TEMGIR

Thermal and electrical Mock-ups for Thermal Management of a Ground Integration Test Rig

State of the art – Background

Management of Aircraft Energy is a key point of the framework of JTI/Clean Sky Systems for Green Operations (SGO-ITD). The More Electrical Aircraft (MEA) philosophy trends to use all-electric equipment system architectures to get a more fuel-efficient use of power. The objective is less fuel consumption and thus reduced environmental impacts.

At aircraft level, some devices need to be cooled and others need to be heated. Moreover, incoming air is cold and unpressurized but it is required both hot and pressurized for fuselage crew as cold and pressurized for cooling electrical equipment. During the transformation, the air is heated and energy is required. Additionally, quick temperature changes or large slew rates (e. g from -20ºC to 30ºC) could damage power electronics. Furthermore, the MEA philosophy trends to include more power electronic devices, which currently each one implements its own cooling system.

Nowadays, Thermal Management System (TMS) is closely related to electrical energy consumption and heat at all levels of the overall aircraft solutions: hot spots in large power electronics, motor drive system cooling, air-conditioning, heat load for kitchen… High point heat loads have to be thermally managed in the most efficient way and this trend is forecast to continue for the foreseeable future.

These reasons bring the need of a new and complex thermal management concept (what, how, many, when and where). Consequently, inside the Clean Sky SGO 4.2, integrated energy large scale ground demonstrator have been developed for electrically powered air systems architectures and its thermal management.

In this framework, after simulations results, the laboratory validation tests require a high amount of energy and real aircraft devices, which are extremely expensive and susceptible to be broken during integration. Moreover, some of this electrical consumers and heat sources can be under R&D development and different performance is required for each validation test. So, for initial tests, it is preferable programmable dummy equipment which simulate the desired behaviour in three ways:

- Load profile to the power electronics
- Thermal behaviour for the cooling loop.
- Energy supply as generation.

Objectives

Under this situation, it was detected the need of building Thermal loads and Electrical loads and generators Mock-ups. The **main goal** of the project has been to develop test bench rig which supplies energy and includes electrical and thermal behaviour emulators to provide a fully integrated replacement for aircraft hardware. Its aim is to create a test set up with the most representative environment of all equipment involve in the electrical and thermal management.

This feature is carried out through **specific objectives:**

1. Design and build a Power Distribution Centre, using available commercial power supplies for different voltage outputs: 28VDC, 115VAC, 230VAC and ±270VDC.
2. Include switching and protection for all outputs of power distribution centre and consumption monitoring and recording for these outputs to allow exact duplication of the load power demand.
3. Build several units of 2000W Heat Load which to simulate heat losses produced by power electronic semiconductors.
4. Cool Heat Load through liquid using cold-plates with provision for air-cooled operation
5. Build a set of programmable current sinks to simulate 115V/230VAC (up to 80kW) and +/-270HVDC (also up to 80kW) equipment under test with a maximum of 160kW
6. Design the current sink as several modules which are able to be coupled to act as one.
7. Develop a software which manage all information at the same time and is capable to use data from power distribution centre or pre-defined profiles from third parties to control Electrical and Heat Loads.
8. Deploy a regeneration module which returns the absorbed current from Electrical Loads back again to the input of TEMGIR (400VAC, 3-phase) to save energy.

The major **challenges** have been:

- Develop a ±270VDC power source up to 225kW output. There is no commercial unit for this typology and the output transient, ripple and slew rate must be compatible with real aircraft equipment.
- Emulate the thermal transfer of Heat Load as similar as possible to real semiconductors.

• Control the Electrical Load (which core is a DC/DC converter) such as their input can be flexible and their output is compatible with regeneration module.
• Integrate commercial regeneration devices (DC/AC inverter) with the consumption profiles of Electrical Load
• Allow a real-time and opened protocol for all signal in order to integrate the test bench rig with the whole architecture.

Description of work

At the beginning of the project, in the **Specification Work Package**, the consortium defined and described the specifications and the design of the TEMGIR test rig, based on the initial requirements given during the negotiation phase and improved during the common work with the Topic Manager. From the requirements catalogue generated in the previous phase, the designers and specialists started to work on the technical solution and the design. They designed and detailed a product that meets customer requirements as well as standards and regulatory requirements.

The TEMGIR structure was defined during the **Architectural Design Work Package** and has been the same during the entirety project, divided in five different blocks:
Package 1 – Power Supply System, also called Power Distribution Centre. Which includes the previous objectives and next power sources: 28VDC up to 20kW; 115Vac 400Hz up to 100kVA; 230Vac 400Hz up to 50kVA and +/-270VDC up to 225kW
Package 2 – Cooling Loop and Heat Loads. It includes a complete liquid cooling system for integration tests and eight (8) units of 2000W thermal loads.
Package 3 – Electrical Active Loads. Eight (8) units of 20kW of which four ones can use both AC as DC input and the other ones only DC input.
Package 4 – Control and Monitoring SW connecting all devices through standard protocols.
Package 5 – Building Power Regeneration Module

The **Detailed Design Work Package** was complete with a description to the most minimum element. Every part of the product was complemented by series of drawings done in CAD, in order to detail the design and help for the manufacture and the assembly activities. The design included also a Part List where all the components were detailed.
For the Power Distribution Centre (PDC) it was decided to include a Main Panel to interface among the building power, the Power Sources and the Regeneration System.

The power sources were selected from commercial devices for 28Vdc, 115Vac and 23Vac - both with fix 400Hz. For the ±270Vdc, there were no commercial one to meet the requirement and a contact for an ad-hoc unit was signed with a supplier.
The number and size of necessary output from the PDC was finally defined. It lead to the design of the Front Panels; that is, the cabinets that works as interface between the Power Sources and the real or dummy loads, including protections, switching, monitoring and connectors.
For the real-time monitoring of the PDC centralized on a TestServer computer, the selected technology for data acquisition was USB devices using CAT5e/USB converters. This was the faster and easier solution for data synchronization. To interface between their TTL discrete signals and the industrial switches, ad-hoc PCB were designed. For the AC measurement, the RMS value was the selected one - instead of an instantaneous waveform. For the data acquisition module, it was necessary an ad-hoc PCB for this transformation.
The Electrical Active Loads were split in two step. The first one was called AC voltage stabilizers which was in charge of accept different input voltage levels and provide always a DC output level to the next step. This one was called Electrical Dummy Load itself, which are 20kW DC/DC converters that controls their input with a dynamic on-line current reference through CANbus and also controls their outputs according to required fix voltage level of the regeneration module.
Protocols for all devices were defined, including the external one for the Control Room to be used for integration with other test bench or equipment. The software architecture was designed including its main modules according to the functionality required.

The partners developed a complete prototypes to demonstrate the feasibility, which were used as baseline for the manufacturing.
During this **Manufacturing Work Package**, it was required an updating of the design drawings. Physical component forms were modelled in CATIA in order to complement the design with manufacturing and the assembling instructions. The Part Lists were increased with extra components required during these phases.
The Power Supply System was developed in line with the design and also updated according to the needs founded during manufacturing and testing, such as safety and usability.
The Heat Loads physical form factor was kept, although internal components had to be changed due to burning during initial tests.

Finally, each one of the 8 Heat Loads is composed by 3 individual unit of 700W each one, which are fed from each one of the 3-phases of the building power (400V-50Hz). The voltage level had a critical influence on the performance. To avoid this, this data was measured at PDC and sent to Heat Loads through the software package 4.
The power of the Electrical Active Loads was increased to 20kW from the initial 15kW specification. This change did not required high modification in the design but had to be agreed with the suppliers of ad-hoc key components as power inductances and transformer
The software was develop according to standard code procedure. This enables easier future modification and a fast documentation process, which is a mandatory key for the future use of TEMGIR with other test benches.
Initially the Regeneration Module was a single commercial DC/AC inverter as the one used for solar or home electricity generation connected to the building network. However it was necessary to increase this system with extra equipment.

After the manufacturing, **Integration Work Package** was performed in the consortium facilities. For Heat Loads testing and integration, it was necessary to implement and set-up a full cooling system, not only the cold-plates but the cooling machine (chiller) and accessories. It is not a cutting edge because this task is not the objective of TEMGIR, but it had to be selected and set-up according to the integration test needs.
For the first test of Electrical Active Load before integrate them with the Regeneration Module, it was required the manufacturing of a resistor bank to dissipate their output power. Although it is not used after the commissioning of the regeneration, it is useful if one Electrical Active Load wanted to be used outside the TEMGIR power distribution centre and regeneration module.
The **Commissioning Work Package** requires an effort on the PDC, which is composed by several cabinets and wires among them. However, the Electrical Active Loads are portable cabinets with wheels and Heat Loads are small devices.

As results of previous work, next main results have been achieved so far:

• The **Power Supply System** is a multi-output distribution centre for the different typologies of voltages that are available inside an Aircraft. The main advantages are two: an easy connections and a standard software control. This last one includes circuit breaker protections, switching on/off and consumption monitoring for all outputs, taking out the hardware differences due the voltage and current specifications of each one.
• Endurance commercial 28Vdc, 115Vac and 230Vac power sources have been supplied and tested to assure compatibility with real aircraft equipment to be connected to TEMGIR
• A +/-270Vdc 225kW power source has been obtained, which is not a commercial device, as a result of a hard search and negotiation with suppliers to develop an ad-hoc unit.
• A framework software has been develop for the **Control and Monitoring SW**, which enables a common procedure for control devices. Internally, it is composed of several layers that make easier an expansion to new drivers for extra devices.
• The devices can be commanded using pre-defined profiles and also the Heat Loads can be commanded according the consumption monitored in a Power Supply System Outputs
• If the Power Supply System give voltage sources, the **Electrical Active Loads** are current sinks. Internally, DC/DC converters allow to demand a desired current consumption to the input where they will be connected, up to 20KW each one of the eight (8) manufactured units.
• A flexible input has been developed for Electrical Active Loads, called Stabilizers. They have been designed in accordance with the available voltage levels inside an aircraft; which will be the inputs of them. But the output is compatible input of previous DC/DC converter. This Stabilizer together with the DC/DC converter make up the Electrical Active Load.
• The internal control of the DC/DC converter has been designed such that it can work with all their output connected in parallel to a DC/AC Inverter (Regeneration Module) or ach one to a resistor bank. They are different configuration since the input voltage levels for a resistor bank is not the same than for an Inverter, and additionally, this last one requires a unique level but each the DC/DC converters can be producing different level among them.
• The **Building Power Regenerating Module** implements a closed-loop such energy used is not lost. Additionally, it has develop such that fulfil with the current civil regulation which avoid get back energy to the external building AC network. The energy regenerated is always a little smaller than the demanded by the Electrical Active Loads – due to devices losses. It can be sent is to their input directly (if 230Vac 50Hz input is used for Electrical Active Loads) or thought the Power Supply System input – if they are connected to a TEMGIR power source.
• The **Heat Loads** can transform the desired power consumption into heat, in the same geometry than aircraft power electronic modules do. They form factor is also a copper plate in their lower side.

This allows the study, design and testing of a full heat cooling system (air forced or liquid one) thanks that no real equipment is needed to produce a desired heat.

- The internal electronic of the Heat Loads has been developed such that it is allocated inside the geometry of the Heat Loads. No external devices are required. Furthermore, to avoid EMC/EMI noise, a Thermal Power Box with filters has been manufactured.
- A low cost liquid cooling system has been built up using commercial devices, keeping away the need of real aircraft cooling systems for internal testing of Heat Loads integration with cold plates – the aluminium heat exchangers.

Results

a) Timeline & main milestones

Next, it is shown the meetings were main milestones and planning were agreed:

- Kick-off meeting (KOM)
October 7th 2014
The WP2 Specifications started

- Preliminary Specification Review
January 15th 2015
The WP2 Specifications finished and the WP3 Architectural Design started

- Preliminary Design Review
April 9th 2015
Some of the WP4 Detailed Design packages started

- Critical Design Review I
July 23th 2015 for Electrical Loads and Power Distribution Centre
Their WP5 Manufacturing started

- Critical Design Review II
October 16th 2015 for Heat Loads and SW
Their WP5 Manufacturing started

- Manufacturing Progress Meeting
May 11th 2016
To review the Manufacturing process and to agree the Testing & Integration

- Pre-Delivery Meeting
June 27th to 29th 2016
To review the Integration and agree the Delivery and Commissioning planning

- Power Distribution Centre Delivery and Commissioning
During January 2017

b) Environmental benefits

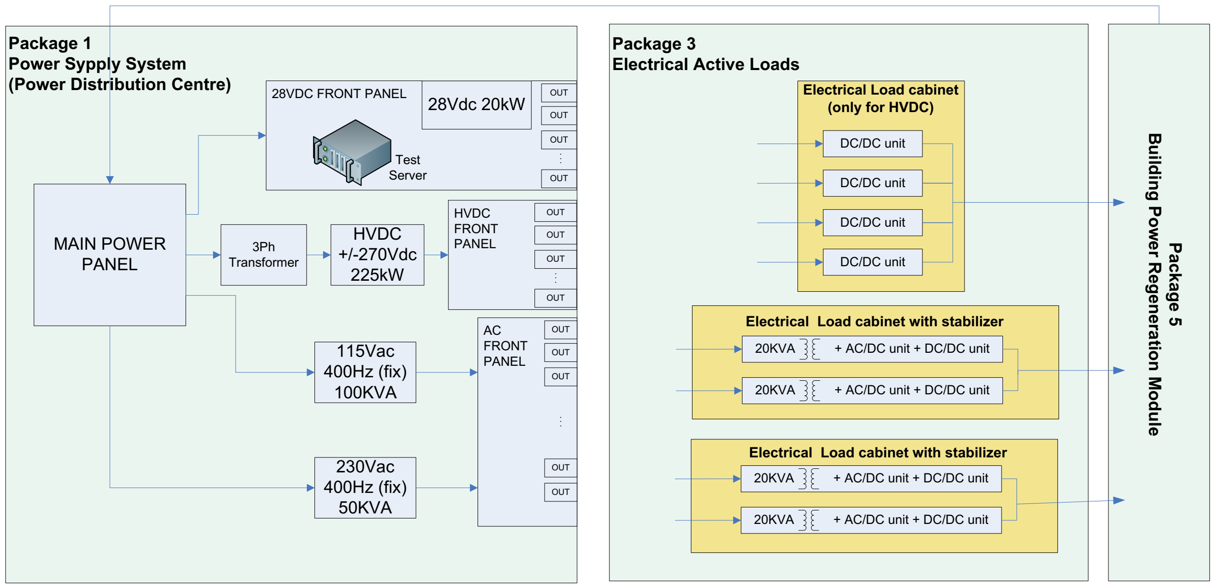
They are shared with the Clean Sky SGO 4.2, integrated energy large scale ground demonstrator since will be used together. Additionally, TEMGIR offer two key advantages.
To be able to define new thermal architecture inside aircraft which re-use the heat obtained by cooling system to heat other devices. This philosophy reach more efficiency aircrafts both in energy consumption as in weight.
Additionally, electrical consumer equipment can be tested without wasting the electrical energy flow, which is returned to the grid.

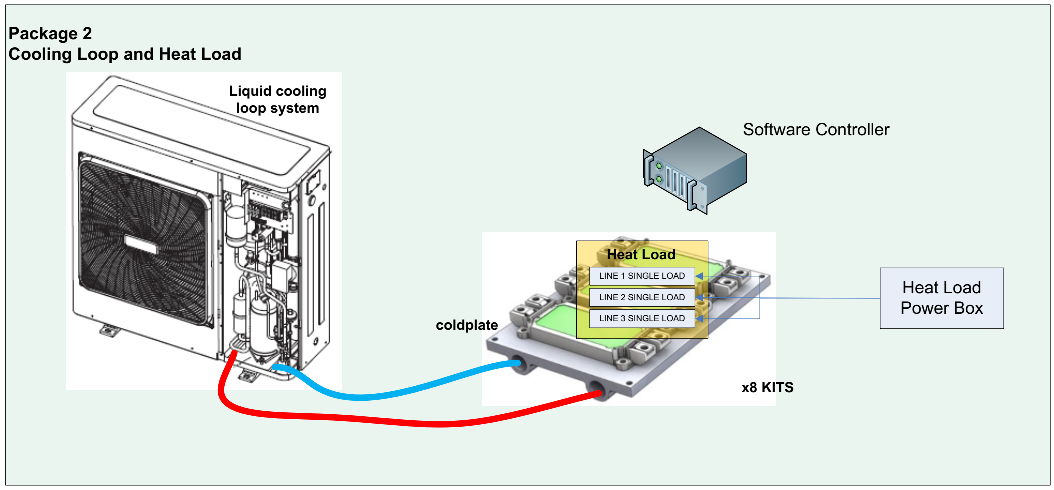
c) Maturity of works performed

AC power sources and Front Panel from Power distribution centre are both commercial as industrial devices high reliable.

The ±270VDC power source maturity is not at the same level but it has been tested, manufactured and designed in a similar way.

Electrical Active Loads and Heat Loads have been tested according CE marking, then they are fully matured


Package 1
Power Sypply System
(Power Distribution Centre)
28VDC FRONT PANEL
28Vdc 20kW
Test
Server
OUT
MAIN POWER
PANEL
3Ph
Transformer
HVDC
+/-270Vdc
225kW
HVDC
FRONT
PANEL
AC
FRONT
PANEL
115Vac
400Hz (fix)
100KVA
230Vac
400Hz (fix)
50KVA
Package 3
Electrical Active Loads
Electrical Load cabinet
(only for HVDC)
DC/DC unit
DC/DC unit
DC/DC unit
DC/DC unit
Electrical Load cabinet with stabilizer
20KVA + AC/DC unit + DC/DC unit
20KVA + AC/DC unit + DC/DC unit
Electrical Load cabinet with stabilizer
20KVA + AC/DC unit + DC/DC unit
20KVA + AC/DC unit + DC/DC unit
Package 5
Building Power Regeneration Module


Package 2
Cooling Loop and Heat Load
Liquid cooling
loop system
Software Controller
Heat Load
LINE 1 SINGLE LOAD
LINE 2 SINGLE LOAD
LINE 3 SINGLE LOAD
coldplate
Heat Load
Power Box
x8 KITS

Project Summary

Acronym:	TEMGIR
Name of proposal:	Thermal and electrical Mock-ups for Thermal Management of a Ground Integration Test Rig
Technical domain:	
Involved ITD	
Grant Agreement:	CS-GA-2013-641463
Instrument:	Clean Sky JU
Total Cost:	1,193,103.80
Clean Sky contribution:	744,907.85
Call:	SP1-JTI-CS-2013-03
Starting date:	01/10/2014
Ending date:	31/07/2016
Duration:	22 MONTHS
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