown on figure 2. For the power switches all types power switching devices can be used. The AC circuit Z (parallel resonant load circuit), must work at frequency above resonant load frequency. In this case we obtained the serial resonant circuit, in which the capacitors are obtained by the displacement of complex load.

The principle of operation follows:

When the switches S1 and S3 are turned-on, thought the load Z flow two currents – the first current is due to the storage energy from the equivalent commutating capacitors and flows through circuit S_1 - Z - S_3 - L_D - D_1 - S_1, and the second is due to the power supply and flows through the circuit (+)U_d - L_k - S_1- Z - S_3-(-)U_d.

They flow to the moment when the difference between them became zero. After that, only the current due to the power supply flows. When the switches S2 and S4 are turned-on, the principle of the operation is the same as when the switches S1 and S3 were turned-on. The improvement of the output characteristics is due to the fact that the energy stored in the equivalent commutating capacitor is returned to the load.

The waveforms given at figure 4 show the principle of operation of RI with VLCI from fig.2. At fig.3 the waveforms when the circuit from fig.2 works as CSI are shown.

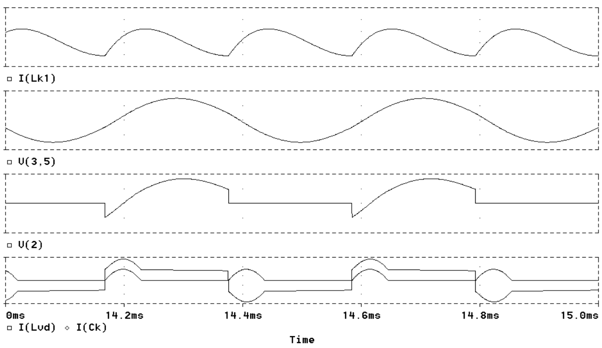

Figure 3. Waveforms for CSI with VLCI

Fig.3 shows the waveforms of: (I_{Lk1})-input current, (V(3,5))-output voltage across the load, (V(2))- voltage across the switch, (I_{Ck})- current though the load and ($I(L_{Vd})$)- current though the additional devices VD_1 and $L_{D.}$ The waveforms make it obvious that the additional circuit decreases the value of di/dt and switching loses.

Figure 4 shows the waveforms, when circuit from fig.2 operates as CSI with LVCI where: (I_{Lk1})- input current, (V(4,6))- output voltage across the load, (V(2))- voltage across the switch, (I_{Ck})- current though the load and ($I(d_1)$) - current though the additional devices VD_1 and $L_{D.}$

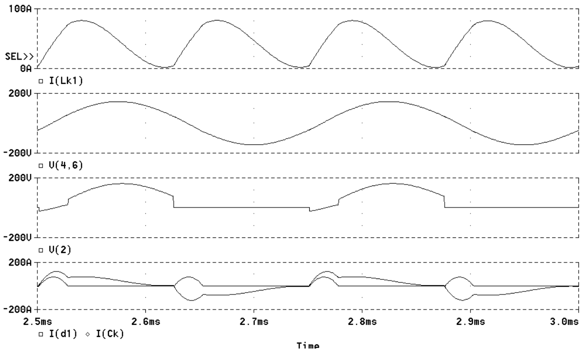

Figure 4. Waveforms for RI with VLCI

The biggest advantage of this method is the possibility of the power circuit to tune the regime at significant load changes or failure situations. The stabilizing effect follows: if by any reasons the energy stored to the commutating capacitors increases than energy at established mode, then for a longer part of the period of the driving frequency the energy will be returned to the load. This decreases the current from the DC power supply (DCPS). On the other hand when the energy stored to the commutating capacitors is decreased, then less energy is returned to the load and this increases the current from the DCPS.

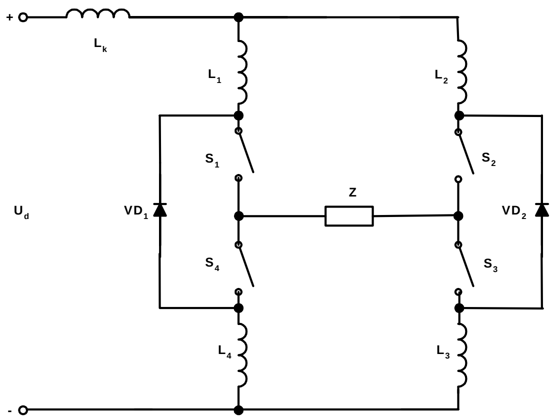

Figure 5. CSI with VLCI and common diode

When using the method of VLCI for a higher output power, it's necessary to use a few limiting diodes in parallel. To avoid the devices, which are necessary to equalize the currents through them, the circuits shown on figure 5 and figure 6 are offered [5].

The inductors $L_1 \div L_4$ are connected in series with the switches and they protect from di/dt. The principle of operation is the same as described above. The protection inductors are to equalize the currents through the limited diodes. Because of the fact, that the limiting diodes VD_1 and VD_2 are on only one time per period of the output frequency, they are in two times lower loaded compared to the main circuit (fig.2).

The circuit shown at fig.6 can be named CSI with reverse diodes. At the classical resonant inverters with reverse diodes, which are dependent of regime of work (above or under the load's resonant frequency), the device that are in on-state can be two diodes, two switches or reverse diode and switch.

For a difference from the classical resonant inverters with reverse diodes, in this circuit (with VLCI) two switches and two diodes are conducting simultaneously.

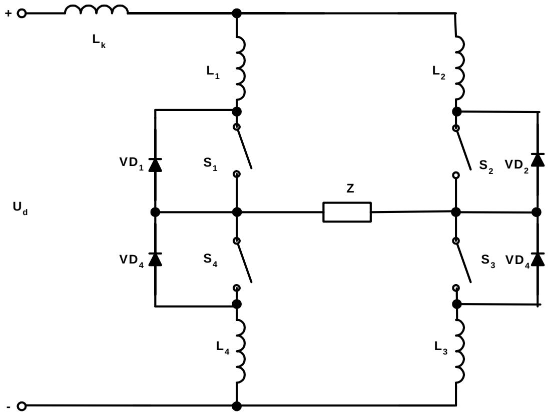

Figure 6. CSI with VLCI and individual diode

The principle of operation for a CSI with RD follows:

When the switches S_1 and S_3 are turned-on, then through the load Z three currents begin to flow – the first is caused by DCPS (+)U_d - L_k - L_1 - S_1 - Z - S_3- L_3- (-)U_d, and the other two are caused by the stored energy in the equivalent commutating capacitors and they flow through the circuit - S_1 - Z - VD_2 - L_2 - L_1 - S_1 and S_3 - L_4 - VD_4- Z - L_3 - S_3. When the another two switches S_2 and S_4, are conducting the processes are the same as when working S_1 and S_3.

In this circuit the diodes are four times lower loaded as comparison with the circuit shown at fig.2.

After this review of the circuits with VLCI, it can be resumed that they have lot of advantages in comparison with the other methods for improving the output characteristics. The advantages of this circuit are: - that it keeps the voltage across the switches constant at significant load changes without complication of the converters driving circuits, regulation and protection system; - lack of regime in which there is a reverse energy to the DCPS; - decreases the switching losses; allow to the circuit to tune the regime of work. The improvement of the output characteristics does not worsen the energy efficiency.

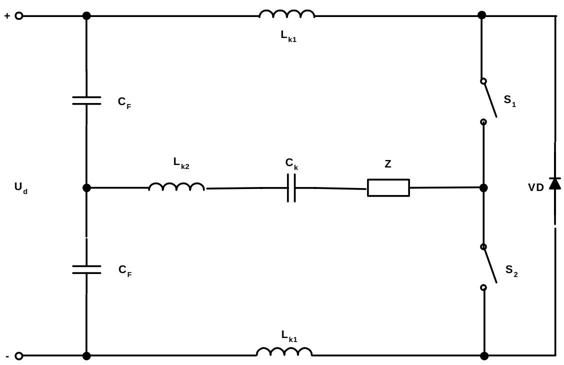

Figure 7. Half-bridge RI with VLCI

An improved half-bridge circuit is shown at fig.7. It has better characteristics due to the fact that a part or the whole of the resonant inductor is outside of the bridge at the DC network. Additional reverse diode, common to both devices is added. It works under the load's resonant frequency.

The waveforms at figure 10 show established mode behavior of the circuit. These diagrams are derived from computer simulation. The voltage across the power switches can be changed by varying the coefficient β, which shows the ratio between the part of the resonant inductor, which is outside the bridge and the full inductor. When the whole inductor is outside the bridge the voltage across the power switches is at its possible minimum and depends on the Q-factor of the resonant circuit. When β is decreased the device becomes similar to the classical RI without RD.

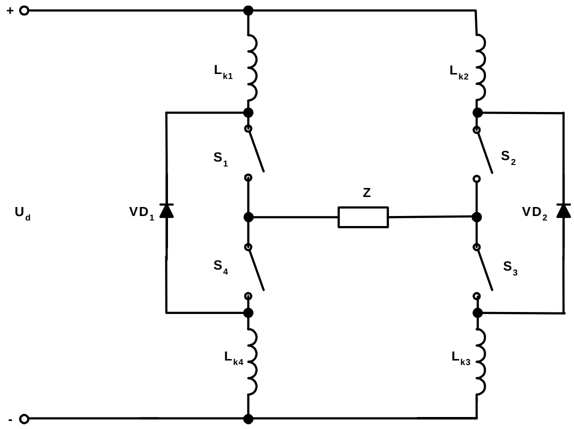

Figure 8. Full-bridge RI with VLCI

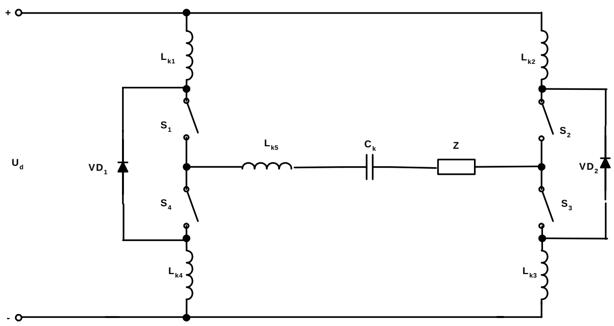

Figure 9. Full-bridge RI with VLCI

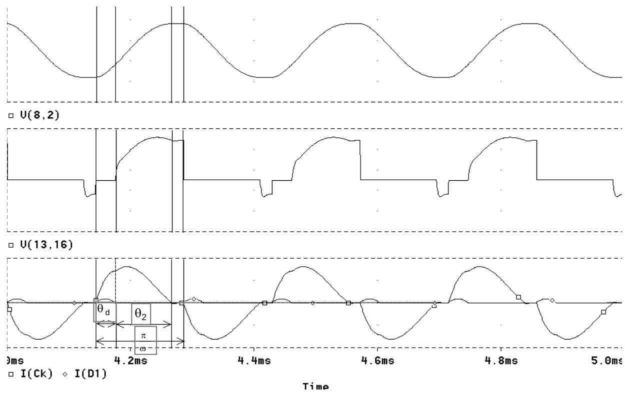

Figure 10. Waveforms for full-bridge RI with VLCI

The circuit shown on fig.8 is the full-bridge RI with VLCI. Its principle of operation is similar to the half-bridge's: When the switches S_1 and S_3 are turned-on, through the load Z three currents flow – the first is caused from +Ud-Lk1-S1-Z-S3-

Lk3- -Ud, the second is caused by the stored energy in the equivalent commutating capacitors and flows by circuit Z-S3-D2-Lk2-Lk1-S1-Z and respectively the third Z-S3-Lk3-Lk4-D1-S1-Z. The currents that flow in the secondary circuits cause faster discharging of the equivalent commutating capacitor and therefore decrease the current from DCPS.

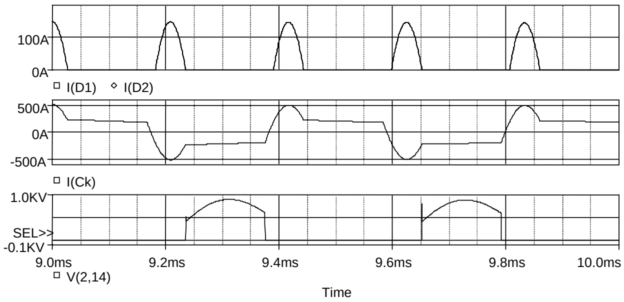

Figure 11. Waveforms of full-bridge CSI with VLCI from fig.5

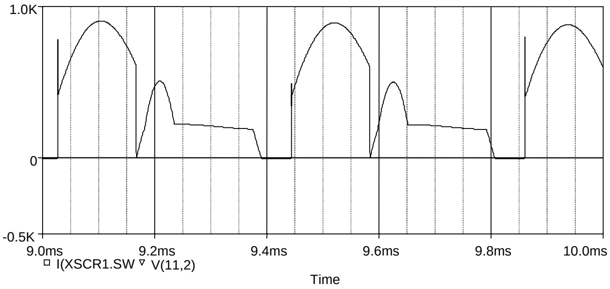

Figure 12. Waveforms of full-bridge CSI with VLCI from fig.5

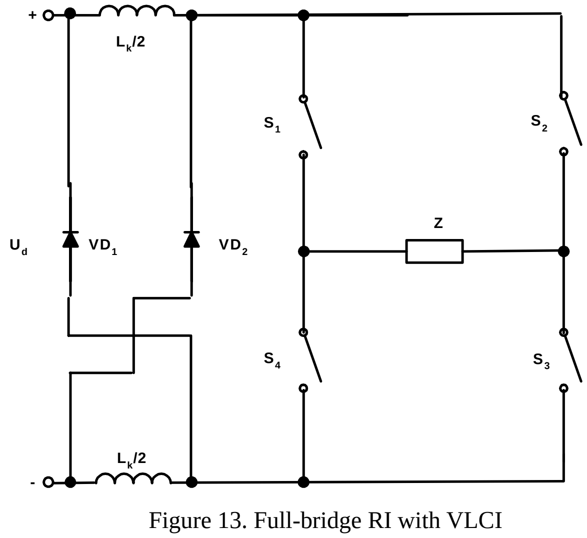

Figure 13. Full-bridge RI with VLCI

Another circuit of inverter with VLCI is shown at figure 13. The principle of operation is not different than the inverters described above. The difference in this inverter is that the commutating inductors are divided in two equal parts (this is the circuit for high power current source inverters). When the diodes are conducting the equivalent commutating inductors is Ld=Lk/4. The better output characteristics of CSI are due to the fact that the diodes limit the voltages across the input inductor Lk. Using the results from the analyses for CSI working with complex load [6] we obtained equations for the inductor's voltage. When S1 and S3 (or S2 and S4) are turned on, the voltages across the inductor Lk/2 is: $U_{Lk}=k_I.Ud$ where, k_I – coefficient of hesitation of CSI, which corresponds to the coefficient k [7] at classical RI. From the operating principle it can be seen that the diodes will not conduct when $k_I<1$. The voltage limitation will occur when $k_I>1$. The other advantage of these inverters is the additional devices that ensure the limitation of the inductor over voltages are not necessary.

The limitation to various voltage levels can be obtained if the voltage is limited only at part of the commutating inductors Lk. This circuit (fig.10) can be used successfully not only for CSI but can be used for inverters with natural commutation.

If the resonant inductor is divided in tree equal parts and the third part (L=Lk/3) is connected in load diagonal, the limitation will occur when k>1,5 (the limiting diodes will turn on). Therefore in normal mode the effect of the additional group is insignificant. At certain conditions it can be used only for protection circuit when an accident situation occurs.

III. Conclusion

This method can be used successfully not only for CSI but can be used for inverters with natural commutation. The better output characteristics of inverters with VLCI are due to the fact that the diodes limit the voltage across the inductors. This is an effective method of protection from over voltages and over currents.

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