



Simulation Study of new Aircraft Electrical Power Network performances

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ABSTRACT

In the frame of new electrical network architectures development for future aircraft, system integration is a key issue. Advanced powerful simulation tools, such as SABER software, have demonstrated in previous European research projects and Airbus aircraft programs that they are precious to optimize designs and to validate electrical network performances. In the MOET project, accurate multi-level integrations of complex electrical systems are achieved in simulation for stability and power quality studies regarding standards requirements. Then, from correlation with experimental data, simulation contributes to equipment design development and validation of electrical network performances.

INTRODUCTION

In order to manage the increase of on-board electric power and new electrical systems, new electrical networks are under definition. Hence, in addition of standard 115VAC network, mainly used for commercial loads and 28 VDC network, used for electrical

system supply, high AC and DC voltage supply new electrical systems such as environmental control systems, wing ice protection systems, electro-mechanical actuators, motor control units and engine starters. The development of these new electrical architectures is a great challenge. In this context, SABER simulation software is a powerful tool to support design and validation of electrical systems and networks.

This paper deals with electrical simulation activities at network level. Considering MOET architectures, the verification of electrical system performances is performed by simulation in correlation with laboratory test results. Two rigs have been developed: Airbus rig and Alenia rig. Aeroconseil Aircraft Engineering is in charge of simulation activities regarding Airbus rig. Dassault Aviation and Eurocopter France are in charge of simulation activities regarding Alenia rig. Simulation activities are:

- MOET models gathering and support to model development
- Model validation regarding equipment performances and verification regarding specifications

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- Model integration at network level: simulation validation regarding test rig data and electrical network performances verification regarding requirement and standards.

In this paper, MOET electrical architectures are briefly described. New aircraft electrical systems such as inverter associated to air conditioning systems or engine starters require the establishment of High voltage DC networks. Such networks have major power quality and stability issues and simulation is a powerful tool to validate electrical performances. However, simulation of mixed electrical networks through SABER integration of partner models is complex. Pre existing know how of simulation platform development from previous European projects and from Airbus aircraft programs was the key of MOET simulation development success. Thanks to successful model integration, simulation contribution to aircraft development is demonstrated through two examples of electrical network study. Results presented in this paper are not exhaustive but emphasize how simulation may support electrical network design. First, large aircraft mixed 230VAC/540VDC network is considered. Compliance of network performances to aircraft standards is studied In terms of power quality and stability. Simulation is also used as a design tool to optimize 230AC/540DC converter pre-charge system. On the second hand, small aircraft architecture is considered. Simulation results have demonstrated the necessity to change voltage regulation of 115VAC generator in order to be compliant with standard at HVDC network level.

MOET TEST RIG ARCHITECTURES

Two test rigs are developed in the MOET project:

- 100m test rig in Airbus facilities
- 10m test rig in Alenia facilities

AIRBUS TEST RIG

This rig is representative of a large aircraft electrical network. Two architectures are studied. Basic architecture, given by Figure 1, is dedicated to mixed 230VAC/540VDC network, in addition of standard 115VAC and 28VDC electrical networks. Variable frequency starter generators supply 230VAC bus bar where new electrical loads such as wing ice protection system and electro-mechanical actuators are connected. 115VAC may be supplied through External Power or autotransformer connected on 230VAC bus bar. Current harmonic rejection from 115VAC network is limited using an active filter system. 540VDC bus bar is supplied through 18 pulses autotransformer rectifier unit in order to reduce current harmonic rejection on 230VAC bus bar or through bidirectional 540VDC/28VDC converter from 28VDC bus bar. 28VDC bus bar is supplied from 115VDC bus bar through transformer rectifier unit or from 540VDC bus bar through buck boost converter or from batteries.

Advanced architecture, given by Figure 2 focuses on 540VDC network study. As there is no power load connected on 230VAC bus bar, there is no need for reducing current harmonic rejection on 230VAC bus bar. 540VDC bus bar is supplied through 6 pulses rectifier. Direct current power flow controller equipment controls power flows through 540VDC bus bars.

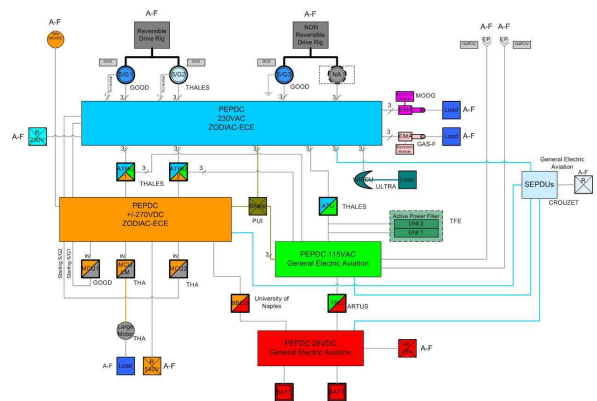


Figure 1: 100m test rig basic architecture

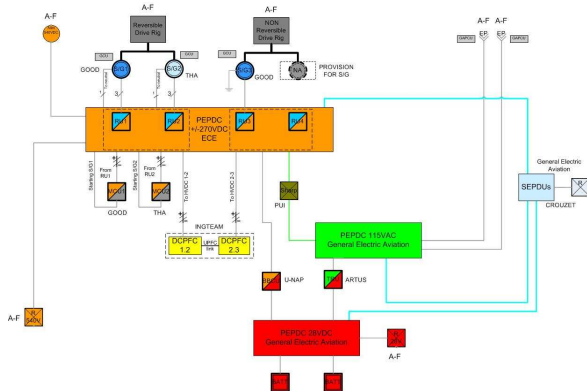


Figure 2: 100m test rig advanced architecture
ALENIA TEST RIG

This rig is representative of a small aircraft electrical network. There is no AC power load and power is distributed through 270VDC bus bar. Two 270VDC generators supply this bar: the association of an AC generator and 18 pulses autotransformer rectifier unit and on the other hand a variable frequency starter generator associated with a bi-way converter. 270VDC loads are wing ice protection system, electro mechanical actuator, resistive loads and a buck boost converter connected to a battery.

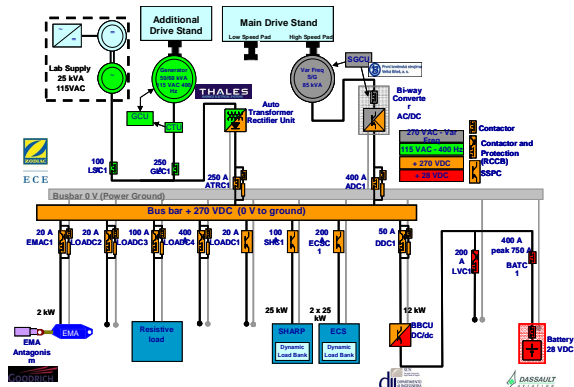


Figure 3: 10m test rig architecture

SABER SIMULATION PLATFORM

Performing complete aircraft electrical network simulation is an extreme complex task even using advanced simulation

software such as SABER. Hence, accuracy of simulation results widely depends of the quality of the simulation platform and unitary models. From pre existing know how (European project and Airbus programs), model requirements have been defined in order to perform complex integrations and to support model development.

A trade off has to be done between the number of integrated model, the simulation time scale and the bandwidth of simulated phenomena. Then, different levels of models are defined according to specific study purposes. Four types of models with different level of complexity can be generally characterized, as illustrated Figure 4.

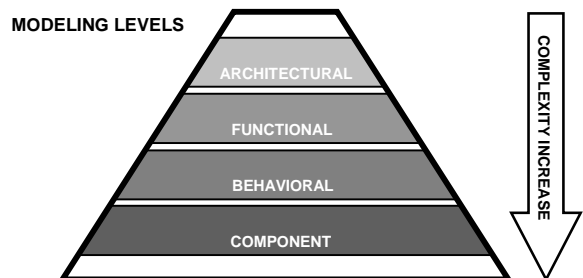


Figure 4: SABER modelling levels

Architectural models are the simpler ones and are representative only of steady state power consumptions. Component models are representative of each single component of the simulated system and are too complex for electrical network simulation. Considering MOET simulation objectives, Functional and Behavioural models are used:

- Functional models are representative of steady state power consumption and transient behaviour and are used for network stability studies and validation of network configuration logics
- Behavioural models are representative of waveforms and are used for power quality studies

Hence, both functional and behavioural models are validated using two criteria:

- Compliance with model requirements to ensure robustness in integration in SABER platform

- Accuracy according to real equipment measurements

Integrating such validated models, the simulation platform, correlated with experimental data, is the digital replica of test rigs. Then, accurate simulations are performed at network level, assessing electrical performances in addition of rig tests.

SIMULATION STUDIES

Two examples of electrical network study are provided: mixed 230VAC/540VDC network (100m test rig in basic architecture) and 270VDC bus bar voltage level regulation of 10m test rig.

MIXED 230VAC/540VDC ELECTRICAL NETWORK

First study example focuses on mixed 230VAC/540VDC network performances of 100m test rig in basic architecture using behavioural models. Simulation is also used as a design tool for autotransformer rectifier unit pre-charge circuit.

Electrical Network configuration

The electrical network is given by Figure 5.

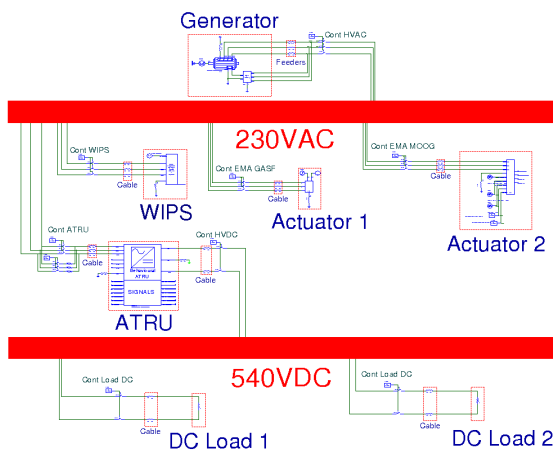


Figure 5: SABER Electrical Network

230VAC bus bar is supplied by Thales generator and voltage point of regulation is placed after feeders. New 230VAC loads are connected: wing ice protection system and the two electro mechanical actuators. An 18 pulses autotransformer rectifier unit is connected through pre-charge circuit and supply 540VDC bus bar. Resistive loads are finally connected to 540VDC bus bar.

Design of pre-charge circuit

SABER simulation gives here inputs for design of pre-charge circuit and autotransformer rectifier unit output capacitor. Main parameters are the pre-charge line resistors and the value of the 540VDC bus bar capacitor. As given by Figure 6, during capacitor pre-charge duration, inrush current has to be limited. Pre-charge line resistors and 540VDC bus bar capacitor have a direct impact on pre-charge duration (τ , defined as the time required to reach 95% of capacitor final voltage value) and inrush current spike value.

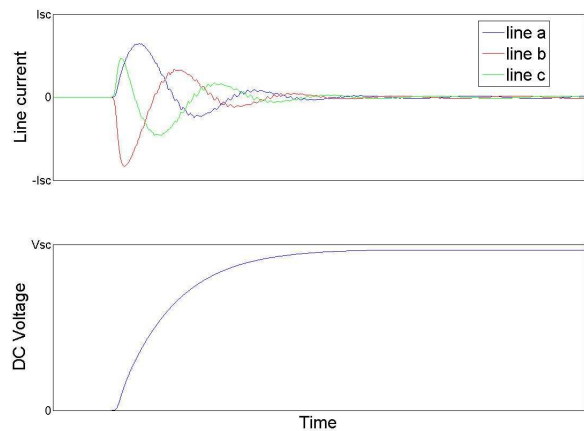


Figure 6: AC currents and DC voltage

Hence, from capacitor interval value (calculated in the frame of stability studies performed by academic MOET partners), an optimization can be performed giving a trade off between capacitor pre-charge duration, given by Figure 7, and maximum value of 230VAC line current, given by Figure 8. This trade off is defined by the Pareto front, given by Figure 9.

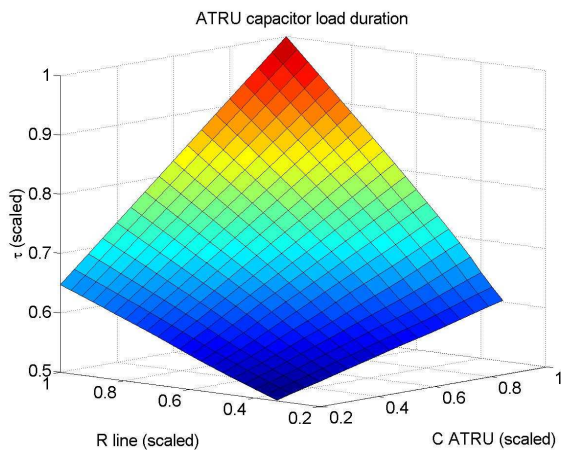


Figure 7: Capacitor pre-charge duration

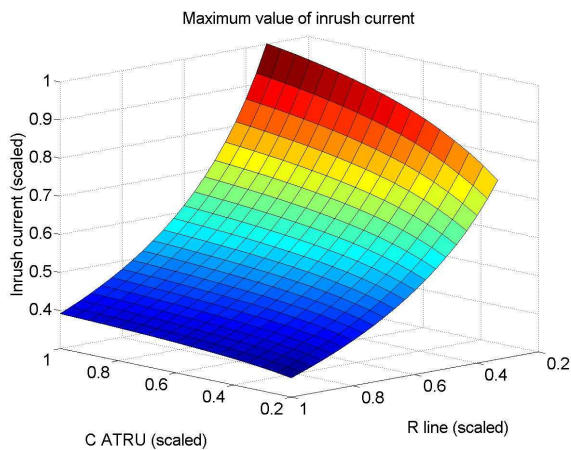


Figure 8: Maximum value of inrush current

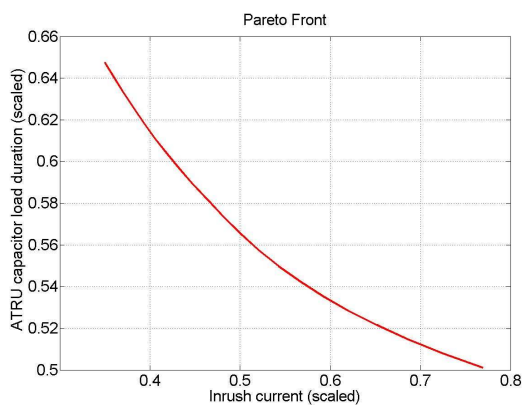


Figure 9: Pareto front

Compliance with standards

Mixed network integration and simulation at behavioural level allow to assess electrical network performances regarding standards. This section focuses on impact of wing ice protection system equipment power regulation. In order to dissipate constant power, in steady state, wing ice protection system resistive loads are switched using a fixed duty cycle, illustrated by current impacts as presented Figure 10. These load impacts through line impedances generate perturbations on 230VAC and 540VDC bus bar voltages, given by Figure 10. Generator controller manages here wing ice protection system impact and system behaviour complies with Airbus directives (ABD0100) and MIL-STD-704F standard, (1 and 2), in terms of load impacts.

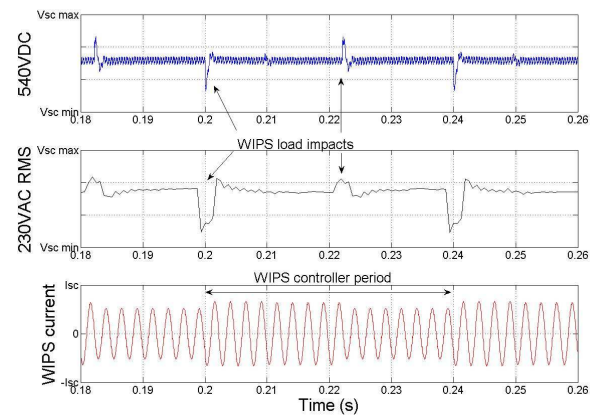


Figure 10: WIPS controller impact on voltages

On the other hand, total 230VAC line current spectrum is computed (Figure 11) and compared to Airbus directives (ABD0100), 1 (Table 1).

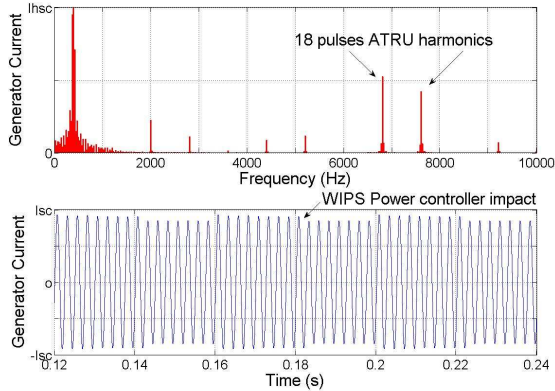


Figure 11: HVAC line current spectrum

Harmonic	Current (% of In)	ABD limit (% of In)
5	0.66	2
7	0.3	2
11	0.26	3
13	0.34	3
17	1.5	4
19	1.2	4
inter	2.7	0.25

Table 1: HVAC line current harmonics

Greatest values of 230VAC current harmonics are harmonics 17 and 19, generated by autotransformer rectifier unit and inter-harmonics, for which wing ice protection system load impacts are main contributors and which exceeds standard limits.

HVDC VOLTAGE REGULATION OF 10M TEST RIG

This section is dedicated to Small Aircraft architecture and focuses on 270VDC bus bar voltage level compliance with MIL-STD-704F standard. Simulation studies give inputs which lead to generator controller equipment modification.

ELECTRICAL NETWORK CONFIGURATION

The electrical network is given by Figure 12.

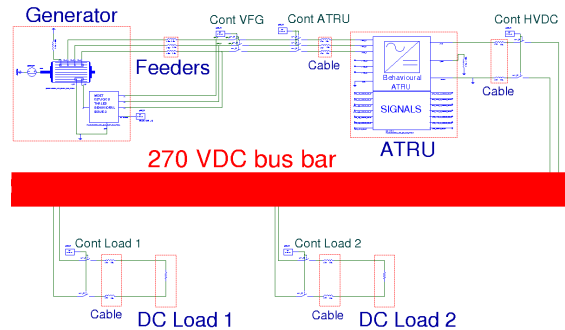


Figure 12: SABER Electrical Network

A variable frequency generator is supplying 270VDC bus bar through 18 pulses autotransformer rectifier unit. AC voltage is regulated and the point of regulation is placed at the input of the autotransformer rectifier unit.

SIMULATION RESULTS

A resistive load impact on 270VDC bus bar from reduced power to nominal power is given by Figure 13, using standard voltage reference of generator controller and is labelled $V_{hvdc\ initial}$ on graph. 270VDC voltage levels are compared to MIL-STD-704F standard limits. Under reduced power, system behaviour is not compliant.

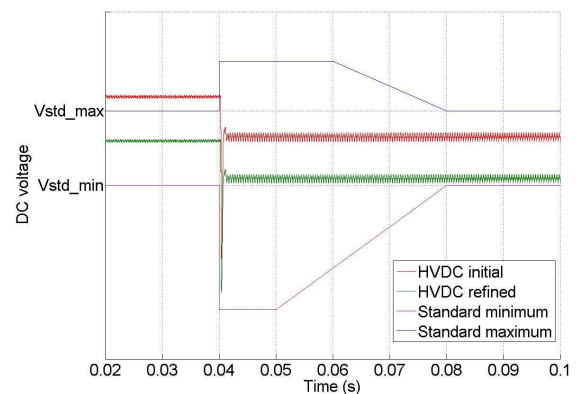


Figure 13: HVDC bus bar voltage

The behaviour of the 270VDC bus bar in steady state is checked under different 270VDC load power values. 270VDC voltage

is compared to MIL-STD-704F standard limits Figure 14.

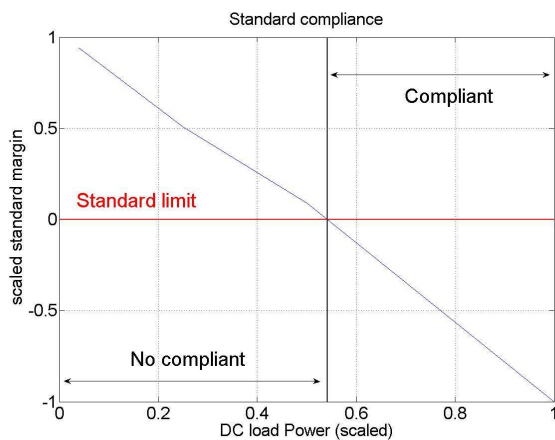


Figure 14: Standard compliance

270VDC bus bar voltage level is not compliant with MIL-STD-704F standard limits when the power is under 54% of the nominal power which is a wide power range. As MOET Alenia rig power loads have been designed according to voltage level of MIL-STD-704F standard, it has been decided from this study in simulation to change the design and the voltage reference of the generator controller to decrease the voltage level at the point of regulation and then to be compliant with MIL-STD-704F standard. Simulation result for this new generator controller is given by Figure 13 and labelled *V_hvdc refined*. This result demonstrates that equipment modification leads to full compliance at network voltage level regarding MIL-STD-704F standard.

CONCLUSION

Within the MOET project, new electrical network architectures are under development and study to face the increase of on-board electrical power and requirements of new aircraft electrical systems, such as environmental control system and variable frequency starter generator equipments. Assessing network power quality and stability regarding suitable standards is a real challenge. In this context, simulation is a powerful and vital tool, supporting design

from equipment stand alone development to electrical network performances assessment.

In the context of MOET project, Aeroconseil Aircraft Engineering, Dassault Aviation and Eurocopter performed complex integration simulation using SABER software to address project objectives. Contribution of simulation has been demonstrated in this paper through examples: power quality verification at network level, optimisation at system level and support to equipment design improvement.

A great simulation platform quality is required to build numerical equivalents of equipments and networks. Pre-existing know how from previous European research project gave some guidelines to reach this objective. More over, in the frame of Airbus programs, Aeroconseil Aircraft Engineering in partnership with Airbus have developed mature skills of complex electrical network simulation using SABER software and is able to give requirements for simulation model development regarding robustness in simulation platform and accuracy of models and to support model development.

ACKNOWLEDGMENTS

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is leader of the sub work package and in charge of Airbus test rig simulation, validation and verification activities whereas Dassav and Eurocopter France are in charge of Alenia test rig simulation, validation and verification activities within the frame of MOET project.

DEFINITIONS, ACRONYMS, ABBREVIATIONS

- **ATRU :** *Auto Transformer Rectifier Unit*
- **BBCU:** *Buck Boost Converter Unit*
- **DCPFC:** *Direct Current Power Flow Controller*
- **ECS:** *Environmental Control System*
- **EMA:** *Electro Mechanical Actuator*
- **EP:** *External Power*
- **GCU** *Generator Control Unit*
- **HVAC:** *High AC Voltage*
- **HVDC:** *High DC voltage*
- **MCU :** *Motor Control Unit*
- **MOET:** *More Open Electrical Technology*
- **POR:** *Point Of Regulation*
- **RU:** *Rectifier Unit*
- **VFSG :** *Variable Frequency Starter Generator*
- **WIPS:** *Wing Ice Protection System*