# Design of an Industrial Power Converter for Adjustable Speed Drives

**Candidate:** Simone GIUFFRIDA **Supervisor:** prof.Radu BOJOI **Advisor:** Fabio MANDRILE

***Abstract*—This thesis deals with the design of an industrial slim dc-link converter, consisted of a three phase diode bridge and a 2-level three-phase IGBT inverter. To increase the system reliability, the DC link capacitance uses the film technology and therefore it is strongly reduced with respect to the traditional values corresponding to electrolytic capacitors. This drastic decrease of the dc-link capacitance can lead to dangerous resonances due to interaction with the grid inductance. However, this problem has been solved at control level using a voltage modulation based on the virtual positive impedance concept, leading to the damping of the resonances. The system was simulated and the results showed an important reduction in the grid current harmonic content, with the expense of the distortion of the motor currents and hence a slight increase of motor losses. Then, the power module has been selected, followed by the development of the converter schematics. Based on the converter losses, the converter heatsink has been selected for the thermal design that has been verified through thermo-fluid dynamic simulation. Finally, the proposed control solution has been tested using an inverter stack employing slim DC link film capacitors.**

## I. INTRODUCTION

Electrolytic capacitors are nowadays widely used as DC link for industrial Adjustable Speed Drives (ASD). However, they present a lower lifetime with respect to other capacitor technologies. For this reason, there is the trend to replace electrolytic capacitors with film ones to increase the system reliability. The film capacitors are characterized by a much smaller capacitance per volume with respect to the electrolytic ones. Thus, the DC link capacitance can be drastically reduced, leading to the concept of slim DC link power converters. However, by decreasing of orders of magnitude the dc-link capacitance, resonances between the dc-link capacitors and the grid inductance can occur. These resonances cause very high dc-link voltage ripple and the increase of grid current Total Harmonic Distortion (THD). This problem has to be properly solved at control level to avoid the use of other hardware components.

The goal of my master thesis is the design of a slim dc-link drive system for ASDs featuring low THD of input grid current, being thus suitable for data centers' cooling system. This is done through the following steps: electrical stress calculation, components selection, losses computation and cooling system design. In addition, the thesis implements a method to actively damp the DC link resonances using the motor control algorithm.

## II. DC-LINK VOLTAGE ACTIVE DAMPING

As mentioned before, the main issue in the slim dc-link converter design are the resonances related to the interaction between the dc-bus capacitance and the grid inductance. To stabilize the system, I decided to use a control solution based on Virtual Positive Impedance Concept [**1**]. The dc-link voltage consists of three main components: DC (mean) component, one component related to the bridge rectifier at six time the grid frequency (300Hz) and one component related to the resonance between DC link and the grid at frequnecy in the 1kHz- 2kHz range. The idea behind the adopted method is to actively damp the dc-link resonances using the electrical machine. This is done by a proper calculation of the dc voltage signal used to compute the duty cycles of the inverter. By using a low-pass filter and a resonance filter tuned at 300Hz, it is possible to compensate only the high-frequency oscillations of the DC link that are caused by the resonances. In Fig.2 is reported the control algorithm block diagram.

I have first simulated the system behavior using the software PLECS. When the compensation starts, the voltage resonance component is damped. Moreover, in the grid currents there are no more resonant components and therefore the THD drops down to approximately 32%, very close to the theoretical limit (31%).

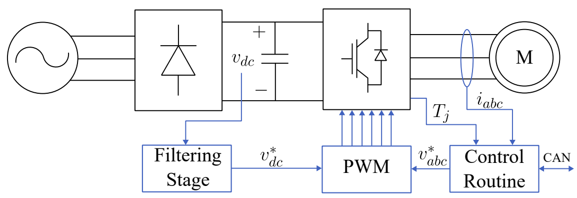


**Figure 1:** Converter structure.

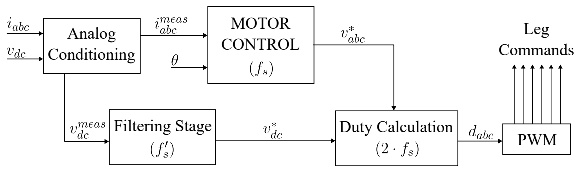


**Figure 2:** Control algorithm block diagram.

## III. CONVERTER SIZING

Based on the current and voltage stresses, I selected first the power electronic module employed for the rectifier and inverter. Then, I have chosen the sensors, the gate drivers and all the devices to develop the converter schematics. In this way, I enlarged my knowledge in terms of: signal analog conditioning, design of the low voltage power supply and the hardware layout of a CAN communication interface. Finally, based on the loss calculation, I selected the heatsink. Moreover, I performed a thermo-fluid dynamic analysis to validate the thermal resistance and the heatsink temperature distribution and the result is reported in Fig.3.

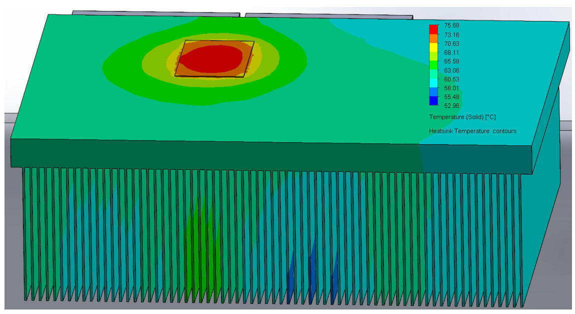

**Figure 3:** Heatsink temperature distribution.

## IV. Experimental Results

The damping control has been validated experimentally. The test bench used for the validation is not the one designed during this thesis, but uses an existing inverter stack using slim DC-link, modified with a slim DC-Link (Fig.4). The experimental results obtained for steady-state operation at 1 kW of a permanent magnet machine fed by the slim DC link inverter are shown in Fig.5. The results show an important decrease of the grid current THD of about 30%, confirming the effectiveness of the adopted damping control. However, the side effect is that the motor phase currents are more distorted, causing an increase of the 4.65% in the current RMS and consequently an increase of 9.5% in power losses.

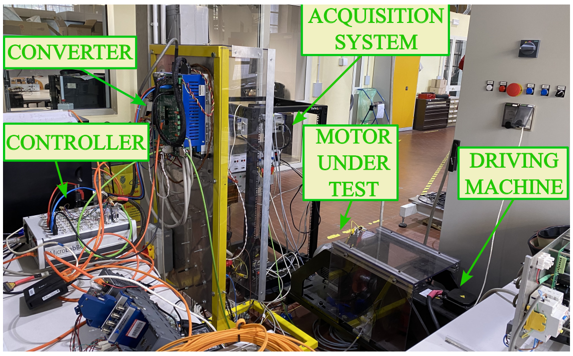


**Figure 4:** Test Bench.

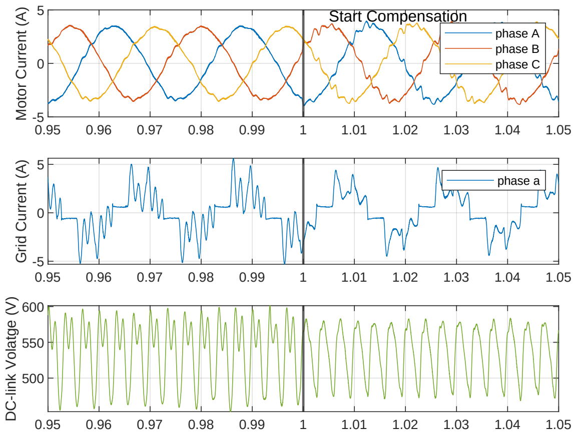


**Figure 5:** From top to bottom: motor phase currents (A), grid phase a current (A), inverter DC link voltage (V).

## V. Conclusions

The thesis includes the analysis and the design of a slim-DC link power converter for adjustable speed drives. The DC-link resonances with the grid are damped using a damping control solution that is embedded in the motor control. In particular, my personal contributions to this work are as follows:

- Literature review about the active damping control algorithm;
- Selection of the most suitable control strategy;
- Simulation of the system and control validation;
- Selection of the power module based on a personalized figure of merit;
- Sensors and devices overview and selection of the most appropriate solution in terms of performance, complexity and cost;
- Heatsink sizing and validation through thermo-fluid dynamic analysis;
- Development of the schematics;
- Selection of the heatsink and fans with thermo-fluid dynamic analysis to validate the sizing;
- Configuration of the microcontroller peripherals and memory optimization to reduce the computational time.

With respect to standard applications with electrolytic capacitors, the pros and cons of a slim dc-link drive with this control strategy are summarized in Table I.

**Table I:** Pros and cons of the slim-dc link inverter using VPIC approach.

| **PROS** | **CONS** |
|---|---|
| higher power density | higher losses |
| higher reliability | higher mechanical stress |
| lower grid current THD | higher complexity |

As expected, the experimental results (using an existing converter with a slightly different topology) show an important decrease in the grid current THD and the almost complete disappearance of resonances in the dc-link voltage, thus validating the control strategy.

## References

[1] Wang, Dong, et al. "Voltage modulation using virtual positive impedance concept for active damping of small DC-link drive system." IEEE Transactions on Power Electronics 33.12 (2018): 10611-10621.