Modeling and Simulation of Aircraft DC Electrical Power Generating and Distribution Systems – Concept and Design Approach

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Abstrac **This paper presents the concept and design approach used in the development of a computer-aided modeling and simulation tool of a small jet aircraft electrical power generating and distribution system. The modeling requirements and approach are presented and discussed. The characteristics of the individual simulated components are described, and the component models are integrated into a user oriented system model. System simulation shows the interfaces between the electrical power system components and other relevant systems, allowing analyses of normal and abnormal operational conditions, and verification of the effects of components and/or functions failure propagation.**

I. INTRODUCTION

Aircrafts Electrical Power Generating and Distribution Systems (EPGDS) generally consist of the following typical components and interfaces: mechanical power sources and loads, primary and emergency electrical power sources, primary and secondary electrical power distribution centers, controlling units, control panels, energy converters, electrical loads, Crew Alerting System (CAS) and Central Maintenance Computer (CMC) messages, and synoptic and aural indicators.

The ever-increasing complexity of aircraft electrical power systems [1, 2], associated with the need for more aggressive corporative time to market strategies, and prohibitive costs of late development and post certification troubleshooting, has led aircraft industry to trail the non-returning path of systems modeling and simulation.

Most of the published simulation efforts either focus on a comprehensive study of a specific operational scenario [3, 4, 5, 6], or on a detailed model of a single component [7, 8, 9], which reflects the strict needs of the aircraft systems development industry, but not the wider interests of the airframe integration manufacturers.

Electrical System Simulation Tool (ESST) project, a joint effort between ITA and EMBRAER, created to study the feasibility of modeling and simulation applied to electrical systems, has developed a VISSIM® [10] based model which simulates a small jet aircraft DC EPGDS. It focuses on the interactions between electrical, avionics and engine systems, using a multi-level non-linear modeling concept. Project goal is to validate EPGDS internal and external interfaces, analyzing normal and abnormal systems operations, as well as propagation of major electrical system's components failure conditions.

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A. *Modeling Requirements*

Models developed by ESST project have been designed to comply with the following requirements:

- Bi-directional power flow
- Real time user interaction
- Failure insertion capability
- Reliable steady state results
- Non-linear representation
- Modularity concept

Bi-directional power flow may not be a desired system behavior, as in the case of reverse current being forced onto an electrical generator, but it is an intrinsic characteristic of any electric equipment, and therefore should always be taken into consideration.

Combination of real time user interaction, failure insertion capacity and reliable steady state representation gives the system integrator the capability to predict and evaluate the overall system's response under the most probable operational conditions.

Non-linear representation capability is required to simulate microprocessor based functions, as well as power switching elements.

Modularity is a wanted feature for any system simulation experiment, as it generates a solid base of simulation models which can be easily transported and adapted to further simulation projects.

One other important feature of modular approach is that it allows model verification at subsystem level, where experimental testing is possible [6].

B. *System Description*

Test case system chosen to be modeled is composed by the following components and interfaces: engines, starter-generators (S/GEN), generator control units (GCU), full-authority digital engine controllers (FADEC), batteries, ground power units (GPU), contactors, relays, circuit-breakers, fuses, bus bars, distribution wiring, switches (inputs), CAS, CMC and synoptic indications (outputs).

C. Modeling Approach

Complex large-scale systems are, by definition, very difficult to be described in terms of equations. The chosen test case system adds even more complexity to this task, as it is intended to provide real time multiple configuration and failure mode insertion capability.

Use of the modular concept allows system modeling and simulation effort to be taken to sub-components level, which can then be separately designed according to specific complexity requirements, as long as they all follow the same interconnection rules.

In order to use modular approach, electrical system sub-components were modeled as four port elements, based on state vector technique and power flow representation [11], with two inputs for incoming voltage and current, and two outputs for outgoing voltage and current.

Terminal characteristics of each component are described by the following equation:

$$\begin{bmatrix} p_1 \\ f_1 \end{bmatrix} = \begin{bmatrix} g_{11} & g_{12} \\ g_{21} & g_{22} \end{bmatrix} \cdot \begin{bmatrix} p_2 \\ f_2 \end{bmatrix} \quad (1)$$

where $[p_2, f_2]$ matrix represents input parameters,

$[p_1, f_1]$ matrix represents output parameters, and

$[g_{11}\ g_{21}\ /\ g_{12}\ g_{22}]$ matrix stands for the transfer function.

D. Components Modeling

1) Battery

Battery model was developed to allow for state of charge constant update according to the units operational mode (recharge / discharge), ease of capacity rating modification, parallel operation capability, and output voltage adjustment according to battery instantaneous electrical current.

2) Starter-Generator

S/GEN model was developed to allow for both start and generate modes of operation, parallel operation capability, armature voltage and current regulation through field current control, and output voltage adjustment according to the starter-generator instantaneous electrical current.

3) Generator Control Units

GCU model was developed to allow for S/GEN field current monitoring and control, distribution system contactors logic evaluation and actuation, circuitry and software time delay simulations, and power supply redundancy with selection capability.

4) Ground Power Unit

Ground power unit model was developed using the same concepts of the battery model, except for a higher capacity.

5) Engines

Engines model was developed to allow for both start and generate modes of operation, based on manufacturer's available data, and output speed adjustment according to engine instant torque variation.

6) FADEC

FADEC model was developed to allow for recognition and processing of an engine start request, with power supply redundancy and selection capability, but it only interfaces with GCUs to notify the status of the engine start process. FADEC model was not developed neither to control monitor nor engine parameters, as the focus of the study was the operation of the electrical system.

7) Switching elements

Contactors, relays, circuit-breakers, fuses and switches models were developed focusing on their power switching functionalities, rather than their protection capabilities. They all account for voltage and current operational thresholds, circuitry time delay simulation, and specific auxiliary contacts distributions (wherever applicable).

Switches are arranged in a simulated aircraft control panel interface, as shown in
Fig. 1

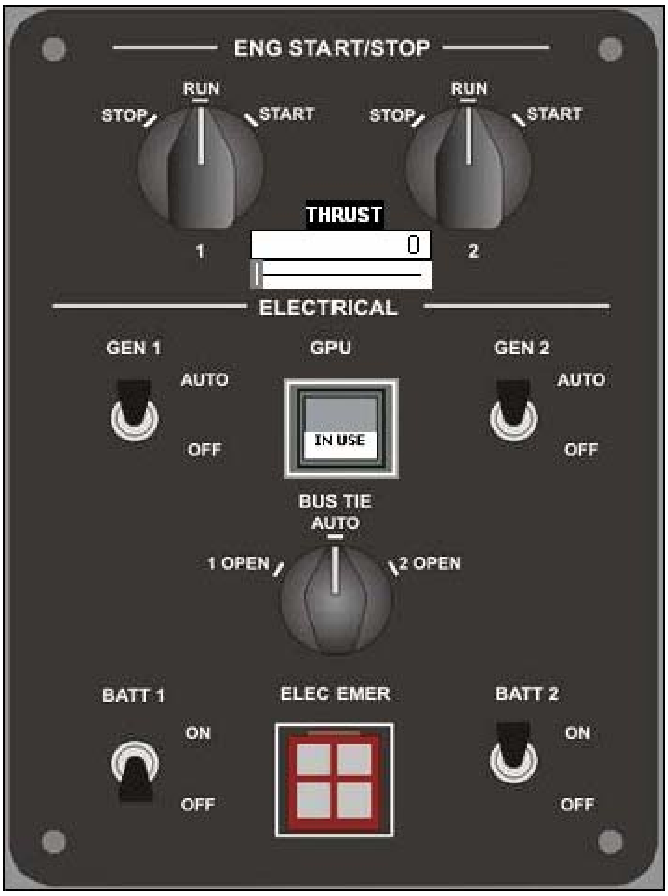

Fig. 1 – Simulated Aircraft Control Panel Interface

8) Wiring and buses

Wiring models were developed according to their direct applications. Only main power distribution system wiring models account for copper losses as low power distribution wiring models account for transmission of voltage and current information.

Bus model was developed using the same concepts of the low power distribution wiring.

9) Avionics System interface

CAS, CMC and synoptic interfaces were developed based on existing avionics system data processing architectures. The different functions were divided among the several processing units, which account for power supply redundancy and selection capability, as well as processing redundancies within the system itself, based on redundant communicating channels and functions. Logics are processed within the system and messages and indications are displayed in a simulated aircraft avionics display interface, shown in Fig. 2

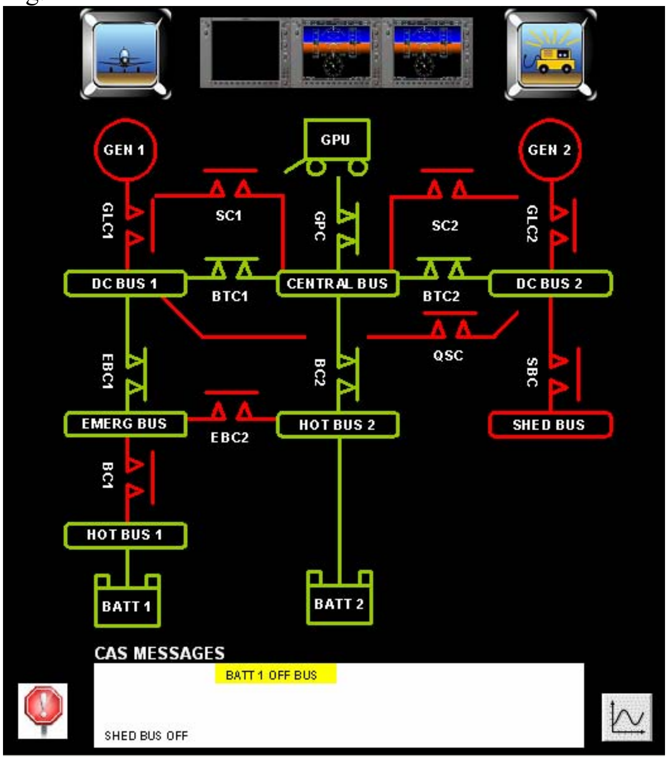

Fig. 2 – Simulated Aircraft Avionics Display Interface

10) Connectors

Every system component was modeled with terminal connectors, and wiring routing was modeled using passage connectors. Connectors show different sets of failure modes aiming to simulate final aircraft installation environment, i.e., open / shorted connector failure effects.

E. System Modeling and Analysis

Simulated aircraft EPGDS architecture and its major components are shown in Fig. 3..

Simulation results demonstrate that models function properly when connected together, and results show system performance according to theoretical results used to formulate the main control functions. Bi-directional power flow is accomplished, and user can activate and verify components and functions failures throughout the entire simulation period.

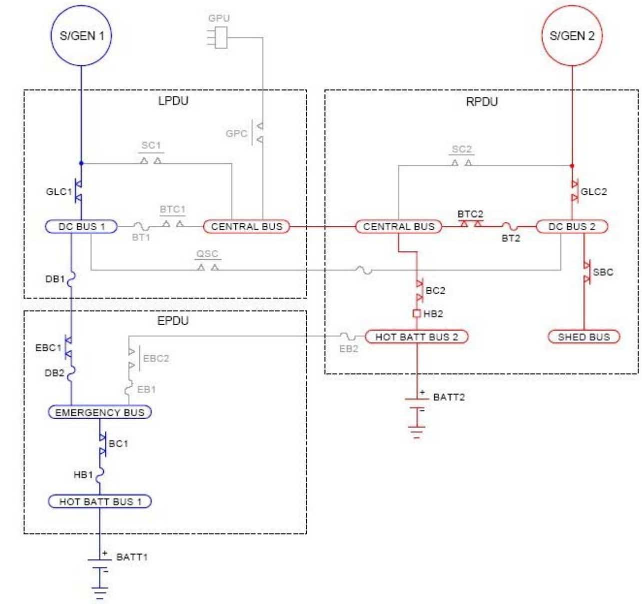

Fig. 3 – Simulated Aircraft EPGDS Architecture

In the next phase of the project the intention is to compare real system performance data to simulation data, and calibrate models based on test results.

F. Conclusions

A comprehensive large-scale EPGDS is modeled using state vector and power flow representation. Model can be used to analyze steady state both normal and abnormal operational conditions, and to verify the effects of components and functions failure propagation. Work in progress focuses on calibrating the models comparing real system performance data to simulation data, aiming to validate developed models using real equipment performance results.

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