BUS BAR CONSTRUCTIONS FOR MATRIX CONVERTERS

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Abstract. This paper explains possible use of bus bars in matrix converts and different layouts and shapes of possible construction are considered. In this paper the most acceptable and cost effective version of layout of bus bars and topology of matrix converter is quested for more detailed analysis in future.

Keywords: Bus bars, matrix converters, AC/AC converters, integrated drives.

1. INTRODUCTION

Main use of bus bars and most studies in this area are done for 2-level VS (voltage source) inverters placed in DC link. But due to VS main drawbacks – high input current THD formed by input rectifier, bulky passive elements in DC link. These problems can be solved using three phase matrix converters, which allow not only PWM control of output voltage and input current at the same time, but also the input power factor can be adjusted and matrix converter has low input current THD due to lack of rectifier on input and DC link [1]. This paper proposes implementation of bus bars in matrix converters as possibility to reduce EMI and improve commutation transients

2. BUS BARS

The bus bars main purpose is to reduce the parasitic stray inductance in the commutation loop, witch improve the switching transients as was proposed for 2-level PWM converters in [2] and [3].

According to [3] the main parameters of bus bars are: resistance, inductance, conductance and capacitance that are distributed along the bus bar structure.

In order to suppress the EMI noise and disturbances the capacitance must be as high as possible. It can be achieved by increasing area of the conductive plates or by reducing the thickness of the insulating material.

The shunt conductance depends on physical dimensions of bus bar and dielectric properties of insulating material.

The most important parameter in this case is the inductance. To ensure a proper EMC this parameter should be kept as small as possible. The inductance of the bus bar reduces as the thickness of dielectric decreases and the width of conductors increases. The commutation frequency has an effect on inductance as well – with higher frequencies the inductance reduces. At high frequencies the skin effect must be taken into account, for square bus bars the highest concentration is in the corners.

Design of bus bars for matrix converter

In order to keep the stray inductance low, the design of the converter must be as compact as possible and installation done with particular accuracy. Specific feature that must be taken in to account for matrix converters is that it operates with current sources on one side and voltage sources on the other side. That means that for the current side of the converter the inductance should be as low as possible, but capacitance should be maximum. As for voltage side of the converter – the capacitance should tend to zero, but inductance to infinity.

An overview of bus bar construction is given in tab. 1.

Planar rectangular construction

The simplest way of placing bus bars is when conductive bars are placed one on top of other as it can be seen in Fig. 1. There are six layers of conducting copper plates, one for each phase. Because converter can be reversed (it can deliver energy to the grid), there should be bus bars on the output as well as on input phases. This kind of layout was initially chosen for laboratory prototype due its simple construction. But in practice it has many drawbacks some of them are: long connection screws between plates and switches, unsymmetrical capacitance distribution, parasitic capacitance in the output. This capacitance can be reduced by eliminating bus bars from the output side of converter.

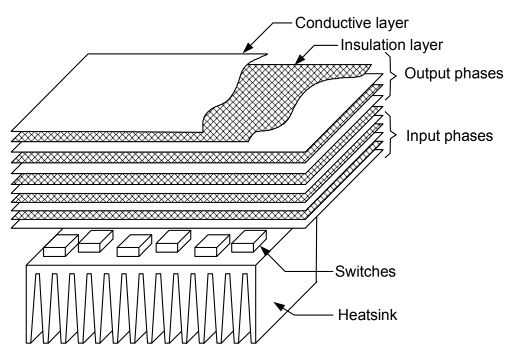


Fig. 1. Set of bus bars and switches

Planar circular bus bars

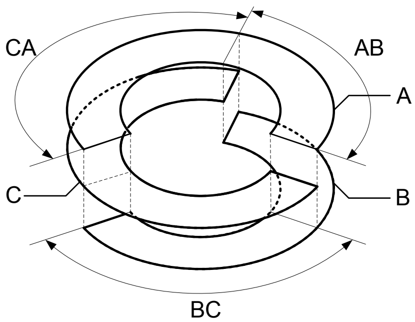
Although in case of round bus bars the conductive planes are harder to shape and produce due to circular form and bending of one bar, this construction distributes capacitance more symmetrical between phases, as bus bars are shifted and overlap for 120 degrees (Fig. 2.). That means that each plane is a part of two bus bars. Another advantage is possibility to use this bus bar construction in fully integrated drive systems. The whole bus bar structure can be fitted in front or at the back side of an AC induction machine. This principle well corresponds to idea of fully integrated drives that is proposed, described and developed in [7]. In case of larger diameter of bus bars, one bar could be bent over a larger distance or the construction could be shaped in a twisted way.

Δ and Y bus bar systems

Unlike two earlier constructions this is not a planar setup of bus bars. Instead, this bus bar system is set on its edge, so that it forms a triangular prism, with two phases forming one side of a triangle (Fig. 3.a). Comparing to planar systems this is more symmetrical and in this case it is easier to bend plates. As with planar circular bus bars, it is possible to implement the converter with a Δ bus bar structure in an AC machine, and for heat-sink the case of the AC machine can be used.

From point of view of assembly a Y bus bar structure is even easier to assemble than Δ structure, as switches can be placed on separate sides of the star (Fig. 3.b).

Both of these structures are not as space effective as planar placement, but in case of positive results these versions can be optimized for specific purposes.



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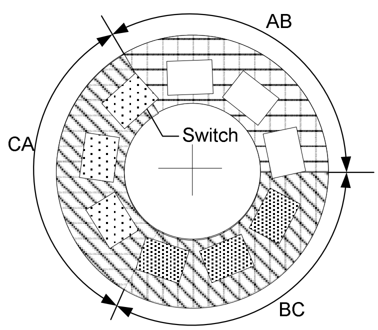

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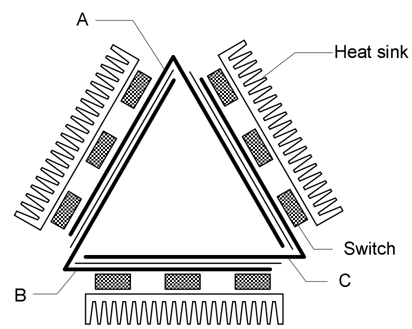
Fig. 2. Planar circular bus bars a) placement, b) placement with switches top view



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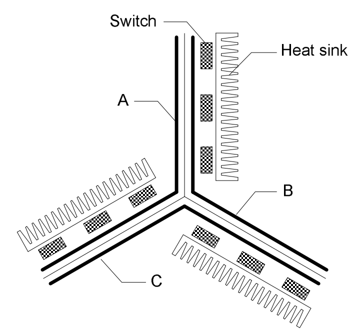

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Fig. 3. a) Δ bus bars and b) Y bus bars

Tab. 1.
Comparison of bus bar structures

Bus bar placement	**Phase symmetry in 3 phase system**	**Construction complexity**	**Space usage**	**Possible use**
Planar rectangular	No symmetry	Easy to construct, problems with placing control	Compact placing	Matrix frequency converters
Planar circular	Possible symmetry	Complex manufacturing	Compact placing	Integrated drives
Δ structure	Full symmetry	Problems with placing switches and bending of planes	Takes more space due to upright position	Integrated drives
Y structure	Full symmetry	Problems with bending of planes	Takes more space due to upright position	Modified – integrated drives

3. SIMULATION OF PLANAR BUS BARS

A simplified PSpice simulation was done using IXSN35N120AU1 IGBT model. The equivalent schematics of a model can be seen in Fig. 4. Due to idealized model there are some inconsiderable inaccuracies in simulation results. Main attention was paid to transients when switches AX and CX were turned on and off not on PWM modulation in general.

As can be seen from simulation results in Fig. 5.a at stray inductance of 500nH in commutation loop, during switch AX (dashed line) and CX (solid line) turn -on and -off the transient voltage peeks across the IGBT are twice bigger than the input voltage (V_{peak}=612V, V_{in}=304V) and transient time is around 0,5µs. This causes serious EMI noise and overvoltage in the output and the IGBTs can damaged if rated voltage is chosen too low.

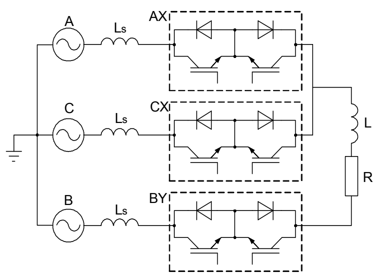
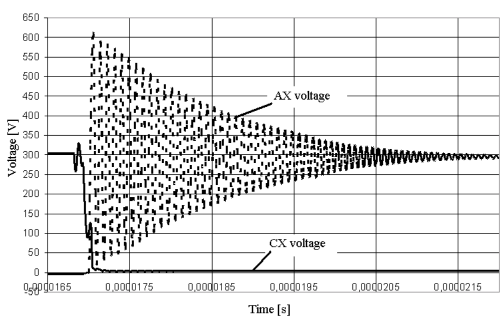


Fig. 4. Equivalent schematics of a PSpice model



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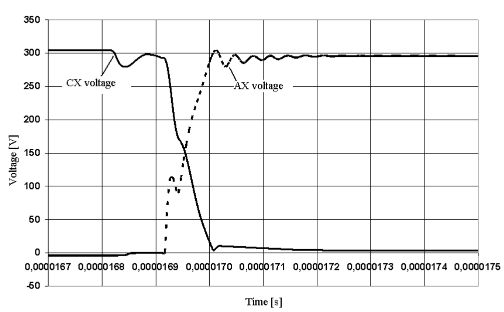

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Fig. 5. Commutation transients a) at LS=500nH AX – turn off; b) at LS=50nH; a) AX – turn off

In Fig 5.b simulation results at stray inductance of 50nH can be seen. The transient overvoltage is greatly reduced comparing to previous results.

Due to rough calculations the simulation has look-over character, which should be considered as guide to future operations.

4. EXPERIMENTS WITH PLANAR BUS BARS

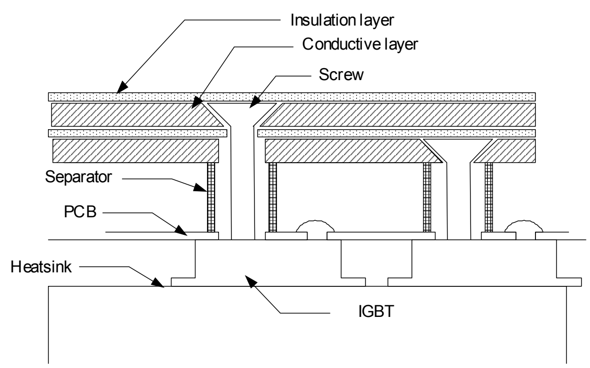
During this study there was built a laboratory prototype of matrix converter with planar bus bars, and some experiments were done to estimate its ability to improve the switching transients.

As the conductor the copper plates with length a=195mm, width b=260mm and thickness c=2mm were used. For insulation a 0,17mm thick material with dielectric permeability ε=1.68, εo=8.85e-12 (permeability of air). With these parameters the capacitance between two proximal plates can be calculated:

$$C = \varepsilon \, \varepsilon_o \, (a * b / d). \tag{1}$$

After insertion of values into (1) the capacitances of two bus bars can be obtained CBB = 3,53nF.

The cross-section of the laboratory prototype of one switch pair and one commutation loop with voltage sources in the input schematic diagram is shown in fig. 6.



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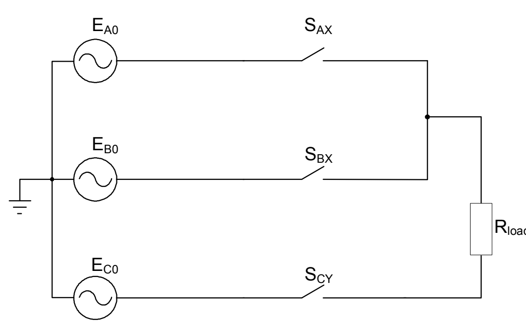


b)

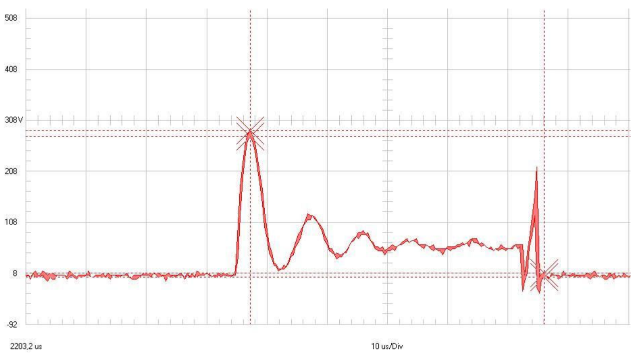
Fig. 6. Experimental setup a) cross-section view of one switch pair with bus bars, b) commutation diagram

In this experiment 137VAC was applied to active load of 100Ω through one commutation loop of matrix converter (Fig. 6.b) and commutation frequency – 10kHz.

First experiment was done with closest bus bars – input phases B and C. The result is shown in Fig. 7.a. In this case there is a voltage transient peak of 280V.

Second experiment was done with distal bus bars – input phases A and C. The result is shown in Fig. 7.b. In this case the voltage transient peak reaches 380V.

Third experimental results were obtained without use of bus bars between input phases. In this case voltage across switch has the most transient peak voltage of 480V. Results are shown in fig. 7.c.



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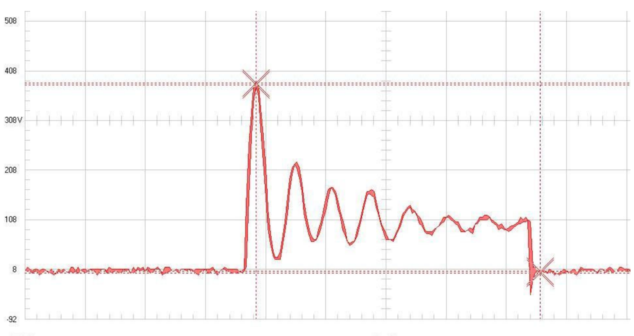

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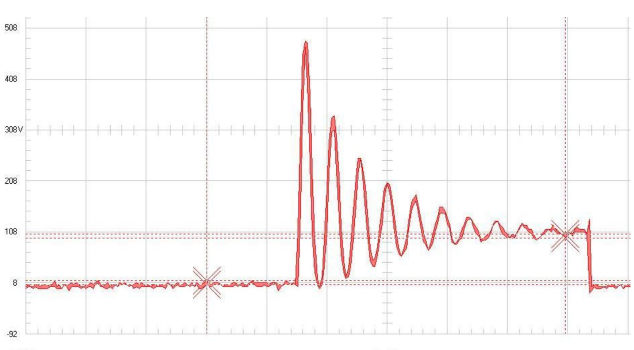

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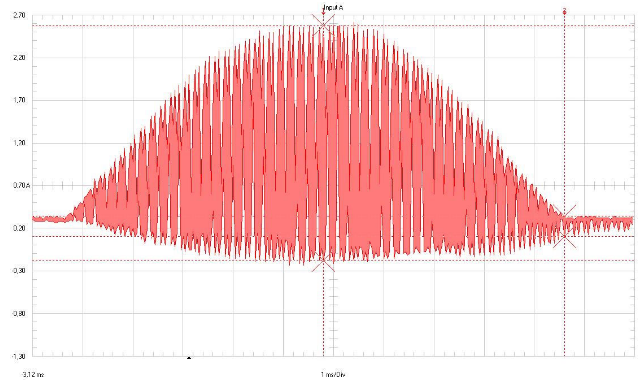
Fig. 7. Experimental results – commutation voltage transients a) with closest bus bars; b) with distal bus bars; c) without bus bars



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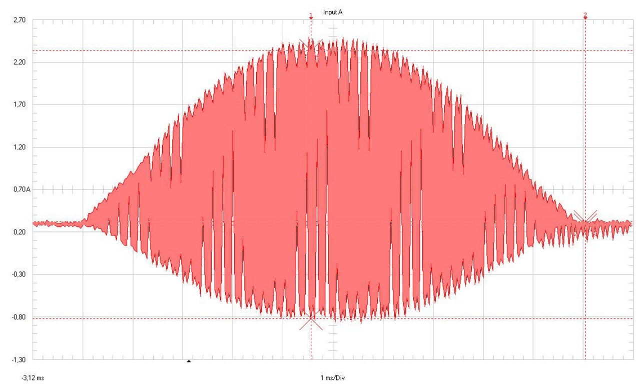

b)

Fig. 8. Experimental results – input current a) with bus bars; b) without bus bars

Not only it is possible to improve commutation by use of bus bars between input phases of matrix converter, but also reduce conducted and radiated noise by decreasing commutation peaks of input current. The input current of one phase can be seen in Fig. 8. The time scale in Fig. 8 is 1ms/div.

5. CONCLUSIONS

The next step is to do more detailed and precise simulation of matrix converter with symmetrical bus bar construction.

The experiments show that the implementation of bus bars in matrix converter could be useful in case of symmetrical design. There is some source of stray inductances in the system that could affect the results. In order to minimize the influence of this, the construction of laboratory setup should be changed and the control PCB should be redesigned as well.

Not only the most efficient and cost effective way of placing bus bars must be chosen, built and tested, but also assembling and mechanical simplicity must be considered. It is difficult to point out one solution, because each has its positive and negative features.

During the study more ways of placing bus bars were found and considered for application with integrated drives.

We tend to do more research in this field.

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