CoPoCo

Optimizing Power Density of Aircraft Inverter by optimized Topology and PWM-Pattern

State of the art – Background

This project was held in the context of research in the Clean Sky Joint Undertaking. The aim of the Clean Sky JU is to develop innovative technology to reduce C02, NOX, gas emissions and noise levels produced by aircraft. With a sustainable and efficient aviation, the societal challenges will be tackled, strengthening the European aero-industry collaboration and transportation demands of goods and people. The project "Optimizing Power Density of Aircraft Inverter Combining Topology and PWM Pattern" with the acronym CoPoCo is part of research in the field of More Electric Aircraft (MEA) and even addresses the All Electric Aircraft (AEA). The concepts of MEA and AEA are aiming to diminish the influence of air traffic on CO2 and NOX emissions through their higher efficiency compared to the state of the art aircraft designs. In the conventional aircraft e.g. the flaps are controlled by a hydraulic system. This hydraulic system is heavy and contains toxic oil if released to nature. Further, the hydraulic system consumes constantly a high power generate by the jet engines to maintain the high pressure. If the flaps would be actuated by an electric motor, the power consumption of the electric motor can be avoided during straight and level flight. To keep the electric system power balance the electric power generation by the jet engines can be reduced resulting in fuel savings and fewer gas emissions.
Another application is the cabin pressurization which is realized through the bleed air from the compressor stage of the engines. This bleed air is causing disturbances of the airflow in the engines and therefore reducing their efficiency. With an electric motor which is used for cabin pressure, this system can further increase aircraft efficiency.

Objectives

These two examples were taken as reference system because of their different power demands. For the flap control, a 10 kW drive application was chosen and for the cabin pressurization, a 50 kW drive was estimated. Since both drives need to be controlled a DC/AC converter is obligatory. DC/AC converters are already widely used in industry in drive applications. Nevertheless, the necessity of a more compact and lightweight converter is given for mobile applications especially in aircraft since every additional kg directly influences the fuel consumption during flight. To realize the above-mentioned tasks through electric systems it is, therefore, necessary to optimize the power density of the converters. In this project, the influence of different components of the converter on weight was analyzed and means of weight reduction have been researched. Here the two critical components have been analyzed to be the heatsink and common mode filters of the converter.
The main objectives of this project are the weight analyses of possibilities to decrease the weight of a converter for a 10 kW and a 50 kW converter. After the analyses phase, a methodology to decrease the weight should be described. With this results, manufacturers of this components will have the possibility to optimize their systems to realize the MEA and AEA.

Description of work

The total project is composed out of two main sections:
1. Study and comparison of solutions to suppress CMV in three-phase inverter applications
- Capability to suppress harmonics
- Influence on filter size and weight
- Selection of a topology, PWM and filter based upon a Pareto-Approach
- Requirement specification for 10 and 50 kW power core
2. Implementation and commissioning
- Implementation of a 10 kW power core
- Implementation of a 50 kW power core
- Measurements of conducted EMI

Results

During CleanSky project with Acronym CoPoCo, which was aimed at reduction of aircraft DC/AC converters weight while keeping certain EMI level, showed good results in technological and scientific areas. Because the goal of the project was proposed to be reached by a combination of various converter topologies and PWM techniques, the variety of achieved results is huge. Moreover, some cutting-edge technologies, like converter based on SiC MOSFETs, were applied, which have a certain impact on the design. Such impact was not reported before, therefore design methodology was developed as well. The R&S outcomes of the project are:

1. Technological outcome
a. Converter based on SiC MOSFETs
During the project, it was estimated, that 10 kW power core will have much lower losses if it will be

built using SiC MOSFET instead of conventional Si IGBTs. From the other side, SiC MOSFET are high-speed devices with very low commutation times in the range of nanoseconds. Such commutation times cause oscillations due to the presence of parasitic inductances. Therefore the design of power converter must be aimed to reduce stray inductance in the commutation path as much as possible.

During the project, elements which have a huge impact on the value of stray inductance were indicated. A design methodology was developed, which takes into account the field cancellation effect. It was possible to achieve very low values of stray inductance without the use of expensive components.

b. 3-level T-type converter based on conventional Si and reverse blocking IGBTs

For the high power core, it was estimated that a 3-level converter is superior to a conventional 2-level converter. It was decided to use a module with reverse blocking IGBTs. Such concept allows to save chip size and therefore slightly reduce dimensions. A power core based on 3-level topology is also new for the aerospace industry. It has lower losses, decreased EMI and has a higher level of redundancy. Some special features need to be also taken into account during design, especially symmetry of the DC link. The design of the converter was developed within the project.

c. Gate drivers for SiC MOSFETs

To operate high speed switching devices several gate drivers were developed and compared. The gate drivers allow to switch SiC MOSFETs at full speed and provide basic safety features.

d. Software for converter with different PWM techniques and for various topologies

To test different PWM techniques and topologies a control system has to be developed. During the project different PWMs for 2- and 3-level converters have been programmed in VHDL. The resulted codes are very flexible. They allow to switch very easy between each other and can be integrated with low effort on the FPGA.

2. Scientific outcome

a. Different models for EMI prediction

In order to evaluate the impact of different topologies and PWM techniques, the model for EMI prediction was developed within the project. Both time and frequency domain models were derived. Time-domain models were aimed to evaluate the impact of different solutions in the low-frequency range. It was also used to estimate overall losses (switching and conduction losses) produced by the converters. The frequency domain model allows to evaluate high-frequency noise and was also used for filter design.

b. Evaluation of dv/dt impact

During the project, it was stated to limit the value of voltage growth (dv/dt) on terminals of the motor. To evaluate these phenomena a model was derived. For the considered system stated value of dv/dt can’t be reached, but from the other side overvoltage on the motor side was observed. The impact of this overvoltage can be a topic for further research.

c. Filter design methodology

During the project, a new EMI filter design methodology was developed. It takes into account material properties of the core, different PWM, hardware topologies and switching frequency. The design methodology is based on the frequency domain models and allows to get result with very low computation effort in a short time.

d. Pareto fronts

Pareto fronts were built including different topologies and PWM techniques. Various solution can be compared by criteria of CM noise and overall losses.

e. HF noise reduction by selective fall time selection

Using simulation and measurements results it was investigated, that it is possible to improve common mode noise in the high-frequency range by means of selection of appropriate rise time. Such approach allows avoiding the implementation of additional filter stages. The results were declared on 18th conference on Power Electronics and Applications, EPE 2016 in Karlsruhe.

f. Investigation of noise coupling between DM and CM

Additionally to the main task of the project, the coupling phenomena between CM and DM were studied. The frequency domain approach was also applied, which is based on mixed mode scattering parameters. The huge impact of this phenomena was found out, that can be a good topic for next research.

g. Investigation of saturation effect in CM chokes

The saturation effects of CM mode chokes were studied experimentally. Evolution of results allowed to include saturation of common chokes in design procedure of EMI filters.

h. Impedance measurement methodologies

During the project, it was necessary to measure impedances of different components in the wide frequency range. Different methods were applied to do it and compared between each other.

a) Timeline & main milestones

01.10.2014: Project Start
28.02.2015: M1 - Project Focus Definition
31.08.2015: M2 - Prototype Definition

30.04.2016: M3 - Prototype Validation
30.11.2016: Project Finish

b) Environmental benefits

This project analyzed two typical applications of DC/AC converters in the More Electric Aircraft (MEA). The first power core has a rated power of 10 kW and could be used to drive flight controls located in the wings. The second converter has a rated power of 50 kW and could drive the compressors to maintain cabin pressure. The project results show a possible opportunity to decrease the weight of converters in this power range and lead to an overall more efficient aircraft. If implemented in TRL7 or higher such systems have the potential to replace the heavy hydraulic and pneumatic systems, which are even less efficient than electric components. Since both converters are fed from a DC-Source it is thinkable to easily recuperate power and use it at other loads in the DC-Bus. With the increased efficiency the fuel consumption of an aircraft can be reduced, resulting in less global pollution, greenhouse gas emissions and consumption of resources.

c) Maturity of works performed

All Demonstrators were designed for TRL4. Since it was not possible to get aircraft specific components e.g. electric machines for the aimed tasks the demonstrators have been designed with industry specific components. The gained results show anyway good feasibility for aircraft and give a good guideline for the design of power cores with high technology readiness levels.

Picture, Illustration

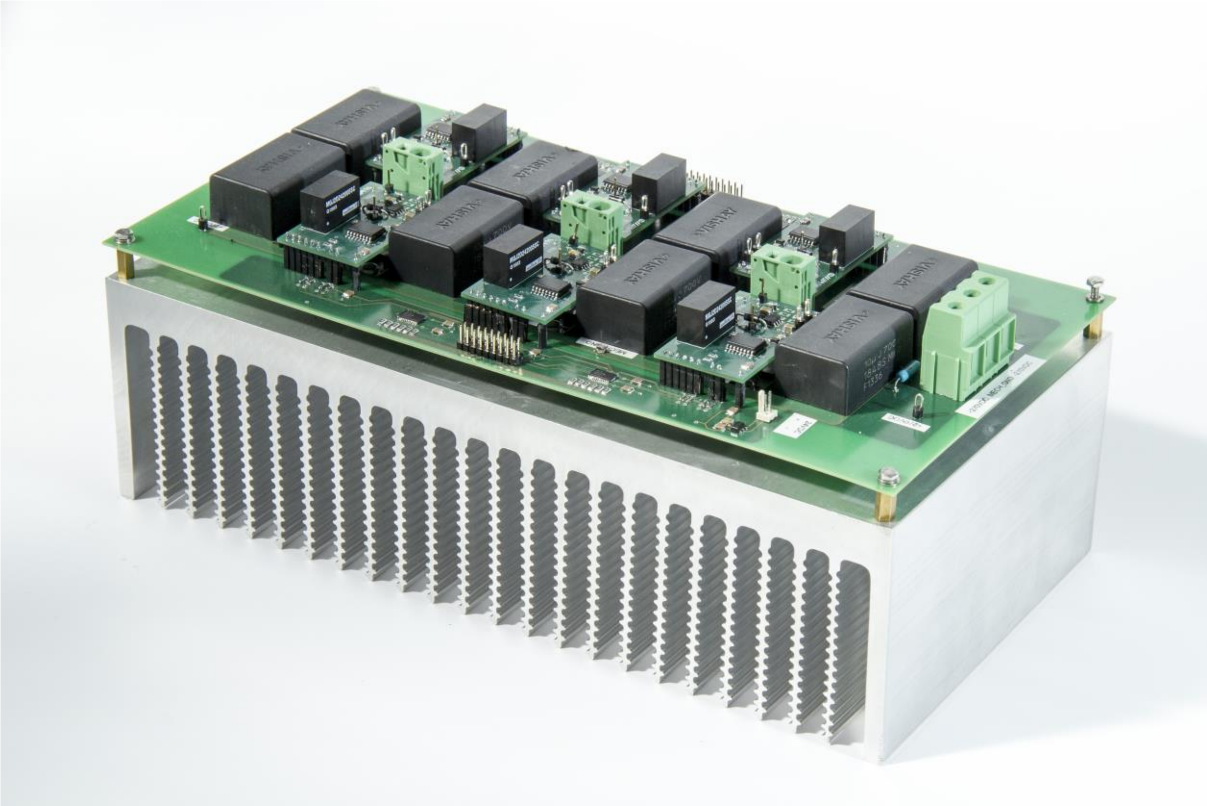

Figure 1: 10 kW Power Core

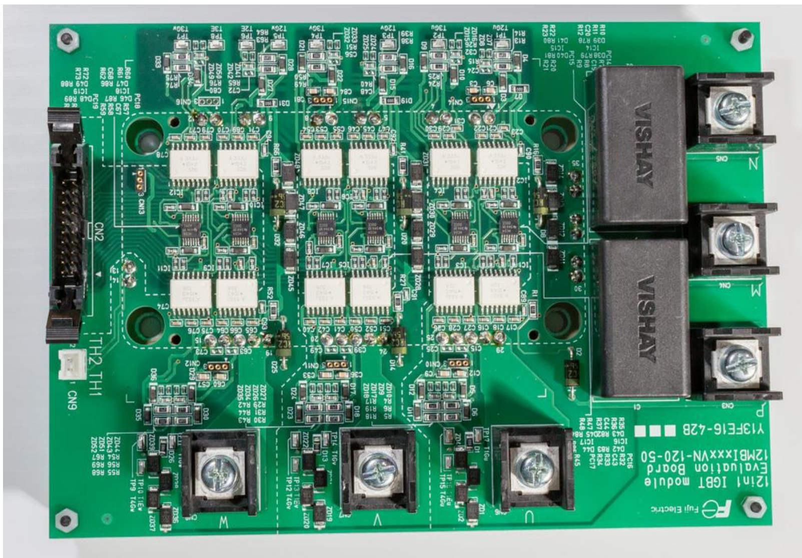

Figure 2: 50 kW Power Core without heatsink and DC-Link

Project Summary

Acronym :	CoPoCO
Name of proposal:	Optimizing Power Density of Aircraft Inverter by optimized Topology and PWM-Pattern
Technical domain:	Electrical Systems
Involved ITD	Systems for Green Operations
Grant Agreement:	CS-GA-2014-640714
Instrument:	Clean Sky JU
Total Cost:	391795.96 €
Clean Sky contribution:	293846.97 €
Call:	JTI-CS-2013-16
Starting date:	1. Oktober 2014
Ending date:	30. November 2016
Duration:	26 months
Coordinator contact details:	Prof. Dr.-Ing. Gerd Griepentrog TECHNISCHE UNIVERSITAET DARMSTADT Institute for Power Electronics and Control of Drives Karolinenplatz 5 DARMSTADT 64289 GERMANY Gerd.griepentrog@lea.tu-darmstadt.de +49 6151 16 20580
Project Officer:	Antonio Vecchio Antonio.Vecchio@cleansky.eu
Participating members	TECHNISCHE UNIVERSITAET DARMSTADT Institute for Power Electronics and Control of Drives Karolinenplatz 5 DARMSTADT 64289 GERMANY