ELECTRICAL POWER DISTRIBUTION ARCHITECTURE FOR ALL ELECTRIC AIRCRAFT

D. Izquierdo [(1)], R. Azcona [(1)], F. J López del Cerro [(2)], C. Fernández [(1)], J. Insenser [(1)]
[1] Military Air Systems - Defence and Security Division (EADS)
[2] Airbus Military (EADS)
Paseo John Lennon, s/n.
28906 Getafe (Madrid) ESPAÑA
Tel.: +34-91-624 7130; FAX: +34-91-624 2411
Keywords: *SSPC, Electrical Power Distribution, High Voltage*

Abstract

In the new designs of military aircraft (cargo and fighters) there is a clear trend towards increasing demand of electrical power. This fact is mainly due to the replacement of mechanical, pneumatic and hydraulic equipments by partially or completely electrical systems. Additionally, common electrical loads onboard are continuously increasing within the areas of communications, surveillance and general systems, such as: radar, lighting, flight management, cooling... To cope with this growing demand for electric power, new levels of voltage, architectures and power electronics devices are being applied to the onboard electrical power distribution systems. The purpose of this article is to present and describe the technological project HV270DC. In this project, one Electrical Power Distribution System (EPDS), applicable to the all electric aircrafts, has been developed. This system has been integrated by EADS in order to assess the benefits of changes, in comparison with conventional electrical power distribution systems.

1 Introduction

There is a strong trend in new designs of military aircraft and unmanned aircrafts towards the More Electric Aircraft (MEA) concept. On the one hand this is a consequence of substitutions of conventional equipments, which depend on pneumatic, mechanic and hydraulic power, by equipments that depend on electrical power. This factor has provoked increase of equipments, which require electric power. Besides, these changes provide a better system performance due to increase of reliability, less maintenance, efficiency on energy conversion and therefore also higher efficiency of aircraft in general. On the other hand, there is an increase of the number of equipments that depend on electric power and form part of the different aircraft systems (flight control, avionics, communications, surveillance, weapons…), such as: actuators, radar, infrared and electro-optical cameras, radios, etc [1] [2] [3] [4] [5] [6].

These beforehand mentioned factors have caused a considerable increase of the demand for electrical power in military aircrafts (fighters and cargo), see Fig 1. To cope with this increase of electrical power in the future distribution architectures, in the area of military aircraft, the traditional voltage levels of 28 V_{DC} and 115 V_{AC} have evolved to 270 V_{DC} [7] [8] [9] [10].

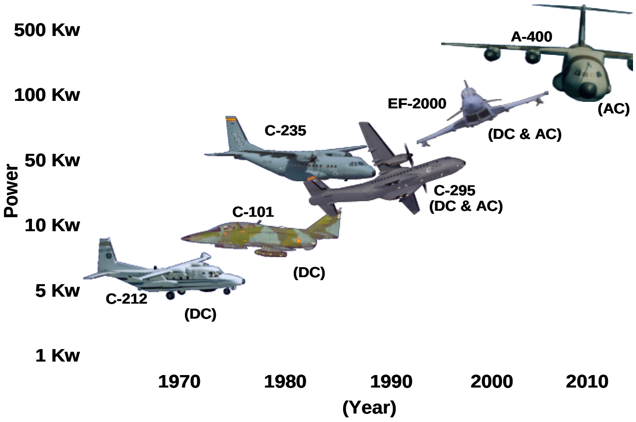

Fig. 1: EADS-CASA Military Aircrafts Electrical Power Demand

The main advantage of these high voltage systems is that current levels are ten times lower than the conventional low voltage levels; therefore it is possible to reduce the section of the wires and by that, also, the weight of the wiring. Furthermore, the major electrical loads are powered directly from direct current instead of alternating three-phase current, which means decrease in number of the wires that are used to connect the aircraft electrical loads.

This considerable growth of the number of electric loads in these new electric distribution architectures has contributed to an increase of the quantity of the electric and electronics components, which could conduce to instability of whole system due to the interactions between the different equipments that compose the system [10]. Also, raising the level of voltage provokes to appear new problems regarding the function of some devices, such as conventional protections [11]; and other inconveniences originated by physical effects in the wires with the new levels of voltage: corona effect, arc fault and others [12]. Therefore, before being applied in the future aircraft programs developed by EADS, it is necessary to study the behavior of the high voltage electrical power distribution systems, as well as the components that form a part of these systems.

This paper describes a Electrical Power Distribution System (EPDS) architecture based on 270 V_{DC}, and equipments that are part of it. The architecture has been developed and integrated by EADS in collaboration with various national companies from different sectors. The proposed EPDS has a smart electrical load management control, which is responsible for managing the connection and disconnection of the electrical loads depending on the operational mode and available power sources. Besides, in the laboratory and virtual test bench have been identified and checked possible problems and risks of this kind of architectures.

2. Technical Approach

Old conventional aircrafts are based on DC voltage level and 10 Kw power distribution architecture, see Fig. 2; this conventional architecture is very limited in the number of electrical loads due to the maximum current level.

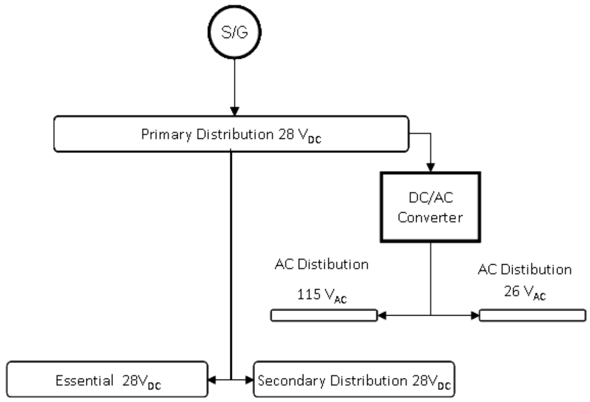

Fig. 2: Low Power DC Electrical power distribution architecture

In the concept of MEA, the new EPDS designs are the key element. These new primary power distribution systems are based on two voltage levels, depending on whether the application is Alternating Current (AC) or Direct Current (DC):

- In case of AC systems in commercial aircrafts, with voltage level of 230 V_{AC}, currently used in civil platforms such as A350 and B787 [7].
- In case of DC with voltage level of 270 V_{DC}, normally used in military aircrafts in platforms like F-22, see Fig. 3, or F-35 [8] [9] [10].

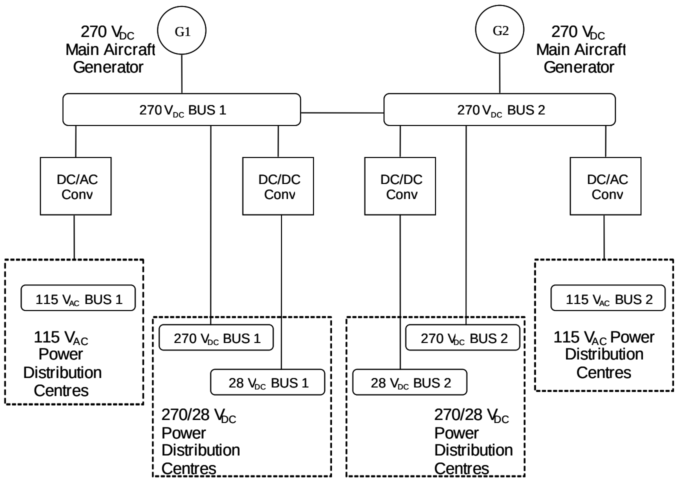

Fig. 3: F-22 Hybrid Electrical power distribution architecture

The origin of the architectures with 270 V_{DC} voltage level is a consequence of the rectification of conventional 115 V_{AC}, produce by the conventional aircraft power sources. There are two main reasons for this new voltage level. Firstly, it is possible to obtain a 270 V_{DC} generator from a conventional generator, by means of integration of natural rectifier built from diodes. Secondly, some of the equipments, that are powered from 115 V_{AC}, have integrated blocks of rectification, that convert the 115 V_{AC} levels to 270 V_{DC}, as in case of some radars and electrical actuator controllers, which are using an internal high voltage bus. In the aforementioned EPDS, it is possible to reduce weight of some electrical loads by eliminating aforementioned conversion block.

In these architectures, due to the new voltage levels, the conventional wiring protection and load control systems, such as fuses, circuit breakers and relays are causing certain limitations in their functionality. Therefore, new components that permit substitution of the mechanical devices have to be introduced. The Solid State Power Controllers (SSPC) permit replacing of the relay and circuit breakers, elements of mechanic nature, for a single power electronic device as SSPC [11][13][14]. These SSPC allow connecting loads to a main bus and provide the function of protecting the electric installations from overloads and short circuits, exactly as it is done by relays and Circuit Breakers (CB).

In the field of military and civil applications, to keep up with the development of the new EPDS, several international companies of the aeronautic and military sectors have developed or are currently developing projects that study the problems associated with these kinds of electrical power distribution systems. Among the most important technological projects that have centered round this problem, is the MADMEL project, developed in the United States by Military aircraft division of the Northrop/Grumman at the end of the nineties [8]. There also have been some less relevant initiatives in Europe, as the TIMES program (Totally Integrated More Electric Systems) [15] or the DEPMA project (Distributed Electrical Power Management Architecture) [16] and MOET (More Open Electrical Technology) program which is leaded by Airbus [17].

In 2005, EADS started the HV270DC project, which is based on the development of one electric power distribution architecture of 270 V_{DC} and its test bench, for its application in future aircraft designs. In this architecture, the primary and secondary distribution systems are designed with a voltage level of 270 V_{DC}, and two additional power converters have been introduced into the final design. These power converters provide conventional voltage levels (28 V_{DC} y 115 V_{AC}), coming from the primary distribution busbars, with a purpose to supply electric power to the equipments that proceed from conventional EPDS and which are powered with the aforementioned voltage levels.

The main objective of the project is to integrate the different equipments and components that contain EPDS of one MEA and test the associate functionality. The main computer constantly controls EPDS, which also is in charge of monitoring the state of the whole EPDS. In this manner, computer configures the system for several operative conditions, depending on the different power sources and operative sceneries. This project is designed with an objective to identify future problems that could arise from the use of this type of EPDS, such as: the problems caused by the new components, like the SSPC and their application on critical loads control, the physical effects generated in the wiring, as a consequence of the new high voltage levels and the interferences that could be introduced in the conventional electric distribution lines, in case both of them co-exist on the same platform.

3. EPDS Architecture description

The EPDS architecture is divided in five main blocks, depending on functionality of each part, see Fig. 4:

- Power Generation area, provides the electrical power to the rest of the system and loads.

- Primary distribution block distributes the electric power to all the points and also protects the connected blocks from overcurrent.
- Conversion area, in charge of converting the 270 V_{DC} level to conventional distribution levels, such as 28 V_{DC} and 115 V_{AC}.
- Secondary distribution area, which provides electric power to the loads. In this EPDS, the secondary distribution is based on power electronic modules, instead of conventional devices, such as relays and circuit breakers.
- Block of management, monitoring and control the correct function of all the equipment and devices, depending on the operative sceneries.

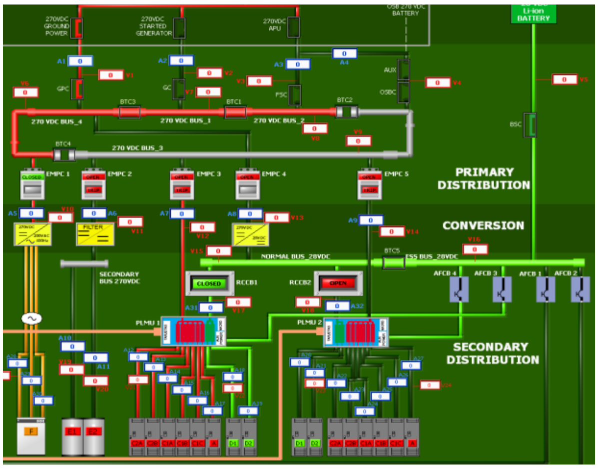

Fig. 4: Proposed EPDS Architecture based on SSPC

The following paragraphs include a brief description of some of the characteristics and equipments that compose each of the areas aforementioned.

A. Generation Block.

In the generation area, the following equipments have been integrated:

The Lithium Ion DC battery supplies the initial electric power for the internal control systems which are integrated inside the equipments that compose the architecture. The battery also energizes the contactors and the Remote Controlled Circuit Breakers (RCCB).

The generation source of 270 V_{DC}, which has three outputs and permits to emulate several generation sources of the aircraft: Ground Power Unit (GPU), Auxiliary Power Unit (APU) and Main Generator. This power source has been adjusted according to military standard, MIL-STD-704 [18]. Furthermore, one APU based on Fuel Cell has been integrated in the EPDS.

B. Primary distribution Block.

The primary distribution block consists of primary distribution busbars, contactors and protections that connect this block with the conversion and secondary distribution areas. All these devices work with 270 V_{DC}. The circular configuration of the primary distribution busbars, see Fig. 4, comparing with the conventional architectures [7], permit a higher number of reconfiguration options. The protections installed in the primary distribution level are the Electro-Magnetic Power Controllers (EMPC). These devices measure the charge and interrupt the current, when charge exceeds the allowed threshold, avoiding the damage to the cables or downstream equipments.

C. Conversion area.

The conversion area is composed of various equipments, which convert the new levels of primary distribution to the levels of conventional distribution of 28 V_{DC} and 115 V_{AC}. These levels have been kept for providing electrical power to the installed equipments in the conventional aircrafts. This is a consequence of the trend in the market to produce new equipments designed for this SPDE.

Fig. 5: DC Converter developed by Greenpower ©

Therefore, it is possible to apply the architecture to different platforms, including this kind of power converters. In this block, two power converters have been integrated:

- The DC-DC converter 270 V_{DC}/28 V_{DC}, provides electrical power to the bus bar of the 28 V_{DC} and charges the battery, depending on the electric power that the primary area provides. The equipment has been designed by the Greenpower Company, with nominal power of 3,5 Kw, see Fig. 5, in conformity to the EADS technical specifications.
- The inverter 270V_{DC}/115V_{AC}, generates a signal in AC starting from the level of 270V_{DC}, see Fig. 6. This equipment has been designed by Ingeniería Viesca Company, with a nominal power of 5 Kw. This inverter has been designed in conformity to military standard, MIL-STD-704 [18].

Both equipments include discrete signals that inform about correct function and differentiate between several failures categories.

Fig. 6: Inverter developed by Ingeniería Viesca ©

D. Secondary distribution block.

In this block have been integrated the equipments and devices that connect the loads to the EPDS.

The Power Load Management Unit (PLMU), see Fig. 7. This equipment is based on SSPC modules [11], which permit remote electrical load control and wiring protection. Indra Company has developed PLMU in different phases in conformity to the EADS technical specifications.

Remote Control Circuit Breaker protections (RCCB) are similar to conventional circuit breakers, but they also have the capability to control and to monitor protection status remotely.

It is important to point out, that in this area 270 V_{DC} coexists with the conventional voltage levels of 28 V_{DC} and 115 V_{AC}.

Fig. 7: PLMU developed by Indra ©

E. EPDS control and monitoring block.

Last block manages the EPDS depending on the operative conditions of connected loads, available power sources and operative sceneries. It is composed of the following equipments:

The Load Management Computer (LMC) runs the software that controls the EPDS. This computer takes decisions according to the information that is received from the data bus coming from the all equipments that are connected to the MIL-STD-1553B data bus. This equipment has been developed by Indra, according to EADS specifications.

The Remote Interface Unit (RIU), see Fig. 8, is responsible for monitoring all the available information from the analogue and discrete EPDS signals, with objective to maintain all this data accessible in the data bus. It also controls the contactors, RCCB and EMPC of the system according to the indications that LMC receives trough the data bus.

Within the particular architecture diverse communication data bus options can be used, such as: RS-232, RS-422 or RS-485; however none of them is in conformity with military standards. The 1553B data bus satisfies military standards and dual communications. From other side, most of the equipments developed during the project come from past projects, which already include this type of data bus, frequently used in the on-board systems [19].

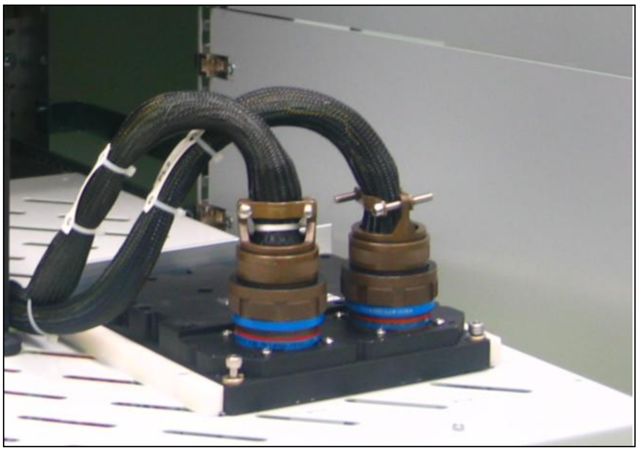

Fig. 8: Remote Interface Unit

The LMC communicates through MIL-STD-1553B data bus with various equipments of the EPDS, such as: PLMU, RIU and other equipments, which belong to other aircraft systems that could have interface with the electrical system: Cockpit Display (CD), Aircraft Computer (A/C) or Maintenance Data Panel (MDP), see Fig. 9.

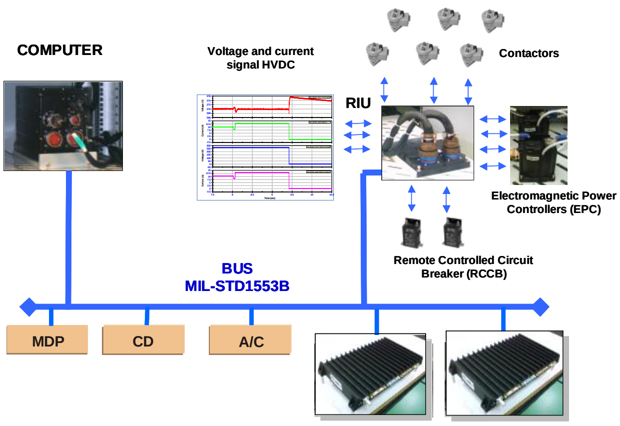

Fig. 9: Equipment connected to 1553B data bus

LMC has bidirectional communication with all of the real or simulated equipments that are connected to the data bus. This way each equipment send the information to LMC and the computer can process the data, and send the commands of control to each of the equipments connected to the 1553B data bus. Therefore, it is possible that LMC warns the other aircraft systems about the EPDS failures, or disconnects automatically the loads during emergency conditions by means of SSPC modules.
This new architecture permit that LMC receives all the information of different phase of flights and commands the equipment in order to maintain the optimum electrical power level.

4. Development of the HV270DC project

The HV270DC project has been designed according to a System Requirements Document (SRD) for its application in the more electric aircrafts. This document is a reference for the rest of the project's documents.

According with the SRD, the equipment specification documents describe the functional and hardware requirements that must be taken into account during equipment design phase. The equipments which have been integrated in the test bench, they are specified in conformity to the aforementioned military standards.

Taking into account the system functionality, it was developed a specific test bench that includes all the elements that shape the architecture and the different interfaces, among them all the equipments that form a part of the EPDS.

Also, the software functional requirements document of the HV270DC Systems control has been defined. This software resides in the LMC and has been developed by the Department of Software within EADS. In order to facilitate the integration tasks, there has been developed a simulated environment that reproduces the behavior of real communication bus. This permits to perform the first tests of the systems software integration in a virtual bench, prior to the systems integration in the real HV270DC demonstration bench. The identified software problems are reported and stored in database; therefore it is possible to trace a problem from its origin until its final solution. In order to verify EPDS functionality and solve integration problems, an electrical virtual test bench has been implemented in PSIM®, see Fig. 10.

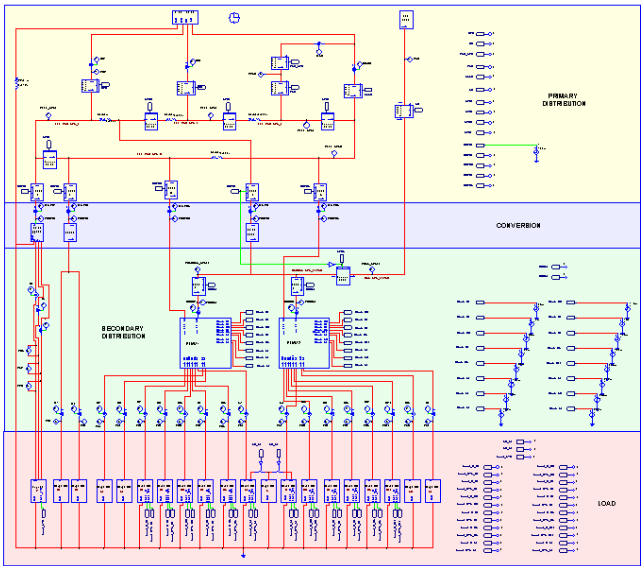

Fig. 10: Electrical virtual test bench

Behavioral and structural models have been developed. Behavioral models are the simpler ones and are representative only of steady state and limited transient behavior, and they are used for electrical network simulation. Structural models are representative of each single component of the simulated system and are too complex for electrical network simulation. Modeling and simulation have been the key tools in the EPDS development during the design process.

Once the architecture was integrated, test requirements were developed to validate the correct function of the EPDS and perform the necessary adjustments to the equipments and smart control software.

The demonstrator test bench includes a monitoring system that permits acquisition and monitoring of all the EPDS parameters: voltage, currents, condition of the device, etc. for processing and analysis. All the information is visible on the screen in the panels generated in the "Labview ©", that permit to check the system status real time.

5. Identified problems

During the test phase in the real test bench, there have been identified some problems, which are described below.

The data bus MIL-STD-1553B imposes a limitation of the minimum times of the EPDS control, which considerably slow down the response of the system, especially when the commands proceeding from the LMC.

There have been detected limitations in the SSPC during the connection and disconnection of specific type of charges. Problems were detected during the connection of highly capacitive loads, and during disconnection of the inductive loads. Other limitation of the devices is in the range of the currents they are able to manage; therefore for high levels of current, it is necessary to use conventional devices. Another problem that could appear is the internal fusion of the SSPC, as a consequence of elevated temperatures that are provoked by uncontrolled high current circulation through the component.

The physical effects, which can appear in the components and wiring of this kind of architecture, are even more critical if we compare them with the conventional EPDS, increasing the probability of the corona effect and arc fault in the wiring due to the high voltage level. Arcs have a high peak current that increases the wire temperature and can cause serious insulation damages. Normally, the arcs have short duration, and they do not trip aircraft circuit breakers.

6. Experimental results

The following paragraph includes some of the experimental results obtained during the test phase in the real test bench.

Tests with different loads of 270 V_{DC} have been done, with objective to detect possible problems of whole systems stability.

During the consecutive closures of the contactors of 270 V_{DC}, the ripple of the voltage in the bus bars of principal distribution was measured. This ripple can cause instability of the system and provoke problems in the downstream equipments operation.

By help of the loads test bench, it was possible to verify the correct function of the I^2t curve in the SSPC for different levels of current and components of different manufacturers. In

Fig. 11, it can be seen how for different current levels in the SSPC reacts the programmed protection of SSPC, in correspondence with the curve defined in the manufacturer's datasheet.

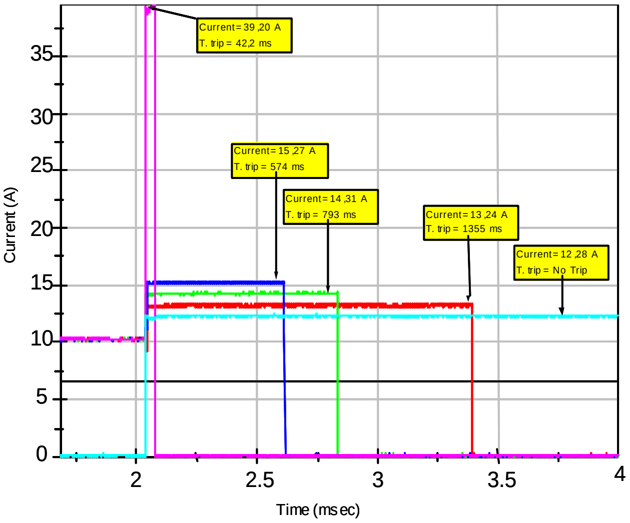

Fig. 11: SSPC I^2t- curve validation

During the normal operation of the DC/DC Converter, it was detected that the device transmits downstream the ripple that is present in the voltage of the primary distribution bars. This ripple provokes non-compliance regarding maximum harmonic distortion value which is included in MIL-STD-704.

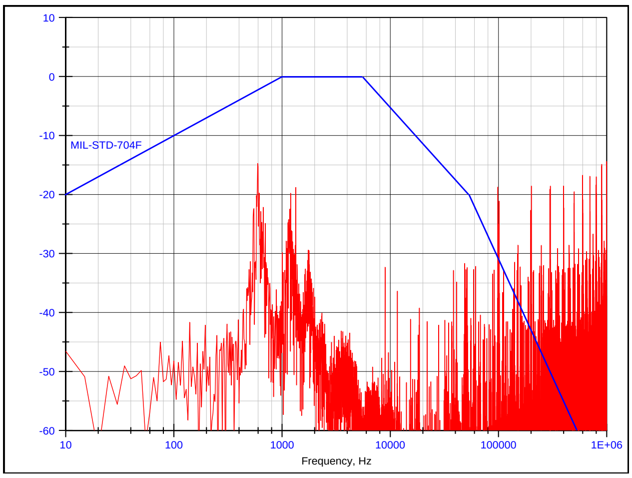

Fig. 12: Measured distortion amplitude without DC Converter

Test results show that the system is out of the distortion spectrum normative in the 270V$_{DC}$ primary and secondary distribution bars when DC converter is activated, see Fig. 12. Besides, it has been checked that when DC converter is disconnected, harmonic distortion is reduced, see Fig. 13.

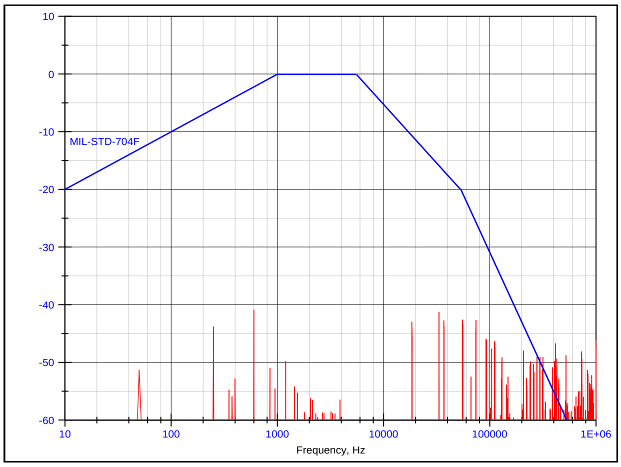

Fig. 13: Measured distortion amplitude with DC Converter

References

[1] Spitzer, C.R. "The All-Electric Aircraft: A Systems View and Proposed NASA Research Programs" NASA Langley Research Center. Aerospace and Electronic Systems, IEEE Transactions. Volume AES-20, Issue 3. May 1984. Page(s): 261-266

[2] Lester F. Faleiro," Trends towards a more electrical aircraft", Proc. 25th International Congress of the Aeronautical Sciences ICAS 2006.

[3] M. Howse, "All Electric Aircraft", Power Engineer, vol. 17, pp. 35-37, 2003.

[4] David Blanding, "Subsystem design and integration for the More Electric Aircraft". Proc. 25th International Congress of the Aeronautical Sciences ICAS 2006.

[5] Rosero, J.A.; Ortega, J.A.; Aldabas, E.; Romeral, L. "Moving towards a more electric aircraft" Aerospace and Electronic Systems Magazine, IEEE Volume 22, Issue 3, March 2007.

[6] M. David Kankam "A survey of Power Electronics applications in Aerospace Technologies". 36th Intersociety Energy Conversion Engineering Conference; Savannah, Georgia, July 29–August 2, 2001.

[7] Moir, Ian; Seabridge, Allan. "Aircraft Systems: Mechanical, Electrical and Avionics Subsystems Integration". 3rd ed. Chichester (West Sussex): Wiley, 2008. 546 p. Aerospace Series. ISBN: 978-0-470-05996-8.

[8] Miguel A. Maldonado et al. "Power Management and Distribution System for a more-Electric Aircraft (MADMEL)- Program Status". Intersociety Energy

Conversion Engineering Conf., August 1997, pp.274-279.

[9] Emadi, K.; Ehsani, M.;"Aircraft power systems: technology, state of the art, and future trends". Aerospace and Electronic Systems Magazine, IEEE Volume 15, Issue 1, Jan. 2000.

[10] Liqiu Han, Jiabin Wang and David Howe " Small-signal Stability Studies of 270 VDC Power System for More Electric Aircraft Employing Switched Reluctance Generator Technology" 25th International Congress of the Aeronautical Sciences ICAS 2006.

[11] D. Izquierdo, et al. "Protection devices for aircraft electrical power distribution systems: a Survey" Industrial Electronics Society, 2008. IECON 2008. 35th Annual Conference of IEEE. Orlando November 11-13, 2008.

[12] I. Cotton, M. Husband; "Higher Voltage Aircraft Power Systems". IEEE Aerospace and Electronics Systems Magazine, IEEE Volume 23, Issue 2, Feb. 2008.

[13] AMC-Plane Talk. Aeronautical Radio INC. Maryland (United States). Industry Highlights "Electrical Protection devices". February 2005. Vol XVI, No. 2.

[14] Friedman, S. N., "Solid-state Power Controller for the Next Generation". Aerospace and Electronic Systems Magazine, IEEE Volume 7, Issue 9, September 1992: 24-29.

[15] Cutts, S.J.; "Totally Integrated More Electric Systems (TIMES) Refer to: A collaborative approach to the More Electric Aircraft"; Power Electronics, Machines and Drives, 2002. International Conference on 4-7 June 2002 Page(s):223 – 228.

[16] Bailey, M.; Hale, N.; Ucerpi, G.; Hunt, J.-A.; Mollov, S.; Forsyth, A.; "Distributed Electrical Power Management Architecture (DEPMA) Electrical Machines and Systems for the More Electric Aircraft (Ref. No. 1999/180), IEE Colloquium on 9 Nov. 1999 Page(s):7/1 - 7/4.

[17] Framework VI: Integrated Projects. More Open Electrical Technologies (MOET). [Ref. Created on October 18, 2004]. Web available: http://www.aerosme.com/download/WorkshopFP6Call3/abstracts/MOET_181004.pdf

[18] "MIL-STD-704, Aircraft Electric Power Characteristics", Military Standard.

[19]F. Dafeng, X. Yan, Y. Shanshui, Y Yangguang, "Electrical Power Distribution System Based on 1553B Bus for Advanced Aircraft"; Electrical Machines and Systems. ICEMS. Proceedings of the Eighth International Conference on; 27-29 Sept. 2005

Copyright Statement