



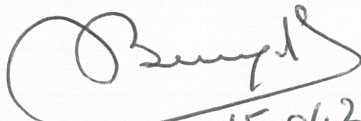
Project acronym: SEPDC

Project Title: Smart Electrical Power Distribution Centre

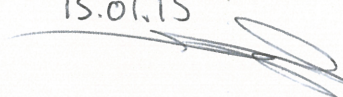
Call and Contract: SP1-JTI-CS-2010-05-  
Grant agreement no: 287098  
Start of project: July 1<sup>st</sup> 2011  
Duration: 2 Years

## FINAL PROJECT REPORT: FINAL PUBLISHABLE SUMMARY REPORT

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15.06.2015

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SEPDC project is supported by funding from the 7th Research Framework Program of the European Union.



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**ACRONYMS**

AC	: alternating current
ADC	: analogue to digital converter
CB	: circuit breaker
CCC	: central command centre
DC	: direct current
ETB	: electrical test bench
GCU	: generator control unit
ITD	: integrated technology demonstrator
LCC	: local control centre
MEA	: more electrical aircraft
PTP	: precision time protocol
RCCB	: remote controlled circuit breaker
RTT	: real-time target
SEPDC	: smart electrical power distribution centre
SSPC	: solid state power controller

## 1. Executive Summary

The SEPDC "Smart Electrical Power Distribution Centre" was developed as part of the Clean Sky partnership between the European Commission and the European Aeronautical Industry, a partnership which is set up to bring significant innovations regarding the environmental impact of aviation by improving aircraft reliability and efficiency by contributing to the continuous development of More Electrical Aircraft (MEA).

SEPDC delivered the distribution centre of the Electrical Test Bench (ETB) which is housed on the premises of the Task Manager, SAFRAN Hispano-Suiza. The multi-disciplinary nature of the project brought together three consortium partners, each with their own specialisation; ESIEE-Amiens (management, power electronics and simulation), Triphase (power electronics, measurement and control) and Hazemeyer (electrical distribution).

The main objective of the SEPDC as a new distribution centre for the already existing ETB was to bring a measure of flexibility to the manner in which equipment was electrically connected to the test bench. To this end the SEPDC consists of a Central Cabinet and drawer-like Racks. The Central Cabinet contains the required  $28V_{dc}$  LVDC,  $\pm 270V_{dc}$  HVDC and  $115/230V_{ac}$  AC bus bars, but is capable of  $540V_{dc}$  operation as well. It also houses the Racks and real-time target (RTT) which acts as the interface to the Racks.

It is through the use of these withdrawable Racks that the SEPDC provides a highly configurable interface through which to connect sources and loads to the bus bars, and the bus bars to themselves. This is made possible by the high power switching element which is housed in each of the Racks, allowing equipment to be permanently connected to Racks, but easily connectable and disconnectable from the bus bars through commands given by the user, with the result that the ETB layout can be reconfigured with ease.

By bringing this high level of reconfigurability to the ETB the SEPDC allows aircraft manufactures to conduct verification activities over the different aircraft electrical architectures for Green Regional Aircraft, Green Business Jets, General Architecture and Green Rotorcraft. The SEPDC, critically, thus also enhances and speeds-up validation and evaluation processes of new technologies (starter/generators, actuators, drives) as required for MEA during test-bench testing, aiding in keeping the European aerospace sector competitive by shortening the delivery to market time of new, innovative and essential aircraft technologies.

SEPDC kicked off in July 2011 and quickly progressed passed both its preliminary and critical design reviews in March and April of 2012, respectively. Following intense development and manufacturing the first of the Racks were successfully put through their factory acceptance tests in January of 2013. Soon after followed the successful factory acceptance test of the SEPDC in April 2013, combining the Racks and Central Cabinet.

The SEPDC was then delivered to Hispano-Suiza (now Labinal Power) in May 2013. Following the completion and delivery of the final Racks, the SEPDC successfully passed its final commissioning in December 2013; proving its full operation, both on hardware and software levels, and verifying that it is ready to play its vital and important role in the Clean Sky Eco Design ITD test regime by enabling the connection and testing of various other Clean Sky related projects such as Smart Programmable Load & Source (SPLS), STARTGENSYS, Helicopter Electro-Mechanical Actuators (HEMAS) and the Electrical Environmental Control System (e-ECS).



FIGURE 1-1: THE SEPDC TEAM

## 2. SEPDC Context and Objectives

The main driver for the existence of the SEPDC is the development of More Electrical Aircraft, or MEA for short. Decades of development by civil aircraft manufacturers to address economical, ecological, regulatory and technological challenges have caused aircraft systems to become ever more complex, resulting in far from optimal and inefficient architectures which are composed out of four power networks, namely hydraulic, pneumatic, mechanical and electrical. The incompatibility of these four power sources reduces the efficiency and reliability of the whole system.

The trend then is to use electrical power for the sourcing and distribution of all non-propulsive aircraft engine power and this trend is defined as MEA.

Many new technologies and concepts are required to make MEA a reality, especially from the field of power electronics, with MEA making extensive use of power conversion and power conditioning equipment. Before any new technologies can be implemented on a fully operational aircraft their operation must be characterized and their safety verified through testing regimes. To this end a test bench was constructed as part of the European Union Power Optimised Aircraft (2002 till 2006) project.

Named Copper Bird © (Characterization & Optimization of Power Plant & Equipment Rig), the test bench mimics the operation of an aircraft electrical system (AES) by allowing the interconnection of loads and sources and enabling aircraft manufactures to conduct verification activities.

Under Clean Sky the requirement was made that airframers be able to only test their new equipment, but be able to do so over different aircraft electrical architectures. From here was born the idea for the SEPDC, an electrical distribution centre that would be installed within the existing electrical test bench and allow the easy connection and disconnection of sources and loads to and from the existing test bench electrical network whilst remaining highly configurable in order to enable different aircraft architecture configurations.

In light of the above the main objectives of the SEPDC was to deliver an easily re-configurable electrical power distribution centre which is adapted to different voltages and tolerant to faults for more reliability, with an openness and adaptability of the system to easily accept other elements (generators, loads) or to be integrated in a centralized control system.

In order to fulfil its objectives, the SEPDC was required to:

- provide high power bus bars compatible with MEA
  - $28V_{dc}$  LVDC
  - $\pm 270V_{dc}$ ,  $540V_{dc}$  HVDC
  - $115/230V_{ac}$  AC
- provide easy connection of
  - AC and DC sources and loads to the bus bars
  - interconnection between bus bars of the same voltage rating
  - synchronised control of the connection and disconnection of the connected equipment
- provide synchronised, high fidelity current, voltage and temperature measurements
- provide fixed and programmable protection to all connected equipment
- provide local control through which the SEPDC can be controlled and monitored via the communications network of the test bench
- provide an user friendly software interface through which to exercise control over the bench, view its status, change its configuration and take measurements.

### 3. SEPDC Main Technological Outcomes

Physically the SEPDC can be divided into two parts: the Central Cabinet and the Racks. The Central Cabinet contains the required LVDC, HVDC and AC bus bars. It also houses the Racks and real-time target (RTT). The **main technological outcomes are the Racks and their embedded proprietary measurements modules which allow time-stamped, synchronised, Ethernet accessible distributed measurements, including programmable protection and control.**

#### 3.1. The Central Cabinet

The Central Cabinet is made up out of seven columns. The central column is reserved for housing the industrial  $230V_{ac}$  protection circuitry,  $28V_{dc}$  emergency network power supply with related relays, the RTT and the terminals for the 3<sup>rd</sup> party sensor outputs. Each of the other six columns can accommodate ten Racks each, giving a system total of 60 Racks. Each of the six columns is separated into two sections (as there are two bus bars per column), giving 50 DC rack positions (five Racks times 10 sections) and ten AC Rack positions (five Racks times two sections). The column to immediate right of the central column is used for the interconnection Racks which ensure the connections between bus bars of the same type.

Concerning the grounding of the SEPDC, it is assumed that most of the loads will be designed to work on  $0/+270V_{dc}$ . However, **innovatively the SEPDC design also allows working with  $\pm 135V_{dc}$ ,  $0/+540V_{dc}$  and  $\pm 270V_{dc}$** , although only one voltage set can be implemented at a time, with no “hybrid” distribution.

#### 3.2. The Racks

The Racks is another innovative concept of the SEPDC and is based on a **multi-agent system** with synchronized measurements and control of contactors from a single master controller with all units integrated in a single engineering interface.

The Rack is the basic building block which allows the connection between equipment (sources or loads) and a bus bar or between bus bars themselves. There are three different Rack types:

- Source Rack: connection between a bus bar and a source. Can be AC or DC.
- Load Rack: connection between a bus bar and a load. Can be AC or DC.
- Bus Tie Rack: connection between a bus bar and another one. Only DC.

The Rack has three main parts. Firstly there is the main switching element, secondly the controller card, and thirdly the proprietary Triphase sensors which provide both voltage and current readings.

#### Technological innovations within the Rack include:

- the ability to accommodate any type of main switching element, such as contactors and solid state power controllers (SSPC);
- the measurement instrumentation
  - synchronized (and time stamped), distributed and galvanically isolated measurements
  - Ethernet access to measurements which enables remote and distributed measurements
  - capable of handling short term current overloads 10x times the nominal current
  - settable alarms and triggers (over-voltage, under-voltage, over-current, ...)
  - the ability to execute a fuse model as the primary form of protection, generally a hard limit or an  $I^2t$  type curve
  - the ability to take high resolution snapshots with the capability of broadcasting messages such as trigger events such that every Rack in the system then takes and stores its snapshot for later retrieval and data analysis

## 4. Potential Impact, Exploitation of Results and Main Dissemination Activities

### 4.1. SEPDC Economic and Societal Impacts

Manufacturers of aircrafts are currently finding themselves in a constantly evolving and competitive environment of economical, ecological, regulatory and technological challenges. Another concern for the aircraft industry is the growing public interest in environmental issues such as pollution, noise and climate change. As it stands, the air transport industry only produces 2% of man-made CO<sub>2</sub> emissions (and 12% of all transport sources), but this is predicted to increase to 3% by 2050 due to the continuous growth of air traffic.

Another concern for the aircraft industry is the growing public interest in environmental issues such as pollution, noise and climate change. ACARE (Advisory Council for Aeronautics Research in Europe) has also set forth in their Vision 2020 goals of reducing fuel consumption and CO<sub>2</sub> emissions by 50% per passenger kilometre, reducing NO<sub>x</sub> emissions by 80% and reducing perceived noise by 50%. The main contributors to achieving the above targets are efficient aircraft: 20-25%, efficient engines: 15-20% and improved air traffic management: 5-10%.

Already looking beyond 2020, ACARE is targeting a 75% cut in CO<sub>2</sub>, 90% in NO<sub>x</sub> and a 65% noise reduction in their Flightpath 2050.

In light of the above, the European Union and its aircraft industry has embarked upon optimization campaigns with the aims being cost reduction, increasing operational reliability and lessening the overall environmental impact of air-transportation systems. Among these campaigns are Power Optimized Aircraft (2002 till 2006), More Open Electrical Technologies (2006 till 2009), Clean Sky (2009-2016) and Clean Sky 2 (2014-2023). All these programs either already have or will facilitate the reaching of these goals. Continuing to play its vital role as a product of the POA campaign is the Copper Bird ®, a ground Electrical Test Bench (ETB).

The ETB aims at evaluating the network characteristics and behaviour when integrating all or part of the equipment constituting the electrical power distribution system on future aircraft. The SEPDC as a power distribution system of the ETB features HVDC and LVDC networks and handles the transfer of power between sources (generators, external power, batteries) and different power end-consumers. The expected final results will ensure that high technology industries remain in Europe and provide directly or indirectly jobs and economic support to its people.

The direct impact of the SEPDC upon the ETB:

1. before being upgraded with SEPDC, the ETB had only one, single fixed configuration. A configuration change would have required several days or even weeks of recabling and verification. Now, with the SEPDC's potential of hosting 60 Racks in total, all ETB equipment can remain connected on a permanent basis. Should a reconfiguration of the test bench be required, such as during an aircraft architecture change, **no time-consuming physical recabling is required**: all that the SEPDC requires for a reconfiguration is the proper software settings for every Rack switching element through the click of a mouse, whilst at the same time offering the flexibility of instantly reverting to the previous testing configuration.
2. the novel design feature of being able to connect not only 0/+270V<sub>dc</sub> rated equipment on the HVDC bus but also ± 135V<sub>dc</sub>, 0/+540V<sub>dc</sub> and ± 270V<sub>dc</sub> rated equipment only serves to **increase the versatility of the ETB and ensures its use in current and future test campaigns** in which these voltage levels might become relevant.
3. the ability to integrate SSPC devices **allows establishing and verifying I<sup>2</sup>t curves for various load types**, and also to characterise its response to different types of loads, especially capacitive loads at switch-on and inductive loads at switch-off.
4. earlier methods of protecting connected equipment relied upon remote controlled circuit breakers (RCCB) or electro-magnetic power controllers (EMPC). The combination of a switching element with measurement instrumentation within the Racks allows for much more flexibility whereby each Rack's **protection can be precisely programmed to match the requirements of the connected equipment**, either through a set current level or customisable I<sup>2</sup>t curves. Should the connected equipment change, there is **no physical need to replace the protection with an accordingly rated protection device**; all that is required is a mere software parameter change of the set protection values.
5. stemming from point four is the **added layer of protection** that the SEPDC adds beyond the capabilities of traditional methods, such as circuit breakers, through the addition of extra programmable parameters such as over-voltage, under-voltage, over-current, etc. Hardware execution of the

protection algorithm within the Rack **eliminates all latency associated with the remote monitoring and control of remote protection devices** such as RCCBs, for example. This added layer of protection is essential given the high cost nature of the equipment connected to the ETB.

6. the combined snapshot and overcurrent abilities of the measurement system allow **in-depth analysis of the response of technologies such as lithium-based batteries**. Given the events that have led to the Boeing 787 battery related problems, better insight into the in-situ behaviour of this and future battery technologies is indispensable.

By taking the above into account it safe to assume that the SEPDC, through its role within the ETB, both directly and indirectly:

- contributes to, **enhances and speeds-up 5 to 10 times the validation and evaluation processes of new technologies** (engines, actuators, drives), as required for More Electrical Aircraft, during test-bench testing, and
- ensures a proper integration of equipment in a highly configurable manner on the Electrical Test Bench to **evaluate the complete network characteristics**, in particular in terms of “Quality”, “Stability”, safety and correct operational use.

The SEPDC thus, by contributing during the validation and evaluation processes on existing and new technologies, aids in keeping the European aerospace sector competitive by shortening the delivery to market time of new, innovative and essential aircraft technologies and help airframers in meeting societal requirements for security and environmental impacts on global climate change by making air transport more reliable and less polluting.

## 4.2. Exploitable Results

Except for its design and specification details the SEPDC as an electrical distribution centre alone does not produce any exploitable results, or at least not any results worthy of scientific analysis. What it is instead is an ‘enabler’ which indirectly produces exploitable results; by fulfilling its primary role of distributing and measuring protected power between sources and loads in a highly configurable manner it facilitates the correct functioning of the Electrical Test Bench, the function of which is the evaluation of state-of-art technologies for future use on More Electrical Aircraft. These technologies include the Electrical Thrust Reverser Actuation System (ETRAS), Electrical Brake Actuation Controller (EBAC) for the Boeing 787, and the Electrical Back-up Mechanical Actuator (EMBA), starter-generators (STARTGENSYS), to name just a few. It is thus the ETB, with the aid of the SEPDC, which will produce exploitable results. But these results are specific to the airframer(s) involved and remain highly confidential.

Contrarily, the **SEPDC project resulted in three commercially exploitable and marketable artefacts, namely the measurement instrumentation, the Racks and the SEPDC concept itself**, together with their operational specifications.

The **measurement instrumentation provides high-speed, high-precision synchronized measurements that can be installed in a distributed manner to monitor voltages and currents** around the lab. Applications include general purpose power measurements (voltage, current, power), AC power and harmonics analysers, power quality and efficiency measurements on motor drives, monitoring of PV panels and renewables, and energy monitoring and energy efficiency analysis.

In addition to the above, **the Racks** as a distributable control platform provide the same functions as it does within the framework of SEPDC:

- remote, synchronised switching of equipment such as sources and loads, either AC or DC;
- fixed and programmable protection of equipment, and
- control of distribution networks such as Smart Grids which include multi energy sources of a hybrid nature (batteries, fuel cells, super-capacitor, auxiliary power unit, generators, ram-air turbine).

**The SEPDC, with its high level of reconfigurability and ability to host LVDC, HVDC and AC bus bars** makes it perfect for the use within Smart Grids, Intelligent Homes and Buildings, and electrical test benches.



### 4.3. Dissemination Activities

The SEPDC was showcased at various high profile and prestigious events, events which include the Hannover Messe of 2013, the Opal-RT Real-time Conference of 2013, and also the 2013 IEEE European Power Electronics Conference. A workshop was also organized and held at ESIEE-Amiens as an information session to students, professors and researchers.

#### 4.3.1. SEPDC Workshop: 2012/10/18

An informative workshop was held at the electrical engineering school ESIEE-Amiens, France. The aim of the workshop was to inform master level students from both ESIEE and UPJV (University of Picardy Jules Verne) about the concept of More Electrical Aircraft (MEA) and the role and development of the SEPDC. Presentations were made by:

- **Augustin Mpanda** (ESIEE) and **Jean Bester** (ESIEE/UPJV): “Smart Electrical Power Distribution Centre SEPDC”
- **Jean-Roch Cossa** (Hispano-Suiza): “More Electric Aircraft: State of the Art and the Way Forward”
- **A. El Hajjaji, H. Dahmani** (UPJV): “Vehicle Dynamics and Road Curvature Estimation For Lane Departure Warning System Using Unknown Inputs Fuzzy Observers”

#### 4.3.2. Picardy Region Research Week: 2012/11/26-30

A poster and presentation giving the general overview of the SEPDC and its role within the development of More Electrical Aircraft was made at the 2012 Picardy Region Research Week, France, which took place between the 26<sup>th</sup> and the 30<sup>th</sup> of November 2012. It is the region’s biggest academic and industrial showcase and an important dissemination platform for Picardie Region, linking industry and academic research. The presentation was given by **Augustin Mpanda**, ESIEE.

#### 4.3.3. Hannover Messe: 2013/04/8-9

A presentation giving the general overview of the SEPDC and its role within the development of More Electrical Aircraft was made at the 2013 Hannover Messe, Germany, which took place between the 8<sup>th</sup> and the 12<sup>th</sup> of April 2013. It is the world’s biggest industrial fair and served as an important dissemination platform for SEPDC. The presentation was given by **Jean Ernst Bester**, ESIEE/UPJV.



FIGURE 4-1: HANNOVER MESSE 2013 PRESENTATION

#### 4.3.4. Opal-RT Real-Time Conference 2013/06/25-27

The Opal-RT Real-time conference was held in Paris, France, between the 25<sup>th</sup> and 27<sup>th</sup> of June 2013. Consortium partner Triphase had a stand at the conference through which the SEPDC/Racks were put on display. **Pieter Coppens** and **Jeroen Van Den Keybus**, both from Triphase, rendered the service.



FIGURE 4-2: TRIPHASE STAND AT THE 2013 OPAL-RT REALTIME CONFERENCE

#### 4.3.5. EPE'13: 2013/09/3-5 in Lille, France

A poster presentation detailing the development and operation of the SEPDC was made at the prestigious 2013 IEEE European Power Electronics conference which was held in Lille, France, between the 3<sup>rd</sup> and 5<sup>th</sup> of September 2013. An accompanying paper was also submitted and is published on the online IEEE Xplore database. The poster presentation was given by **Jean Ernst Bester**, ESIEE/UPJV.

Triphase also had a stand at the conference through which the SEPDC/Racks, its measurement system and the real-time target were demonstrated with the participation of **Pieter Coppens** and **Jan Pannier**.

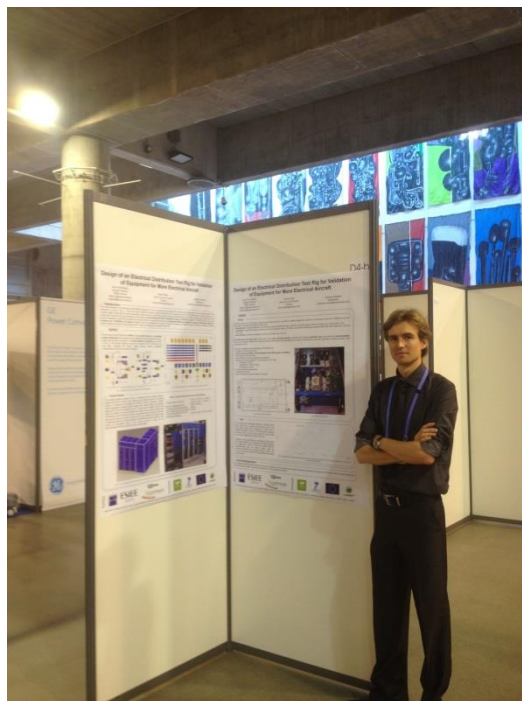


FIGURE 4-3: POSTER PRESENTATION AT EPE 2013

## 5. Website and Contact Details

### 5.1. SEPDC Website

The SEPDC web site contains information on the project scope and objectives, information concerning the project time schedule, the activities undertaken and the remaining activities to be implemented. It also contains public documents (reports, working papers, published papers, announcements, etc.) produced during the project, the agenda of prospective dissemination activities such as seminars, meetings and conferences. Links to other sites of scientific and technological interest, including other EU-funded projects in related fields, are also presented.

The website can be readily accessed at the following URL:

<http://www.sepdc-fp7.eu>



FIGURE 5-1: SCRENGRAB OF THE SEPDC WEBSITE HOMEPAGE

## 5.2. Contact Details

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