A New Double Resonant Zero Current Switching Matrix Converter.

This paper was the synopsis, send to the EPE'95 in Sevilla. The complete Paper can be found in the proceedings, pages 2-100ff.

1 Abstract

A new zero current switching matrix converter with only three resonant networks and its control is described. The resonant networks are improved and extended to double resonant networks to reduce the r. m. s. current through the switches and therewith conduction losses while using zero current switching.

2 Introduction

The theory of self commutated matrix converters for multiphase input and multiphase output is well known since the early seventies [1]. In [2] is shown, that reactive power and real power can be controlled separately for three phase input and three phase output matrix converters and that the energy flow is bidirectional. In [3] a zero voltage switching topology was applied to a matrix converter to reduce the switching losses and two years later a zero current switch was applied to a matrix converter [4]. Here a topology is introduced, which allows zero current switching (ZCS) with only three instead of nine resonant networks and nine bidirectional switches. This topology is used to show the possibilities of reducing the inherently enlarged conduction losses at zero current switching by means of a double resonant network. This double resonant network reduces the r. m. s. current and the peak current which flows through the switch.

3 Topology of the proposed Converter

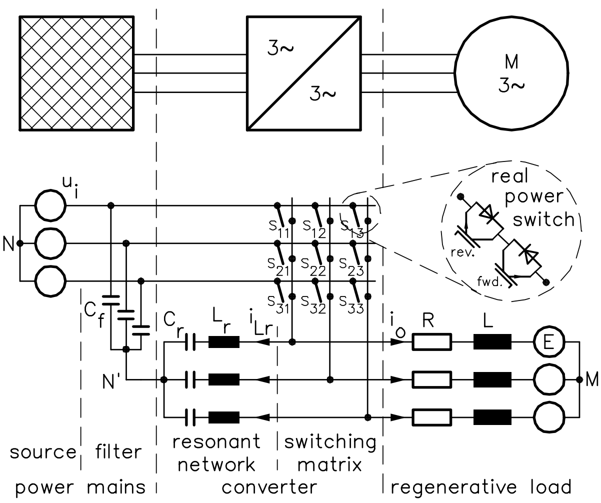

Figure 1: ZCS matrix converter

The topology of the proposed zero current switching converter is given in figure 1. For simplicity we consider only on output phase and assume ideal devices. Furtheron we consider only a very short time interval within the input voltages U_{i1}, U_{i2}, U_{i3} can be assumed as constant with $U_{i1} > U_{i2} > U_{i3}$. The load current i_o should be assumed as constant too. A hard switching converter can deliver any output voltage $U_{i3} < u_o < U_{i1}$ by means of PWM. With help of the resonant network L_{r1}, C_{r1} a possibility for zero current switching is given while using PWM or a two level controller to control the output current.

For analysis let us assume that all switches $S_{11} \dots S_{11}$ are open and the capacitor voltage is greater or equal to the largest line voltage: $u_{Cr1} \geq U_{i1}$.

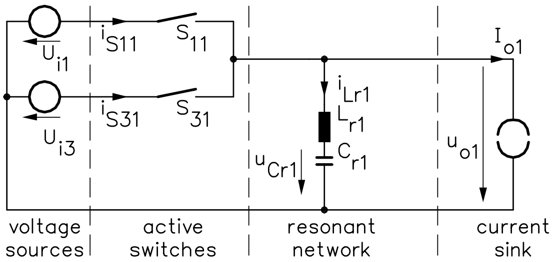

Figure 2: One phase of the zero current switching converter

Consequently $i_{Lr1} = -i_{o1}$ and the capacitor will be discharged linearly (see a at figure 3 and 4). If u_{Cr1} is small enough ($u_{Cr1} = U_{i1} - \Delta u\, ; \Delta u > 0V$) we can close S_{11} (see b) and observe a sinusoidal oscillation of i_{Lr1} (c) and u_{Cr1} until i_{S11} becomes zero again (d, figure 3 and 4). For that we have to remember, that a bidirectional switch is build by two unidirectional semiconductor switches, e. g. two IGBT's, so that we can turn off the conducting part of S_{11} under zero current switching conditions if i_{S11} becomes zero.

$$u_{Cr1}(t) = U_{i1} - \hat{u}_{Cr1}\cos(\omega_{r1}t + \varphi_1) \text{ where } \hat{u}_{Cr1} = \sqrt{Z_{r1}^2 i_o^2 + (U_{i1} - u_{Cr1}(0))^2}$$

$$i_{Lr1}(t) = \hat{i}_{Lr1}\sin(\omega_{r1}t + \varphi_1) \text{ where } \hat{i}_{Lr1} = \frac{\hat{u}_{Cr1}}{Z_{r1}} \text{ and } \varphi_1 = \arctan\left(\frac{i_o Z_{r1}}{u_{Cr1}(0) - U_{i1}}\right)$$

$$\text{where } Z_{r1} = \sqrt{\frac{L_{r1}}{C_{r1}}} \text{ and } \omega_{r1} = \frac{1}{\sqrt{L_{r1}C_{r1}}}$$

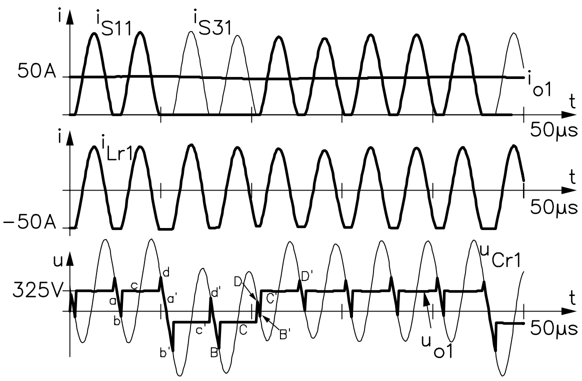

Figure 3: Switch currents i_{S11} and i_{31}, output current i_{o1}, inductor current i_{Lr1}, output voltage u_{o1} and capacitor voltage u_{Cr1}

This oscillation can be repeated periodically so that the mean output voltage is equal to $\bar{u}_o = U_{i1}$. At descrete time instants (if S_{11} is in OFF state) we can realize a *down commutation* to the next line voltage U_{i3}. In figure 3 we can observe two of these down commutations. The periodical operation can be continued with U_{i3} and S_{31} so that the mean output voltage will become $\bar{u}_o = U_{i3}$. Unlike the down commutation the *up commutation* is more complicated. To turn S_{11} on while u_{Cr1} is near to U_{i3} would result in a very disadvantageous trajectory (X in fig. 4) with high current and voltage stresses. To avoid these stresses two steps are required. In the first step we enlarge Δu to move the trajectory in the u_{Cr1} - i_{Lr1} - plane on a higher radius and turn S_{31} on (B, fig. 4). The second step waits until S_{31} is turned off under zero current conditions and turns on S_{11} immediatly (D). In the following Δu can be reduced to its normal value and the commutation is completed. In figure 3 we observe one of these up commutations.

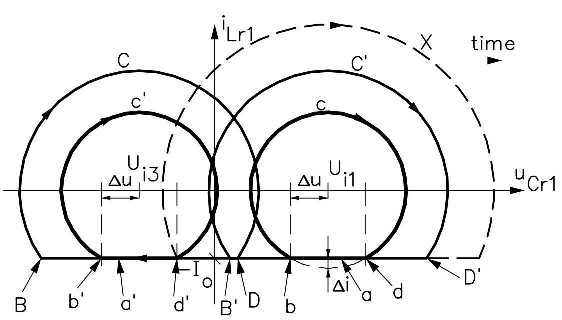

Figure 4: Stateplane of resonant circuit

This simulated example demonstrate the feasibility of zero current switching in a matrix converter with only three resonant networks. One disadvantage which is inherent with all resonant switching networks are the enlarged conduction losses. The following section will show a way to reduce conduction losses in this zero current switching application.

4 Improved zero current switching with double resonant network

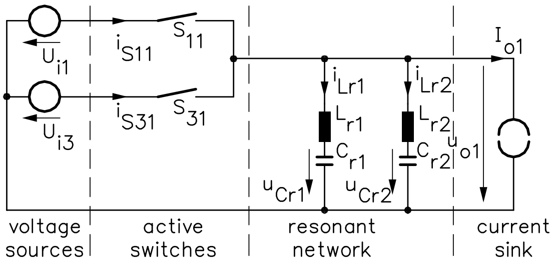

Figure 5: Improved resonant network for less conduction losses

Conduction losses in semiconductor switches can approximately be calculated by $P_V = U_S \bar{\imath} + R_S I^2$ where U_S is the threshold voltage and R_S the differential resistance of the switch. $\bar{\imath}$ is the mean and I the r. m. s. current through the switch. In the application above the mean current through the switch is given directly by the output current i_o and cannot be reduced. But the peak current and thereby the r. m. s. current can be reduced by connecting a second resonant network in parallel to the first (figure 5). Its resonant frequency have to be double to the first resonant network.

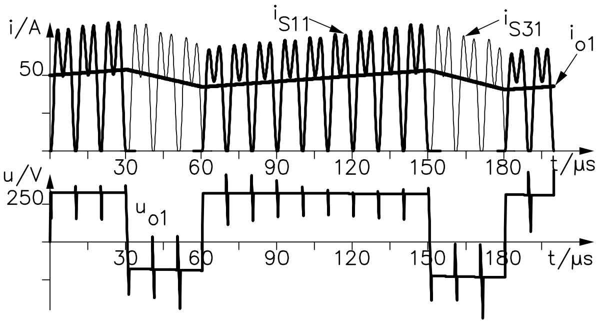

Figure 6: Capacitor voltages, switch currents 1 and 2, output current and output voltage with the double resonant network and one down commutation

Figure 6 shows simulational results. With fitting initial conditions of $i_{Lr2}(0)$ and $u_{Cr2}(0)$ more than the peak current of i_{Lr1} will be delivered by L_{r2} and C_{r2} and the resulting current through the switch is reduced. To ensure the fitting initial conditions at every current pulse a regulator is needed which controls the phase between the two resonant networks by means of Δu. The effect of the double resonant network is a reduction of about $5\% \ldots 10\%$ of the conduction losses.

References

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