Problems related with use of bus bars in matrix converters

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Abstract
This paper explains possible use of bus bars in matrix converters. There are also considered different layouts and shapes of construction. In this work 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 bar, matrix converter, EMI, AC-AC converter

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.

1. Bus bars
The bus bars main purpose is to reduce the parasitic stray inductance in the commutation loop, which 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.

2. 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 into 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.

2.1. Planar rectangular construction
The simplest way of placing bus bars is when conductive bars are placed one on top of other as can be seen in figure 1.

![Figure 1. Set of bus bars and switches](image)

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.
2.2. 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].

Figure 2. Planar circular bus bars: a) placement; b) placement with switches top view

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.

2.3. $\Delta$ 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 $\Delta$ bus bar structure in an AC machine.

From point of view of assembly a Y bus bar structure is even easier to assemble than $\Delta$ structure, as switches can be paced 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.

Figure 3. a) $\Delta$ bus bars and b) Y bus bars

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.

Figure 4. Equivalent schematics of a PSpice model

As can be seen from simulation results in figure 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 peaks across the IGBT are twice bigger than the input voltage ($V_{\text{peak}}=612$ V, $V_{\text{in}}=304$ V) and transient time is around 0.5$\mu$s. This causes serious EMI noise and overvoltage in the output and the IGBTs can damaged if rated voltage is chosen too low.
In figure 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.

Experimental results could be affected by the imprecise design of control PCB.

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. Experimental results (fig. 6.) show that there was no obvious difference between converter with bus bars and without them if there are current sources in the input.

This problem could occur due to such construction drawbacks as: large distances between switches and bus bars that could increase the stray inductance; connections between bus bars and screws; stray inductances of input and output connections or other sources of stray inductance; as well as unsymmetrical structure of bus bars and other features that could affect experimental results.

Some positive results were obtained when bus bars were used with voltage sources in the input. Experimental results in figure 7 show that there is a fair difference between overvoltages in cases with and without bus bars.

Due to voltage sources of one side of converter, the parasitic capacitances may appear, that could cause an undesired voltage ringing at switch turn on (figure 7.b). All these problems could be solved by improvements of construction of the test bench.
Conclusions

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.

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

The experiments show that 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. Instead of 6 bus bars a construction of only 3 should be considered and tested. The control PCB should be redesigned as well.

We tend to do more research in this field.

References


