Development of a 12kW isolated and bidirectional DC-DC Converter dedicated to the More Electrical Aircraft: The Buck Boost Converter Unit (BBCU)

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Abstract - This paper introduces the development steps of a specific converter dedicated to the More Electrical Aircraft (MEA). This is a 12kW DC-DC converter called BBCU (Buck Boost Converter Unit), isolated, bidirectional and designed in the context of an increased embedded electrical power in aircraft. In recent years, two prototypes have been created to answer the challenges of the BBCU function, but also to reach the maturity and reliability needed for aerospace implementation. Retained technologies and solutions are presented in order to answer to the constraints related to integration, power density and future aircraft performance.

1. Power Electronics in the More Electrical Aircraft (MEA)

   a. The More Electrical Aircraft (MEA) Context and Challenges

The context of this communication is the More Electrical Aircraft (MEA), already presented in numerous publications [1]. Because of the increasing demand of electrical applications in the current and future aircraft, a coherent energy transition is needed by partial or full abandonment of the pneumatic and hydraulic sources in favor of the electrical one [2]. Some challenges of this transition relate to Power Electronics, with the creation of new electrical networks and static converters to support and supply them. The challenges on these new systems are in our case their increasing integration and power density and their decreasing losses, weight and time of development, as shown in figure 1. Our application, the BBCU (Buck Boost Converter Unit), is a perfect example of a power converter that can be integrated in the MEA, but also an example of design and embedded technologies optimization.

![Figure 1: Power Electronics Challenges in the MEA](image-url)
b. One specific function of the MEA: the BBCU and its specification

In a few words, the BBCU is a bidirectional and isolated DC-DC converter dedicated to the energy conversion between an embedded network +/- 270 VDC – currently studied for an implementation in the MEA - and a 28 VDC network, which is the classical distribution basis. The BBCU offers transfer power up to 12 kW, which makes its design quite tricky to size. The global principle is exposed in Figure 2. In addition, numerous operation modes answer to the mission profiles of the aircraft, including a wide range of input and output voltage that imply major difficulties for the design and the control scheme. The Airbus specification gives more details on the BBCU background and specificities.

![Figure 2: BBCU Principle Schematic](image)

2. BBCU - Version 1

a. Presentation of the first prototype: context and maturity

This chapter presents the complete design of the first BBCU converter. This prototype has been developed by Airbus in a research activity to demonstrate its feasibility in the electrical architecture of the MEA. The work started in 2012 with the aim to optimize individually the different technologies of the design. We have already presented in detail a part of this work in the paper [1]. This first prototype was achieved in 2015. It was compliant to all the norms and answered to the different challenging aspects (electrical, EMC, mechanical, thermal etc.). This prototype, shown in Figure 4 with its different operation stages, is currently under test in an aircraft bench. This means that the concept is totally demonstrated with a high maturity (Technology Readiness Level (TRL) 5), proving the possibility of implementation in future Airbus programs. The key information of this converter are a weight of 25kg for 12kW, and a power density of 0.5 kW/kg with an efficiency of 85% (Figure 3).

![Figure 3: BBCU v1.0 Efficiency Measurement](image)
b. Topological choices

The topology is composed of four parallel 3kW cells which are designed using the current sharing concept, i.e. each brick receives the same current. Each brick is composed with the following pattern: the HV side contains a two-stages conversion with a double serial-buck converter. It is connected to a full bridge converter (current-fed full-bridge type) in order to better adapt the operation point to the DC-AC conversion imposed by the presence of a transformer for the galvanic isolation. On the LV side, we find a double push-pull topology. A filtering stage is added for each power side in compliance with the required input/output impedance and aeronautical norms ABD100.1.8, DO160G and Airbus HVDC directive. A principle schematic is given in Figure 5.

Figure 5: Electrical Topology of the BBCU
c. Power Control

The control is realized thanks to a classical phase-shift method. Because of the different operation missions during a flight, the BBCU has to comply with constrained rules and operations imposed by the aircraft bench in order to test all main systems, realize their certification and control their industrial feasibility. It induces different tests: Under voltage/Overvoltage, Power cut, Load impact, Soft start, Battery interface, Inrush current, etc. Complex control voltage and current loop has been set up according to 4 axes: HVDC regulation, Boost power way, Buck power way and battery charge (Figure 6).

![Figure 6: Measurements (transformer voltage & inductor current) and strategy of BBCU control](image)

Figure 6: Measurements (transformer voltage & inductor current) and strategy of BBCU control

d. Work on Integrated Technologies

The BBCU Prototype was the opportunity to evaluate existing or emerging solutions and to assess the capability of PE suppliers to offer their products for an industrial production. The first technological example relates to the power modules and allows significant integration improvements with a proven reliable solution. Its contents is up to 42 integrated dies. We used the last generation of available high speed Mosfet semiconductor achieving a 100kHz switching with anti-parallel SiC diodes. The module packaging is realized thanks to AlSiC Baseplate (142g Lightweight), which is compliant with the Aeronautic Standard lifetime and mission profile, insuring a high reliability. In addition, this technology is mature because it reaches TRL6 and is already used in automotive applications to achieve semiconductor integration.

![Figure 7: 3kW Power modules (62x108mm) - a) HVDC side– b) LVDC side](image)

Figure 7: 3kW Power modules (62x108mm) - a) HVDC side– b) LVDC side

The second example relates to the cooling. Liquid cold plates have been investigating to play the role of the key element to manage power losses. Two independent loops of folded fin technology have been integrated to comply with the cooling loss and ensure good
performance (Figure 8). The flow is realized through a standard liquid, the Propylene Glycol Water (PGW), while standard thermal performance is reached with low pressure drop, low thermal resistance (Rth) and low thermal gradient. The final integration has a light structure ~3.5kg (heat Sink & Structural part). Moreover, various shapes are achievable at a reasonable cost. Tests have been achieved to assess the robustness of the cold plate and connectors assembly at 10 Bar. This technology is today mature enough, easily replicable and already used on one specific application in A380. Thus, liquid cold plate technology is now available and mastered.

![Figure 8: a) Water Cold Plate – b) Example of two loops of folded fin technology](image1)

The third example is about planar transformer, which is a key component for efficient power transfer and galvanic isolation (Figure 9-a). First of all, low primary leakage inductances were measured (500nH). Then, considering the planar form factor, better thermal characteristics such as a lower thermal resistance compared to conventional wire wound transformer (up to 50%) have been achieved compared to conventional wire wound transformer. Very low profile EE43/10/28 ferrite are used for a 210g weight. In addition, higher repeatability and higher control of parasitic elements (capacitance & leakage inductance) than conventional wire wound transformer are possible because the industrial process contains a minimum of handcraft operation. The maturity is certified for planar technology, with current application for automotive equipment. As a conclusion, with the emergency of DC/DC topologies in the mass market (automotive and renewable energy), planar transformers become an unavoidable technology for future development in power electronics.

![Figure 9: a) Planar Transformer – b) Stacked Capacitors integrated in copper bus bar](image2)

The last example relates to the BBCU LVDC side, which implies high current and low voltage range. Stacked SMD ceramic capacitors have been used with less parasitic elements and more compactness than film ones (<1nH versus 10th nH). In addition, they were integrated in the copper busbar technology (Figure 9-b) because it is more suitable for high current (500A) versus traditional PCB. The maturity has been proven for the laminated busbar technology used in A/C equipment and for Stack ceramic used in the automotive equipment.
3. BBCU - Version 2

a. Presentation of the first prototype and its maturity

In parallel of the first BBCU feasibility demonstration, a research project gathering Airbus and academics named ETHAER has been launched in 2013 [3]. The aim was to improve the efficiency and power density of the BBCU converter by different ways: 1) Global Optimization of the converter, to establish the best choice of topology and get the best technological trade-offs and sizing - 2) Integration of semiconductors and passive components in order to improve the losses, thermal management and electrical parasitic effects – 3) Creation of a new prototype considering both previous work packages and current new technologies such as the wide band gap switches for instance. This whole project leads to a new converter prototype, expected early 2016. Currently, we already have an elementary brick of 3kW realizing the same operation as the final converter and proving the interest of this new development (Figure 10). The key information of this 3kW converter are a power density of 1 kW/kg and an efficiency up to 95%.

![Available 3kW Prototype](image1)

![Future 12kW Interleaved Prototype](image2)

Figure 10: Picture of a 3kW BBCU v2.0 and an example of efficiency measurements in Buck Mode

a. Topological choices

In order to define the best topology (among 8 candidates) and technologies to realize the BBCU conversion, calculation and prototypes have been realized. The different parts of the equipment on local and global optimization have been assessed. An example of the multilevel interleaving trade-off is presented in Figure 11. Similar work has been applied on the filtering part for differential and common modes.

![Optimization of the current doubler topology for different multi-level interleaving](image3)

Figure 11: Optimization of the current doubler topology for different multi-level interleaving

Calculation and experiences led to choose the current doubler topology (Figure 12), which is s
et in multi-level parallel configuration with 8 cells, and uses a “neutral common” configuration to realize the final converter. In addition, CALC (active clamp circuit) have been added to improve the switching operation of semiconductors and so to reach a better efficiency. The relative and complete work of this design and sizing is explained in [4].

![Diagram](image)

**Figure 12:** Final current-doubler topology retained for the second prototype

### a. Work on Integrated Technologies

Technologies of the first prototype were reported on the second one. In addition, a deeper study mainly focused on the semiconductor, and package and driver integrations was realized. As an example, we investigated several thermal management techniques for GaN transistors with a Wafer-Level Packaging (WLP), mount on Direct-Bonded Copper (DBC) ceramic substrates to detail the manufacturing process and get thermal simulations and experimental results.

![Photographs](image)

**Figure 13:** a) Photographs of the two integrated switching cell prototypes - b) Temperature distribution by thermal simulation.

The current work is focused on embedding several dies at once (diodes and transistors) in order to form a complete switching cell (including DC capacitors and drivers). More details can be found in two publications [5][6], where demonstrators are presented and that show satisfying results and characteristics on the packaged die.
4. Conclusion and Expectations for the future

As a result, we can provide the key values of the different BBCU prototypes on the weight and power density by weight and volume. In addition, we can present other research and commercial prototypes, sold for the automation industry in order to make comparisons with our prototypes [7] [8]. To conclude, the initial objective on the BBCU equipment was to reach a power density of 1kW/kg (Table 1), in order to potentially embed it in the future airbus MEA. This objective was achieved on the second prototype (estimation from 3kW available prototype), with impressive advancements due to improved topological choices and additional switching circuits, orientated by preliminary studies and global sizing. A parallel integration study of drivers and semiconductors has been conducted, which let think that the present results can be improved with these technologies.

<table>
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<tr>
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<th>BBCU v1.0</th>
<th>BBCU v2.0 (estimation from 3kW available prototype)</th>
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</thead>
<tbody>
<tr>
<td>Weight (kg)</td>
<td>24,5</td>
<td>12</td>
</tr>
<tr>
<td>Ext. power Density (kW/kg)</td>
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<td>1</td>
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<tr>
<td>Total volume (L)</td>
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<td>13</td>
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<tr>
<td>Ext. power Density (kW/L)</td>
<td>0,27</td>
<td>0.92</td>
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<tr>
<td>Efficiency</td>
<td>85%</td>
<td>95%</td>
</tr>
</tbody>
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Table 1: Synthesis of both BBCU prototypes

References

1 Bourdon Jérémy, Asfaux Pascal, Morentin Etayo Alvaro “Review of power electronics opportunities to integrate in the more electrical aircraft” ESARS. Aachen, 2015.
2 Roboam Xavier "New trends and Challenges of Electrical Networks embedded in "more electrical aircraft"".
4 Brunello Julien „Conception de convertisseurs de puissance DC-DC isolés pour l’avion plus électrique” 2015 PhD Thesis
8 Krismer Florian “Modeling and Optimization of Bidirectional Dual Active Bridge DC–DC Converter Topologies” 2010.
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