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Novel Modular Device for a Decentralised Electric Power System Architecture for More Electric Aircraft

GAIZKA MARTÍNEZ, FERMÍN RODRÍGUEZ LALANNE, IGNACIO SÁNCHEZ-GUARDAMINO, SERGIO RODRÍGUEZ BENITO, AND JOSE MARTÍN ECHEVERRÍA
Department of Electric Vehicle, Ceit-Basque Research and Technology Alliance (BRTA), 20018 Donostia/San Sebastian, Spain
Universidad de Navarra, Tecnun, 20018 Donostia/San Sebastian, Spain

Corresponding author: Gaizka Martínez (gmzubizarreta@ceit.es)

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ABSTRACT The aeronautical industry is one of the last groups which has decided to join the distributed architecture trend in order to increase both the safety and efficiency of future aircraft. However, the actual power system used in aircrafts has certain limitations that makes it difficult to achieve this objective due to its high centralisation. This paper proposes a novel methodology for the design of a new modular power electronic device that is based on semiconductor technology, which provides the equipment and functionality that makes the full decentralisation of the aircraft DC power system possible in the near future. The proposed and developed device can be adapted to the requirements of the system where it is going to be implanted, as it is possible to add as many devices as the system needs and have as many modules as needed. All the modules are bidirectional, which makes the system more redundant and fault tolerant, as the number of possible paths to feed the loads is increased. Tests were carried out with 5 devices (4 modules per device), 3 power supplies and 2 loads, where the correct operation of the system (path search, load feed and failure management) was proved.

INDEX TERMS More electric aircraft, modular, power systems, efficiency, safety.

I. INTRODUCTION

The airline industry has quickly grown in recent years thanks to various socio-economic activities such as tourism, air freight and business. Taking into account that aircraft currently use fossil fuels for their propulsion, the more air traffic density there is, the more gas emissions, having an impact on world's climate. The Advisory Council for Aeronautics Research in Europe (ACARE) states in [1] that air traffic not only accounts for 3% of annual global CO2 emissions but also 12% of transport activity emissions. Given the expectation that air traffic density will continue to grow in the coming years, ACARE addresses the reduction of current emission rates by proposing a list of requirements that the airline industry has to meet for 2020 (short-term goals) and 2050 (medium-term goals). For each set of requirements, ACARE has published two official documents [2] and [3], where these goals are explained.

These two documents stipulate that CO2 emissions have to be reduced by half and NOx emissions must decrease by 80% per passenger kilometre before 2020. Furthermore, the aviation industry has until 2050 to additionally reduce CO2 and NOx emission by 25% and 10%, respectively (table 1). It is also expected that aircraft safety will be increased by reducing the accident rate from 1 out of 7 million aircraft flights to 1 out of 10 million flights [3].

TABLE 1. Reduction goals for 2020 and 2050 horizons.

Requirements	Reduction rates for Horizon 2020	Reduction rates for Horizon 2050
CO2 emissions	50%	75%
NOx emissions	80%	90%
External noise	50%	65%
Fuel consumption	50%	-

In order to achieve these goals, it is necessary to increase the efficiency of the overall system. A review of the literature

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shows that some researchers have proposed replacing the devices that use non-electric energy, such as mechanical or hydraulic devices, with electrical ones [4]–[7] as a feasible solution. These solutions are based on the fact that the efficiency of the devices that use electrical energy is greater than those devices that do not use it. Moreover, due to improvements not only in power electronics but also in motor-drive systems technology, the airline industry is actively involved in the More Electric Aircraft (MEA) concept. For instance, two examples where the MEA concept has been developed are the Airbus A380 [8] and the Boeing 787 [9] aircraft.

With regard to MEA, the core of this concept relies on replacing devices that use non-electric power with devices that do use electric power such that future aircraft have a single Electric Power System (EPS). These changes produce certain challenge which requires that some areas, such as power transmission and electrical distribution network inside the aircraft, be rethought. In table 2, the differences between current aircraft and future MEA are shown [10]–[14].

TABLE 2. **Differences between traditional aircraft and MEA.**

Current/Traditional Aircraft	MEA
Traditional engine (generation of electric, pneumatic and hydraulic power); pneumatic start-up	Bleed-less engine; electric start-up
Auxiliary power unit (generates electric, pneumatic and hydraulic power)	Auxiliary power unit (generates electrical power)
Hydraulic and pneumatic actuators, mechanical breakers, AC and DC low voltage circuit barkers	Electric actuators, electric breakers and solid state relay
Batteries are used only in emergencies and for auxiliary power unit start-up	Used along different flight phases

Although many of the devices and subsystems that are going to be implemented in MEA are currently being developed by different companies, there is no agreement on what the structure or the voltage levels of the EPS will be. In addition, this lack of agreement on the EPS characteristics makes it difficult to standardise the operating range of the subsystems. Therefore, it is necessary to apply power electronics in developing subsystems that can operate in different ranges.

This paper presents a distributed power centre unit (DPCU) developed for a decentralised architecture. Apart from the general considerations such as, redundancy levels and weight, the characteristics of self-reconfiguration, modularity and replicability have been taking into account in the development of the DPCU device. The rest of this article is structured as follows: the differences between current EPS, and decentralised EPS are summarised in Section II and Section III presents the requirements identified for the DPCU device. Section IV explains the main steps of developing the DPCU, and Section V shows the results obtained from the hardware test. Conclusions are discussed in Section VI.

II. ELECTRIC POWER SYSTEMS IN CURRENT AIRCRAFT AND DECENTRALISED ARCHITECTURE FOR MEA

In order to obtain an efficient aircraft which reduces power losses and increases safety as much as possible, a novel EPS needs to be developed. In the last few years, there has been a strong research and development effort in aircraft EPS due to the expectation of high electrical dependence in future aircraft. For instance, the rising number of electrical energy dependant subsystems that are replacing other technologies such as hydraulic or pneumatic systems, requires that future EPS have a larger power capacity and greater management skills. This section compares current aircraft EPS and the EPS of future MEA based on a review of the literature [15]–[23].

A. CURRENT EPS

With regard to the EPS, aircraft have undergone relevant changes to ensure greater efficiency of the overall system and increase aircraft reliability and safety. Regarding energy efficiency, manufacturers have standardized Direct current (DC) and Alternating Current (AC) voltage levels:

- ±270 Vdc
- 230 Vac (400Hz)

These changes to voltage levels have yielded the following advantages:

- The ±270 Vdc is able to feed loads that require high power with a lower current, meaning a lower area can be used in the conductors. This current reduction not only reduces the Joule effect and the DC/DC power converters' losses but also lowers the final cost and the total weight of the aircraft.
- The greater the power density that is achievable in the design of an AC/DC converter, the higher its output voltage is. Thus, increasing the Vdc voltage allows the weight and volume of these devices to be minimised and deliver the same power output.
- The standardised Vdc voltage value makes it easier to integrate different storage technologies into the aircraft, such as electrochemical (batteries) and/or electrostatics (supercapacitors).
- The increase from 115 Vac (400 Hz) to 230 Vac (400 Hz) reduces the power conduction losses in the rectifiers that generate the DC voltage. In addition, the efficiency of the power generators increases due to the current reduction in the wiring. This, in turn, makes it possible to increase their volumetric and specific power density.

Given the new standardised voltage levels, generators and power converters that were traditionally used on aircraft need to be redesigned. In order to ensure that these new devices fulfil all the electrical, thermal, safety and reliability requirements and validate them, Airbus developed a benchmark in Hamburg.

To improve fault tolerance, aircraft EPS have been gradually decentralised, although a completely decentralised network has not yet been achieved. Figure 1 shows the degree of decentralisation that is currently being carried out, which can be described as follows:

- Two generators (GEN1 and GEN2) linked to the 270 Vdc power distribution system by AC/DC converters (AC/DC1 and AC/DC2). In addition, there are two main power distribution buses: High-Voltage Primary Power Centre (HVPPC) and Low-Voltage Primary Power Centre (LVPPC).
- The power distribution system that works at 270 Vdc can also be powered through the auxiliary power unit if the aircraft turbines incur any damage during the flight phase or externally through the EXT entry during the connection of the aircraft to the ground after the landing.

In addition, figure 1 clearly illustrates how these primary power centers (HVPPC and LVPPC) architectures work like centralised systems that are located in specific places in an aircraft. Therefore, if a failure occurs in any of these parts of the EPS, the linked loads cannot be fed. To avoid this situation, a high number of redundancies are introduced in the EPS to ensure that there is a sufficient number of links, which are controlled either by mechanical relays or solid state relays (SSRs), between all the devices. The main disadvantage of this centralised configuration is the need to customise this EPS for each aircraft design, which makes it impossible to design a general PPC that can be easily reconfigured. Finally, the HVPPC is linked to the LVPPC through four different DC/DC converters. This connection between HCPPC and LVPPC has been made highly redundant to ensure the supply to LVPPCs loads.

The increased number of electrical subsystems implemented in aircraft have two main consequences: firstly, the number of critical loads that must be fed rises, and secondly, the length of the aircraft's wiring increases owing to the fact that HVPPC and LVPPC are located in a part of the plane which is not usually next to the loads that they must feed. Therefore, if the aim is not only to increase the overall efficiency and safety of the aircraft but also to implement distributed energy storage technologies, a completely decentralised EPS needs to be developed.

B. DECENTRALISED ARCHITECTURE FOR MEA

A search of the literature did not yield any research related to completely decentralised power system architecture prototypes in the airline industry. Figure 2 shows a layout where each node represents a device in the EPS in an aircraft. As it can be seen, not all nodes are necessarily connected to the same number of nodes; for instance, while "Load 5" is linked to three systems, "Load 4" is linked to four systems. This variability will be supported by the power electronic DPCU device that all of the aircraft's systems (generators, loads and storage technologies) will have and which will be reconfigurable due to its modularity.

The objective of the developed system is to ensure that the transmission of the High Voltage (HV) DC power and the Low Voltage (LV) DC power from figure 1 is as safe and decentralised as possible, so that reliability is improved. Power conversion, management of the power generated and management of the electric load are beyond the scope of this prototype. This system (formed by a number of DPCUs) needs to receive information regarding which power source is going to feed each load at the initial stage. Once the information is received, the DPCUs will find the best path for connecting the power elements (power sources and loads) with each other. When a failure occurs, the system tries to feed the load with the generator specified at the initial stage. However, if it is not possible to find another path because many failures have been detected, the system has to be informed about which other generator, battery or APU will feed the load so that the best path can be selected and the load can be powered. A simplified example of a possible implantation of these DPCUs in a MEA is shown in figure 3.

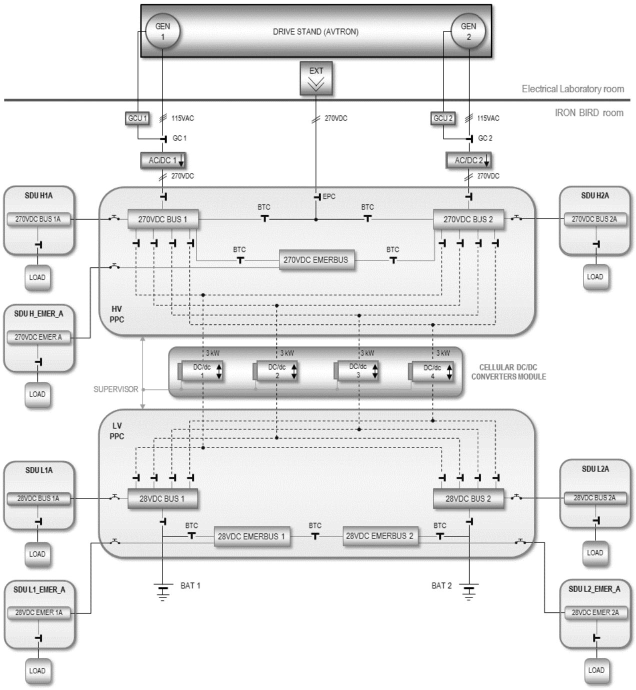


FIGURE 1. Architecture for HVPPC and LVPPC electrical distribution networks [24].

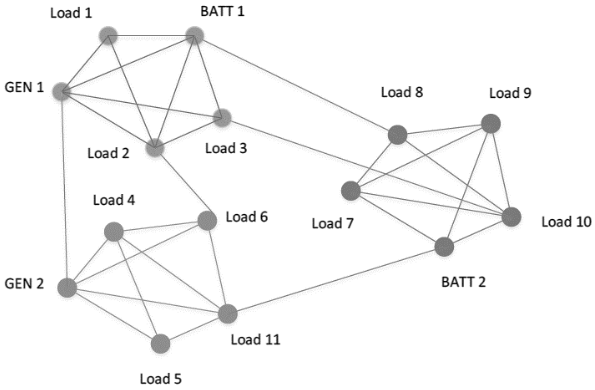


FIGURE 2. Possible layout network for an aircraft.

To test the developed DPCUs, a test bench was built to simulate the HV part of the EPS shown in figure 3.

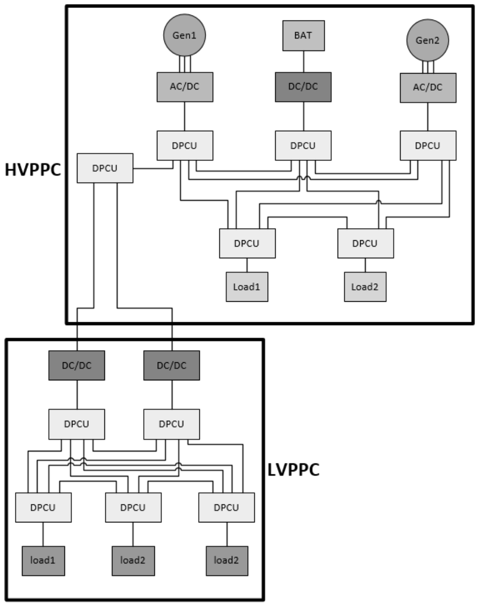


FIGURE 3. Simplified example of a possible application of DPCUs in a MEA.

Figure 4 shows the layout of the test bench, which consists of two Power Sources (PS) of at least 7kW (540V/13A) that simulate the generator's power but after conversion from AC to DC, two resistive loads of 58 Ω and another power source that simulates the battery after DC/DC conversion (also at least 7kW). Although the DPCU has a single input, which makes the connection between the DPCU and any other device of the test bench possible, it has more than one output so different network configurations can be tested. In addition, it can be seen that the DPCU developed here is made up of four different modules, but this number can be easily increased in accordance with hardware development.

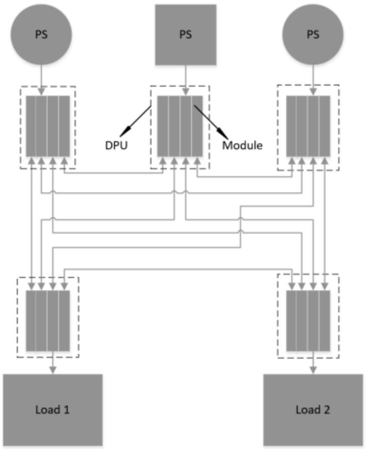


FIGURE 4. Test bench developed for DPCU validation.

III. IDENTIFIED REQUIREMENTS

Before designing a decentralised EPS for a MEA, the requirements of the system must be identified. Considering that the objective of the DPCU is to provide a modular power unit for decentralising the future system, the device must meet the following requirements:

- Redundant: redundancy is one of the most important requirements to consider in designing a DPCU for a MEA, since it is essential that it be fault-tolerant. If any element (wires, semiconductors, connectors, sensors, etc.) that is part of the main energy transfer path is damaged, there must be alternative choices for feeding the loads that will require it.
- Replicable: the main application of the DPCU is to allow the decentralisation and modularity of a MEA, but it should be applicable in other applications e.g. electric ships or small and medium electric grids. For this reason, making the DPCU replicable is fundamental in order to transfer it to another application. This means that the DPCU should be able to manage as many modules as the application requires and connect to an unlimited number of DPCUs to decentralise the system without redesigning the DPCU device. In addition, it must be able to operate in a wide power range, as long as maximum power ratings are respected, without replacing the components.
- Modular: the DPCU must be modular, i.e. it must be composed of identical and interchangeable modules that will make the substitution and repair process easier. Thus, if a DPCU module is damaged or needs to be replaced, it could be replaced by other module without needing to make changes to the other DPCU modules. Furthermore, the developed device must have the capacity to increase the number of modules if the system requires it. In a decentralised EPS, new loads or power supplies will be implemented through a DPCU that will be interconnected with the other system's DPCUs.
- Bidirectional: there are two reasons for satisfying this requirement in DPCUs. First, aircraft usually have a battery that has to be managed, so the DPCUs have to be able to inject and extract energy from it. Taking into account that all the modules and DPCUs have to be identical and interchangeable, it is necessary to provide bidirectionality to all modules. The second reason is that the system's redundancy needs to be increased in such a way that, when the modules are completely bidirectional, the number of possible paths for transferring the energy from a power supply to a load is increased.
- Decentralised: having a master node that manages the entire system has some disadvantages. One of them is the reduction in fault-tolerance, since, should the master node experience some damage or error, the whole system would collapse. The second disadvantage is the loss of the modularity requirement described above: if there is a master node, the DPCUs are not identical and consequently not interchangeable. That means that if there is no master node in the system, all the Digital Signal Processors (DSP), which are inside the DPCUs, have to be intercommunicated so they are able to inform

each other about the state of their own DPCU. If a sudden break of any element in the system occurs, the DSPs must democratise the new best path to transfer the energy from the power supplies to the loads using the best criterion, for example, the shortest wire length or the minimum number of Insulated-Gate Bipolar Transistors (IGBTs). The implemented communication protocol in DSPs for this democratisation will be the CAN protocol.

IV. METHODOLOGY

As mentioned in section II-B., the test bench that was fabricated to validate the design of the prototype was made up of five DPCUs, and each DPCU was composed of four modules (see figure 4). Apart from the four modules, each DPCU had a power supply to feed the DSP and the other low voltage circuitry. In addition, the DPCUs also had a DSP, which controlled the entire system in collaboration with the DSPs from the other DPCUs.

The modules comprised six SSRs that worked as controlled switches with a maximum rating of 1200V and 84A. Therefore, each module was able to safely withstand a power of 20kW, as the voltage of the grid was established at 540V. However, in the test bench, each module has a power rating of 5kW. Taking into account that the SSRs were going to commutate at low frequency, it was necessary to add a heatsink to dissipate the conduction loses. However, in other cases where a chosen heatsink is not able to sufficiently dissipate all the power losses, a fan may be needed.

The modules were equipped with two voltage sensors, three current sensors and a temperature sensor that provided to the DSP with information about the current and voltage rating in the system, and they also informed the DSP about possible errors in the SSRs or wires. Figure 5 presents a simplified layout of a module, where it can be seen that current sensors are connected next to the outputs of the module.

A. VOLTAGE MEASUREMENT

In order to reduce the overall cost of a DPCU and minimise the weight and volume of each module, the voltage measurement circuit was designed to include a voltage divider. Figure 6 shows the block diagram of this circuit. As it can be seen, after the voltage divider, there is an isolation stage that is performed by an isolated amplifier, which is prepared to connect it to high-voltage voltage dividers. After that, the signal is adapted to a maximum value of 3,3V and then analysed by the DSP.

B. CURRENT MEASUREMENT

Similar to the matter of the voltage measurement circuit, in order to reduce costs and space, a Rshunt resistor was used to design the current measurement circuit. The block diagram of this circuit is shown in figure 7, where the adaptation and DSP reading stages are the same as in the voltage divider circuit. However, the isolation stage was designed with an isolated amplifier which is optimised for connecting directly to shunt resistors.

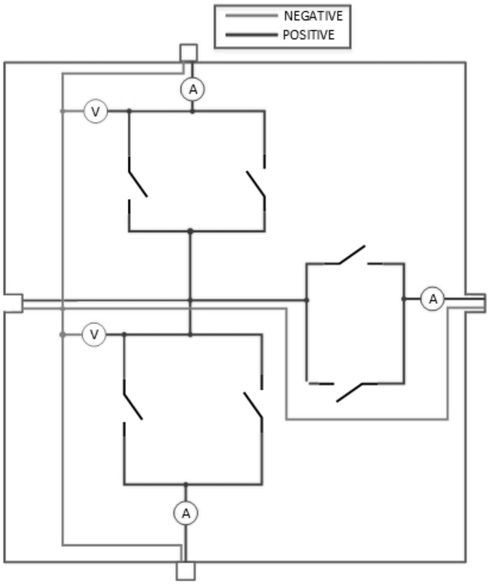


FIGURE 5. Simplified layout of a module.

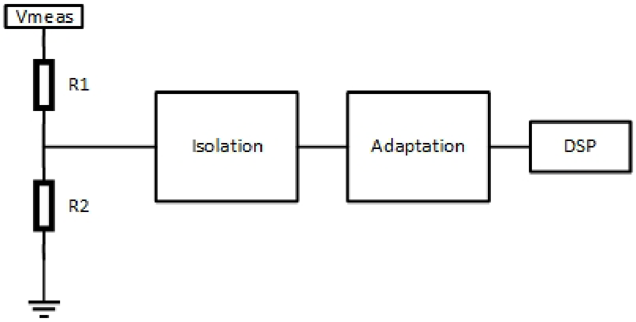


FIGURE 6. Voltage measurement circuit block diagram.

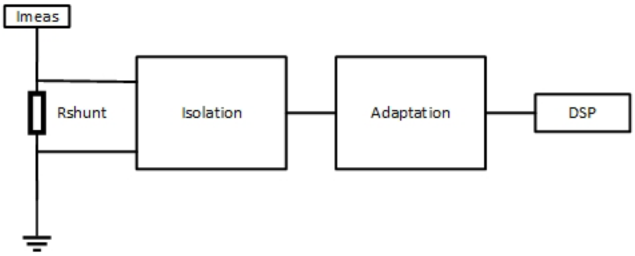


FIGURE 7. Current measurement circuit block diagram.

C. TEMPERATURE MEASUREMENT

As it can be seen in figure 8, the temperature measurement circuit was designed with a Wheatstone bridge and an adaptation stage. After that, as occurred in the other measurement circuits, the signal was analysed by the DSP.

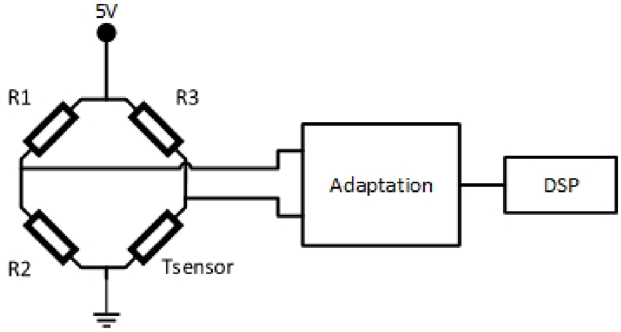


FIGURE 8. **Temperature measurement circuit block diagram.**

To ensure that the temperature sensor correctly measures the hottest part of the heatsink, how the sensor is positioned in the heatsink is essential. In these modules, because there was a fan for increasing the dissipation of power losses, the sensor needed to be located in the middle of four SSRs and as far as possible from the fan, as can be seen in figure 9.

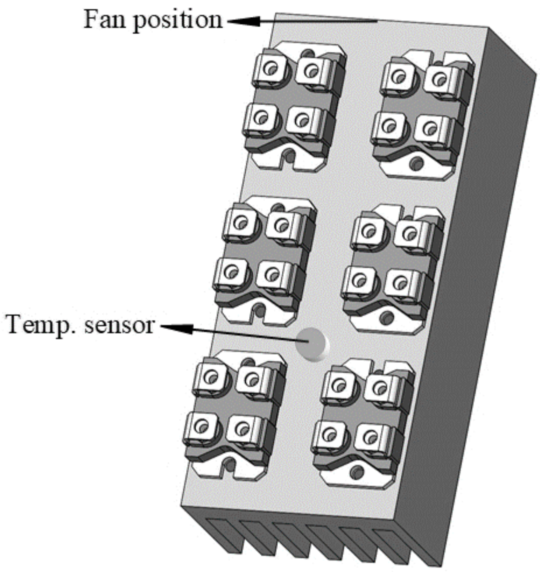


FIGURE 9. **Position of the temperature sensor in the heatsink.**

D. POWER SUPPLY

The general power supply of a DPCU converts the 540V/9.26A extracted from any of the inputs/outputs of the system into 28V/5A. Consequently, the DPCU stays turned off until the energy reaches one of its input/output, and because of this, the total energy consumption of the system is reduced. Apart from the general power supply, there are some DC/DC converters and voltage regulators that feed operational amplifiers, triggering the circuits of the SSRs, the Analog to Digital Converters (ADCs) of the DSP, etc. The block diagram of all the power supplies needed for powering all the components of the system is shown in figure 10.

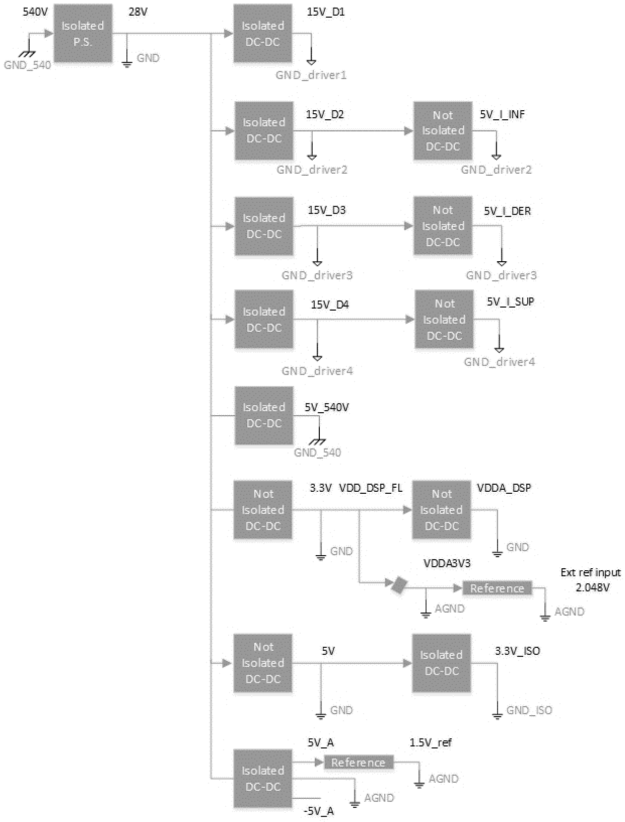


FIGURE 10. **Power supply block diagram.**

V. RESULTS AND DISCUSSION

With regard to the validation of the developed device, the prototype was built in a 19'' rack cabinet, as there are very few 23'' rack cabinet producers. The four modules of a DPCU were housed in a 6U rack mounted case, allowing the modules to be easily connected, as seen in figure 11. Using a rack cabinet to house all the DPCUs also allowed them to be easily interconnected as the heat dissipation is improved.

Figure 12 shows the 3D design of a DPCU without the 6U case, where it can be seen that the modules were placed at different heights to ensure that they fit in a 19'' rack mounted case and the recommended space between Printed Circuit Boards (PCBs) was guaranteed. The DSP was positioned in the front part of the DPCU near the general power supply, although here it is intentionally hidden to facilitate the visualisation of the modules' location.

To validate the performance of the DPCUs, a test with 540V/9.26A has been run. The objective was to ensure that the developed devices worked correctly and they were capable of transmitting that amount of power without incurring any damage. For this test, the worst operating case was simulated, where the three nearest SSRs worked at the same time. However, this configuration of SSRs was not the usual one, since the chosen topology ensured that only 1 SSR worked per row. During the test, the temperature of a SSR was measured to ensure that it was working in a suitable temperature range.

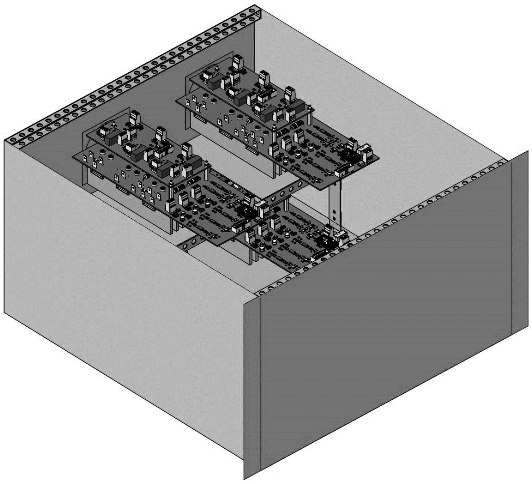


FIGURE 11. **3D design of a DPCU.**

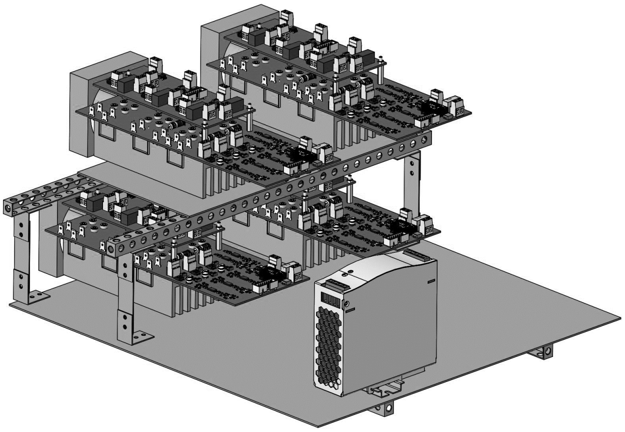


FIGURE 12. **3D design of a DPCU (without case).**

As can be seen in figure 13, the temperature was stabilised at 70 degrees after 20 minutes, which is within the operating range of the SSR.

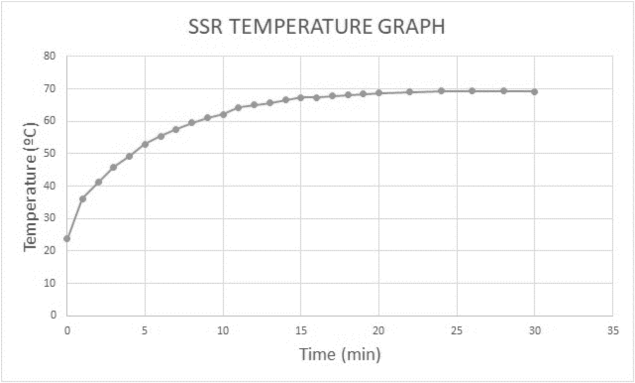


FIGURE 13. **SSR temperature during a test.**

In addition, the test shows that the path selected by the DPCUs was the correct one, since the loads were fed correctly with 540V and 9.2A. Moreover, when a fault occurred, the system was able to find another path to continue feeding the loads.

After the DPCUs were designed and tested, a number of upgrades that would improve the DPCUs and the behaviour of the EPS of a MEA were identified. In future work, the addition of a bidirectional DC/DC buck/boost converter inside the DPCU will be examined. This new DPCU will have one HV input/output and one LV input/output. In the HV and LV parts, there will be a number of modules (as many as the system needs) and, the buck/boost bidirectional converter will be placed between them, as shown in figure 14. With this improvement, the amount of wires needed to connect the HV and LV loads will decrease considerably. An example of a possible implantation of the improved DPCU in an aircraft is shown in figure 15. Moreover, the system could be able to manage the electric load taking into account the flight phase and the load priority level.

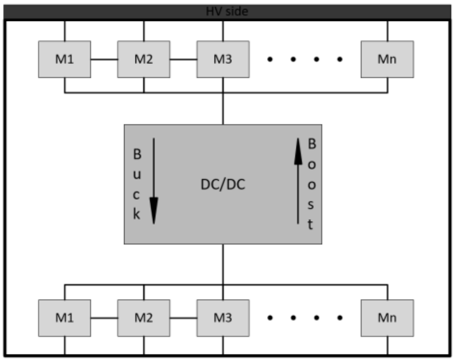


FIGURE 14. **Internal layout of improved DPCU.**

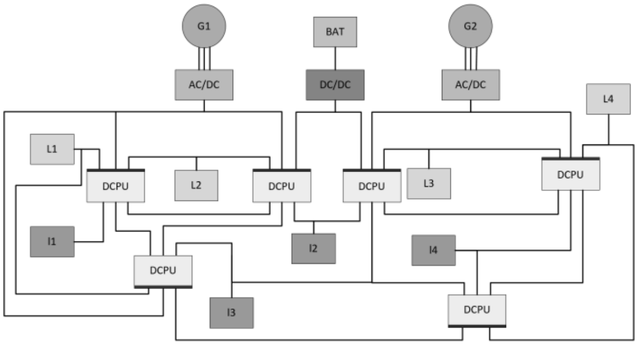


FIGURE 15. **Example of a possible implantation of improved DPCU in an aircraft.**

VI. CONCLUSION

This study presented a novel modular device for a decentralised EPS architecture for use in a MEA. It also addressed a gap in the literature on different EPS architectures for MEA, where there are no studies to date that have developed a modular and decentralised system for future MEA. The study's main contributions are:

- A first approximation to a decentalised MEA was developed thanks to a modular system composed of an unlimited number of DPCUs designed to be installed in a centralised system. Each DPCU is totally bidirectional, making the system more redundant.
- The DPCUs are able to house as many modules as the user wants, limited only by DSP processing capability and the available space in a DPCU. Thanks to this modular topology and because the modules are identical, if an error is detected or internal equipment in the DPCU needs to be replaced, the repair process simply consist of replacing the broken module with a new one.
- The DSP and the power supply housed in the DPCU are easy to exchange if either of them experiences a functional error.

REFERENCES

[1] (Jun. 2010). Advisory Council for Aeronautics Research in Europe. *Aeronautics and Air Transport: Beyond Vision 2020 Towards 2050*. Accessed: May 15, 2020. [Online]. Available: https://op.europa.eu/en/publication-detail/-/publication/028f443e-8b6b-4052-9940-d47fe5b38e8a

[2] *European Aeronautics: A vision for 2020*. Accessed: May 15, 2020. [Online]. Available: https://www.acare4europe.org/sites/acare4europe.org/files/document/Vision%202020_0.pdf

[3] *European Commission Flightpath 2050: Europe's Vision for Aviation*. Accessed: May 15, 2020. [Online]. Available: https://www.acare4europe.org/sites/acare4europe.org/files/document/Flightpath2050_Final.pdf

[4] S. N. Motapon, L.-A. Dessaint, and K. Al-Haddad, "A comparative study of energy management schemes for a fuel-cell hybrid emergency power system of more-electric aircraft," *IEEE Trans. Ind. Electron.*, vol. 61, no. 3, pp. 1320–1334, Mar. 2014.

[5] Y. Jia and K. Rajashekara, "Induction machine for more electric aircraft: Enabling new electrical power system architectures," *IEEE Electrific. Mag.*, vol. 5, no. 4, pp. 25–37, Dec. 2017.

[6] B. Sarlioglu and C. T. Morris, "More electric aircraft: Review, challenges, and opportunities for commercial transport aircraft," *IEEE Trans. Transport. Electrific.*, vol. 1, no. 1, pp. 54–64, Jun. 2015.

[7] D. Tan, "Transportation electrification: Challenges and opportunities," *IEEE Power Electron. Mag.*, vol. 3, no. 2, pp. 50–52, Jun. 2016.

[8] E. Alcorta-Garcia, A. Zolghadri, and P. Goupil, "A nonlinear observer-based strategy for aircraft oscillatory failure detection: A380 case study," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 47, no. 4, pp. 2792–2806, Oct. 2011.

[9] A. Ghodbane, M. Saad, C. Hobeika, J.-F. Boland, and C. Thibeault, "Design of a tolerant flight control system in response to multiple actuator control signal faults induced by cosmic rays," *IEEE Trans. Aerosp. Electron. Syst.*, vol. 52, no. 2, pp. 681–697, Apr. 2016.

[10] P. Wheeler, "Technology for the more and all electric aircraft of the future," in *Proc. IEEE Int. Conf. Automatica (ICA-ACCA)*, Oct. 2016, pp. 19–21.

[11] N. Nagel, "Actuation challenges in the more electric aircraft: Overcoming hurdles in the electrification of actuation systems," *IEEE Electrific. Mag.*, vol. 5, no. 4, pp. 38–45, Dec. 2017.

[12] T. Neuman, "Fly the electric skies," *IEEE Spectr.*, vol. 53, no. 6, pp. 44–48, Jun. 2016.

[13] Y. Shen and Y. Wang, "Operating point optimization of auxiliary power unit using adaptive multi-objective differential evolution algorithm," *IEEE Trans. Ind. Electron.*, vol. 64, no. 1, pp. 115–124, Jan. 2017.

[14] L. Yu, Y. Zhang, and H. Liu, "Performance analysis and optimization design of dissimilar redundant hybrid electro-hydraulic actuation system," in *Proc. IEEE Int. Conf. Aircraft Utility Syst. (AUS)*, Beijing, China, Oct. 2016, pp. 10–12.

[15] X. Zhao, J. M. Guerrero, and X. Wu, "Review of aircraft electric power systems and architectures," in *Proc. IEEE Int. Energy Conf. (ENERGYCON)*, Dubrovnik, Croatia, May 2014, pp. 13–16.

[16] A. Eid, H. El-Kishky, M. Abdel-Salam, and T. El-Mohandes, "Constant frequency aircraft electric power systems with harmonic reduction," in *Proc. 34th Annu. Conf. IEEE Ind. Electron.*, Orlando, FL, USA, Nov. 2008, pp. 10–13.

[17] A. Eid, H. El-Kishky, M. Abdel-Salam, and M. T. El-Mohandes, "On power quality of variable-speed constant-frequency aircraft electric power systems," *IEEE Trans. Power Del.*, vol. 25, no. 1, pp. 55–65, Jan. 2010.

[18] L. M. Lobo, C. Dufour, and J. Mahseredjian, "Real-time simulation of more-electric aircraft power systems," in *Proc. 15th Eur. Conf. Power Electron. Appl. (EPE)*, Lille, France, Sep. 2013.

[19] A. L?cken, J. Brombach, and D. Schulz, "Design and protection of a high voltage DC onboard grid with integrated fuel cell system on more electric aircraft," in *Electrical Systems for Aircraft, Railway and Ship Propulsion*. Bologna, Italy: IEEE, Dec. 2010.

[20] H. Zhang, F. Mollet, C. Saudemont, and B. Robyns, "Experimental validation of energy storage system management strategies for a local dc distribution system of more electric aircraft," *IEEE Trans. Ind. Electron.*, vol. 57, no. 12, pp. 3905–3916, Dec. 2010.

[21] Y. Xu, Z. Zhang, J. Li, and Y. Yan, "Architecture analysis and optimization of high voltage DC parallel electric power system for more electric aircraft," in *Proc. IEEE Int. Conf. Aircr. Utility Syst. (AUS)*, Beijing, China, Oct. 2016, pp. 10–12.

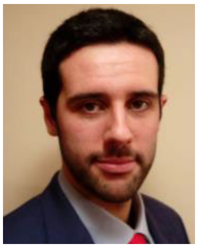
[22] Q. Xu, J. Chen, P. Wang, C. Wen, L. M. Yeong, and R. Simanjorang, "Investigation of the future MEA power system architecture-from the perspective of system stability," in *Proc. 8th IET Int. Conf. Power Electron., Mach. Drives*, Glasgow, U.K., Apr. 2016, pp. 19–21.

[23] T. Yang, S. Bozhko, and G. Asher, "Application of dynamic phasor concept in modeling aircraft electrical power systems," *SAE Int. J. Aerosp.*, vol. 6, no. 1, pp. 38–48, Sep. 2013.

[24] *7 Call for Proposals (CFP07): List and Full Description of Topics*. Accessed: May 15, 2020. [Online]. Available: https://ec.europa.eu/research/participants/portal/doc/call/h2020/jti-cs2-2017-cfp07-air-01-36/1800105-cfp07_call_text_-_list_and_full_description_of_topics_r2_en.pdf

GAIZKA MARTÍNEZ was born in Andoain, Spain, in 1992. He received the B.S. degree in industrial electronical engineering from the University of Mondragon, Arrasate/Mondragon, in 2015.

Since 2017, he has been working developing and designing novel hardware and software in power electronics, novel devices to increase the decentralization of power systems and creating simulations to estimate the battery consumption of an electric vehicle at the Transport and Energy Division, Centro de Estudios e Investigaciones Técnicas (CEIT), BRTA. His research interests include power electronics and energy conversion.



FERMÍN RODRÍGUEZ LALANNE was born in San Sebastian, Spain, in 1993. He received the M.Sc. degree in industrial engineering and the Ph.D. degree from the Tecnun-University of Navarra, San Sebastian, in 2017 and 2021, respectively. Since 2017, he has been working on applied research projects not only in the development and design of novel hardware and software in power electronics, but also in the development of novel devices to increase the decentralization of power systems at the Centro de Estudios e Investigaciones Técnicas (CEIT), BRTA. Since 2021, he has been an Associate Professor with the University of Navarra, where he is currently a Lecturer in power electronics and power systems. He has authored or coauthored about ten scientific and technical publications in international journals and conference proceedings.

IGNACIO SÁNCHEZ-GUARDAMINO was born in San Sebastian, Spain, in 1971. He received the B.S. degree in electronics from the UPV, San Sebastian, in 1996.

Since 1996, he has been working as Researcher with the Electric Vehicle Group, Transport and Energy Division, Centro de Estudios e Investigaciones Técnicas (CEIT), BRTA. In this group, he has actively participated in the development of different projects related with electronic design for power electronics and power systems (dc/dc and dc/ac), sensor conditioning, and digital signal processing. His research interests include the design and development of energy storage systems and power converters for electronic vehicles and smart grids.

SERGIO RODRÍGUEZ BENITO was born in Vitoria-Gasteiz, Spain, in 1992. He received the degree in power electronics engineering and the master's degree in power electronics from the University of Mondragon, Arrasate/Mondragon, in 2014 and 2016, respectively.

Since 2016, he has been working on applied research project with the Centro de Estudios e Investigaciones Tecnicas (CEIT), where he is currently a Research Assistant with the Transport and Energy Division. His main research interests include the modeling and design of high-power resonant converters oriented to transport and aerospace applications.

JOSE MARTÍN ECHEVERRÍA was born in San Sebastian, Spain, in 1972. He received the M.Sc. and Ph.D. degrees in electrical engineering from the University of Navarra, San Sebastian, in 1996 and 2005, respectively.

Since 1997, he has been working on applied research project with the Centro de Estudios e Investigaciones Técnicas (CEIT), BRTA, where he is currently the Director of the Transport and Energy Division. He has also been an Associate Professor with the University of Navarra, since 2011. He has authored or coauthored about 30 scientific and technical publications in international journals and conference proceedings. His main research interests include the analysis, modeling, and design of high-power density power electronic devices oriented to transport and aerospace applications.

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