A Novel ZCS Single Phase Matrix converter for Traction Applications

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Keywords

«AC-AC Converter», «Matrix Converter», «Soft switching», «ZCS», «Traction Applications»

Abstract

This paper proposed a new ZCS single phase ac-ac matrix converter for the traction applications. The proposed soft switching matrix converter is enhanced with an auxiliary resonant circuit in order to achieve the zero current switching for main bidirectional switches of the matrix converter. The main advantage of this proposed topology is soft switching of matrix converter to achieve switching loses limitation. This paper describes the operation of the proposed matrix converter, simulation analysis and experimental validation of the prototype for 50V-16.7Hz-100W-400Hz.

Introduction

In recent years of research, the development of AC-AC (matrix converter) converters for traction applications has gained a lot of attention. The main problem of matrix converters is commutation between the switches resulting in current spikes. Resonant soft-switching topologies have already been successfully employed in classic power converters. But still resonant soft switching (ZVS or ZCS) has not been yet employed in single phase matrix converters especially for traction applications. It has already been applied in three phase matrix converters [1] [2] for adjustable speed drives. Three phase matrix converter presented in [3] uses a soft switched bidirectional switches in order to obtain zero switching losses. It has a major drawback which is that each bidirectional switch requires resonant elements which results in losses increase. This topic concerning the matrix converters is more attractive for farther research. Zero current switching in matrix converters results in switching losses reduction and also reduction of current/voltage spikes during commutation interval. The single phase conventional matrix converter with enhanced control techniques is well presented in e.g. [4] employing of soft commutation principles for a three phase matrix converter is in [5] . Single phase matrix converters where high switching frequency is used, are presented in e.g. [6] [7] ,where soft switching condition ZVS turn on obtained by adding resonant elements to the load. In [8] two step resonant three phase matrix converter with higher switching frequency has been presented. The suggested topology in this paper has the major advantages like reduced voltage and current spikes,

reduced switching losses and etc. The disadvantage of the proposed topology is only increased component amount by adding a soft switched cell with resonant elements e.g. an inductor, capacitor and a diode rectifier. By the inclusion of this resonant circuit the conventional matrix converter operates as a soft-switched AC-AC matrix converter with reduced switching losses and more efficiency.
The topology shown in Fig.1 is classical direct matrix converter for electric trains (AC Locomotives) with 15kv/16.7Hz as input voltage and frequency and it has 400Hz output frequency. The main aim of this paper is to verify soft switched single phase matrix converter using auxiliary resonant circuit for the traction applications mainly in electric trains (AC locomotives). The proposed system verified on a laboratory prototype 50V as input voltage with frequency 16.7Hz and output 100W/400Hz output frequency taken into consideration to develop resonant soft switched matrix converter. The results shown in this paper are the proposed converter can be applicable for high output power level by choosing the proper auxiliary resonant elements.

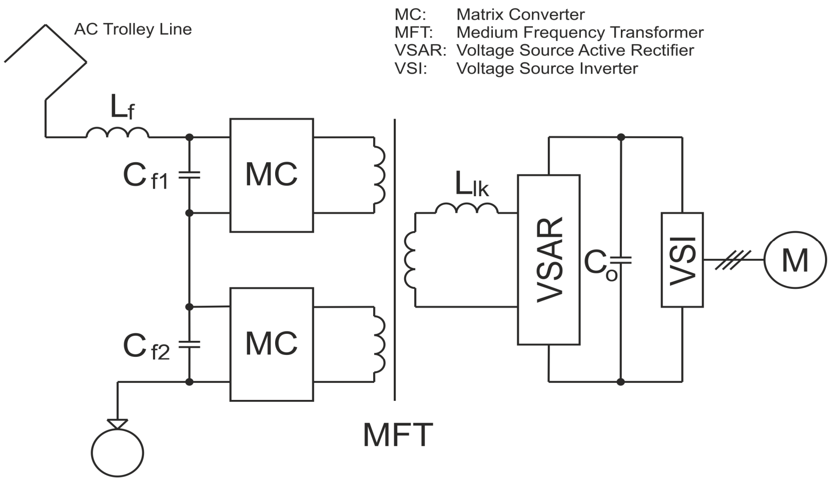

Fig. 1: Topology of Electric Train with Direct Matrix converter

In this paper a new topology of matrix converter is presented. The methodology based on additional two resonant bidirectional switches(S_{r1}-S_{r4}) connected as shown in fig. 2, which allows the half of the main switches turned off under zero current switching of each bidirectional switch. The proposed concept is beneficial, when multiple matrix converters connected in series, for increasing the output power The proposed circuit uses the auxiliary switches of the type proposed in [1-2] two such switches are used per output phase, one for positive load current and other switch for negative load current. The positive and negative conducting switches are connected to diode rectifier as shown in fig.2. The overall circuit proposed here is different in concept from that proposed in [2] [5] the difference is that the auxiliary cell switches only conducts the load current during commutation.

Operation of the Auxiliary resonant circuit

As can be seen on Fig. 2, the proposed auxiliary resonant circuit consists of two diode rectifiers *(D_1, D_2 and D_3, D_4)*,two switches (S_{r1},S_{r2} *and* S_{r3},S_{r4}) which are turned on and turned off simultaneously, a small inductor (L_1 *and* L_2) and a capacitors *(C_{r1},C_{r2})* whose current direction and voltage polarity are unidirectional. Now consider the turn on process, initially the capacitor C_{r1} voltage is charged to some value before turning on. When S_{r1},S_{r2} and S_{r3},S_{r4} are turned on during the proper commutation period of the main switches S_{a1},S_{a2} and S_{d1},S_{d2}, they can be turned off under zero current switching conditions as the auxiliary circuit takes over their working current. The commutation of the auxiliary circuit switches shows soft switching characteristics so the loss increase by employing a number of auxiliary switches is mitigated. When the auxiliary circuit is turned on the current rise is limited by a coil L_1 or L_2 therefore the turning on comes under near ZCS conditions. On the other hand turning of the auxiliary switches leads to slow voltage rise of the C_{r1} or C_{r2} and thus the turning off transient is cunducted under ZVS conditions. To make all the switches in single phase matrix converter are ZCS turn off, it is necessary to add two more resonant circuits auxiliary resonant circuits(AR_3 AR_4) to the other node.

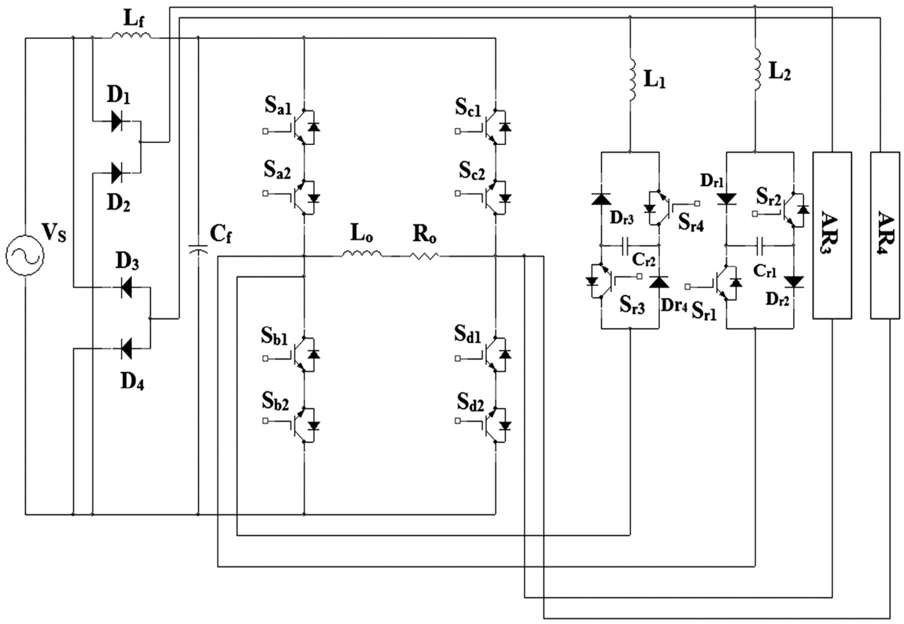

Fig. 2: Proposed ZCS single phase matrix converter

Operation of the proposed converter

The purpose of the auxiliary resonant circuits is to sink or source current from or to the switching node of the converter. As they are unidirectional only one of the pair actually connected to the common node can operate at the moment depending on the current direction. The appropriate circuit should be turned on soon after the first step of the typical four-step commutation technique. Once turned on the current of the conducting main switch is decreasing to zero. After that the new conductive path can be created. The operating auxiliary switch should be turned off before the final step. Since the new path creation is made with no current flowing through the switches simplified three step technique can be employed. Fig.2 illustrates the single phase matrix converter with only two auxiliary circuits providing soft-commutation for the left leg only. The operation of the converter (during commutation period) is explained with the help of theoretical waveforms shown in Fig.3. Assuming that S_{a1}, S_{a2} and S_{d1}, S_{d2} are the incoming switches and outgoing switches. The gating signals are applied to S_{r1}, S_{r2} and S_{r3} S_{r4} at t_0. From t_1 the load current is commutated by S_{r1}, S_{r2} S_{r3} S_{r4}. During t_1 to t_2, the resonant capacitor current remains constant equal to load current and charged voltage is discharged linearly. Between t_2-t_3 the voltage on resonant capacitor C_{r1} reaches zero. At t_3, the resonant switches S_{r1}, S_{r2} and S_{r3}, S_{r4} are turned off; the voltage across resonant capacitors C_{r1} linearly increases to greater than the input voltage until t_4. At t_4 the voltage on C_{r1} clamps to higher voltage($>V_{dc}$).

Simulation results of the proposed matrix converter

The simulations are performed for single phase matrix converter using with Matlab – PLECS. The simulation parameters considered as mentioned in Table I. Fig.4(a,b,c) illustrates the zero current turn off the main switches($S_{a1}S_{a6}$) and auxiliary switches(S_{r1}) turn on and turn off voltage and current during commutation period. Fig.5. (a) Voltage and current on the resonant capacitor and the voltage and current through the resonant inductor depicted in Fig.5 (b). Fig.6 (a) (b) shows the output voltage and current of the matrix converter

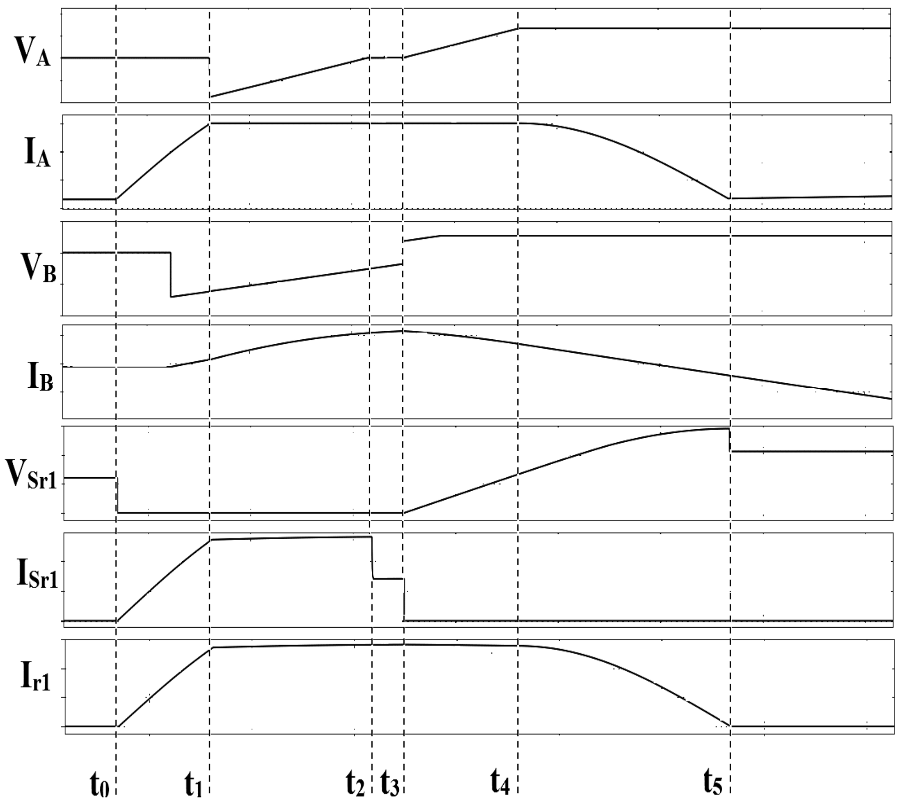

Fig. 3: Theoretical waveforms

Table I: Simulation Parameters

Parameter	Value
Input voltage	50V
Input frequency	16.7Hz
Output voltage	50V
Output frequency	400Hz
Output power	106W

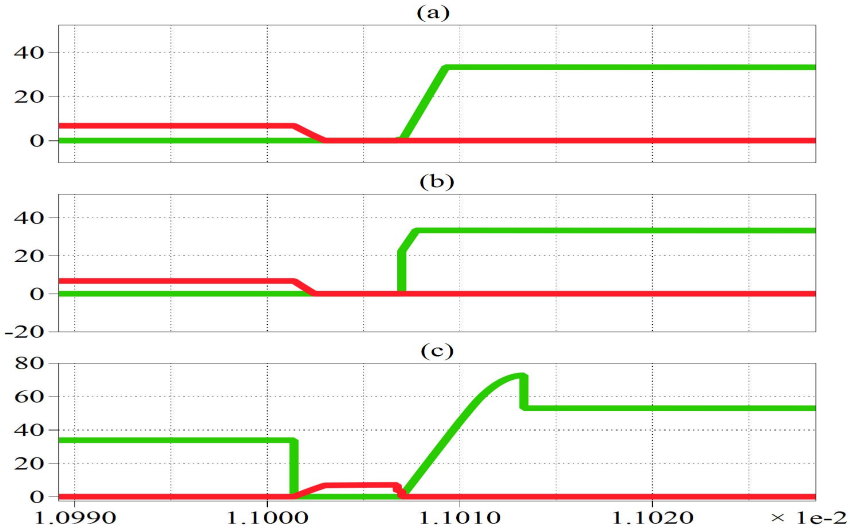

Fig. 4: (a) collector to emitter voltage and currents of S_{a1} (b) collector to emitter voltage and currents of S_{a6} (c) collector to emitter voltage and currents of S_{r1}

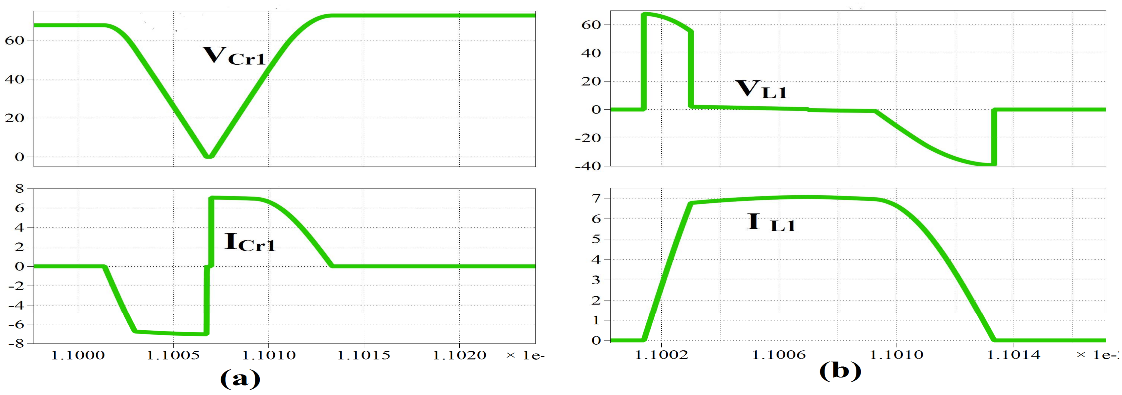

Fig. 5: (a) & (b) Resonant capacitor and inductor voltage and current

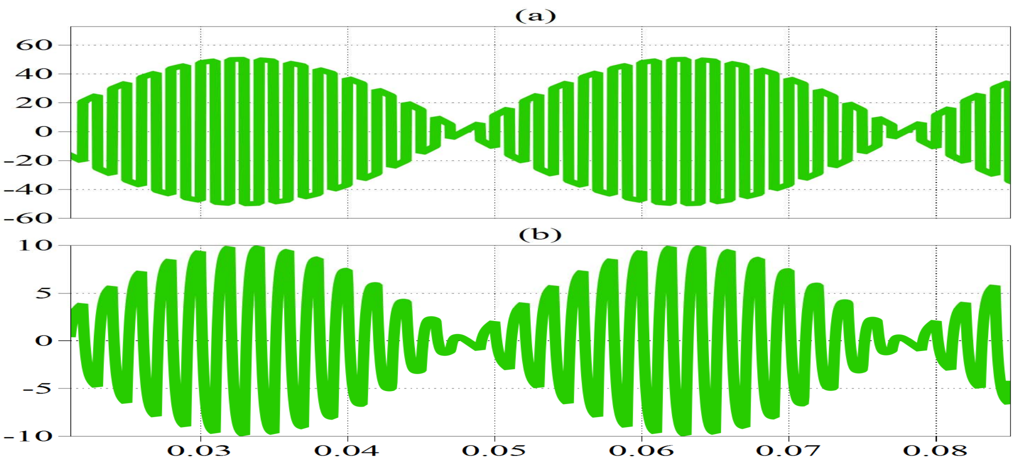

Fig. 6: (a) & (b) Output voltage and current

Experimental results

Main circuit

The experimental laboratory prototype has been tested on 50V /16.7Hz as input source for 106W output power with 400Hz as output frequency. The bidirectional IGBT modules uses four SK 60 GM 123(Semikron).To generate the switching pulses to the matrix converter and auxiliary circuit TMS320F28335 used. The load resistance 13Ω, inductance values 2.3 mH are used. These results confirm that the soft switching condition for the matrix converter with additional auxiliary resonant circuit are provided by achieving ZCS turn off of the main switches during commutation period. Fig.7(a) shows the collector to emitter voltage and currents in hard switching for the S_{a1},S_{a2} and zero current switching condition for the S_{a1},S_{a2} shown in Fig.7(b) and Resonant capacitor , inductors voltage and currents are shown in Fig.8. The auxiliary resonant switch S_{r1} collector to emitter voltage and current is depicted is in Fig.9. Fig.10 shows the output voltage and current. Fig. 11 illustrates the generated gating pulses to the IGBTs with four step commutation.

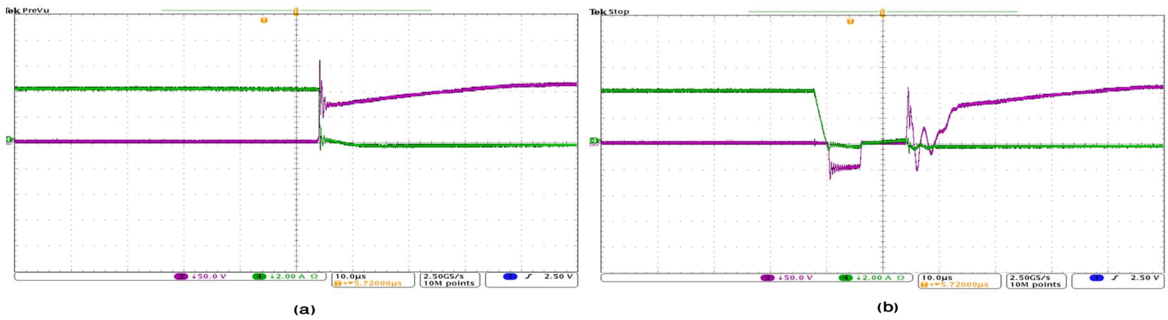

Fig. 7: (a) Collector to emitter voltage and current for hard switching (b) Collector to emitter voltage current for ZCS turn off

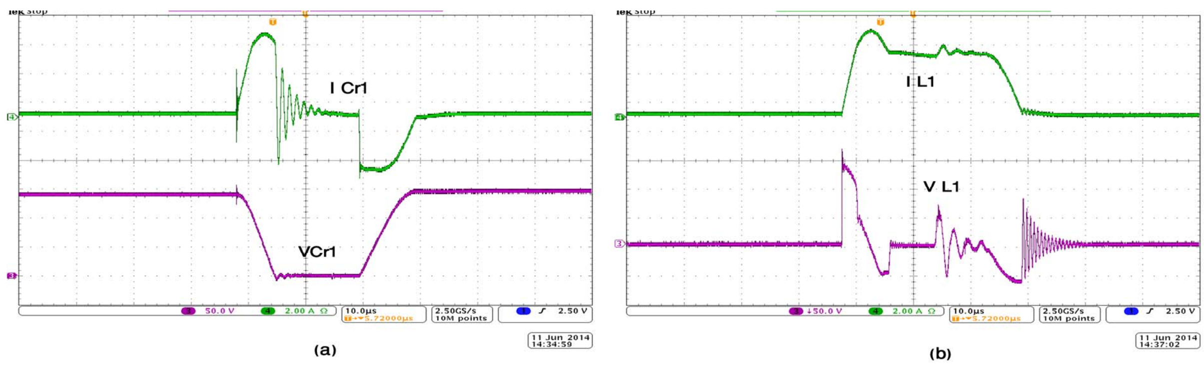

Fig. 8: (a) Resonant capacitor voltage and current (Ch4: 2A/Div , Ch3: 50V/Div) (b) Resonant inductor voltage and current(Ch4: 2A/Div, Ch3:50V/Div)

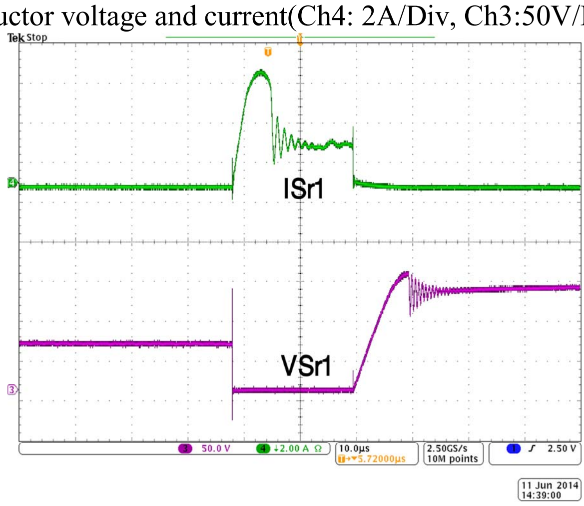

Fig. 9: Resonant IGBT S_{r1} collector to emitter voltage and current (Ch3: 50V/Div, Ch4: 2A/Div)

Auxiliary resonant circuit components

The IGBTs type chosen for the auxiliary resonant circuits is IGW40N120H3 and resonant capacitors C_{r1}, C_{r2} are 0.2µF and values of resonant inductances L_1, L_2 are $67\mu H$.
The values of resonant capacitor and inductors have been chosen large values to increase the switching speed of auxiliary IGBTs (S_{r1} S_{r2}, S_{r3},S_{r4}) and to keep low current during turning on.

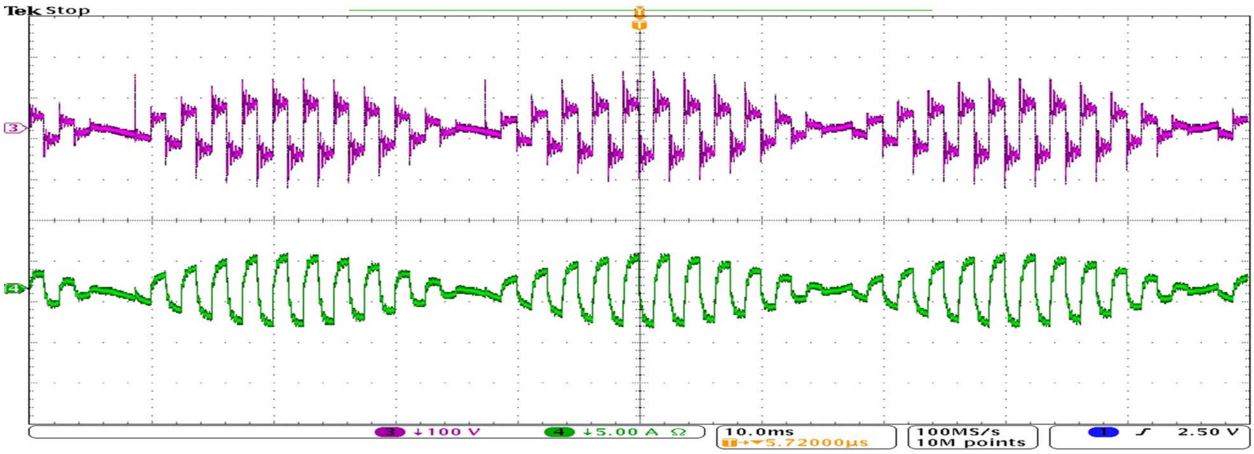

Fig.10: Experimental waveforms of output voltage and current (Ch3:100V/Div, Ch4: 5A/Div).

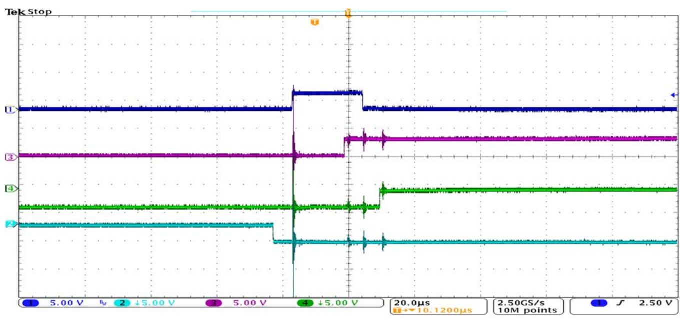

Fig.11: Generated pulses to IGBTs (matrix Ch2, 3, 4) and Resonant switch (S_{r1}, Ch1)

Conclusion

This paper proposed a new ZCS single phase ac-ac matrix converter for traction applications. By additional auxiliary resonant circuit, the zero current switching condition was achieved for the half of the switches in this matrix converter. Employing the same circuits connected to second switching node of the converter would ensure soft switching for the whole matrix converter. This proposed auxiliary resonant circuit works during the 4-step commutation period. Major advantage is reducing the commutation spikes, switching losses and major drawback is the additional circuit increasing the cost of converter (additional resonant components and switchers). The main aim of this paper is to verify the soft switching version of single phase matrix converter for the applications of AC locomotives electric trains. Further scope of this proposed concept will be helpful to get soft switching condition not only for one matrix converter, it will provide soft switching for multiple matrix converters especially in single phase, when they are connected in series. Laboratory prototype has been implemented with 50V/16.7Hz input source and 106W of output power with 400Hz output frequency. The experimental result proves that soft switching condition was obtained during commutation period and that might improve the efficiency in terms of switching losses.

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