

Solid State Power Control as a Network Backbone for Aircraft System Health Management

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ABSTRACT

Aircraft-level health management requires effective management of data flow. As future aircraft adopt conditioned base maintenance (CBM) and/or integrated vehicle health management (IVHM) protocols, there is need to manage infinitely more data communication on and off the aircraft.

This paper explores the idea of employing an Electronic Power Distribution System (EPDS) as a “network backbone” for aircraft-level prognostics. Using EPDS to capture and distribute this data provides a practical solution that minimizes system hardware on future CBM/IVHM enabled aircraft. Employing the Electronic Circuit Breaker (ECB) in a more enhanced sensor state and as a data communication tool, provides tremendous value given its multipurpose capability.

A “distributed” electronic power distribution architecture, is comprised of groupings of remotely operated electronic circuit breakers (ECBUs), System Control Interface Units (SCIUs), primary power distribution units (PDU), bus transfer contactors, and so on, all of which will play a future role in aircraft level health management. The ECBUs will be the initial interface for both structural and electrical health sensors. The ECBU will take on an additional data concentrator function, interfacing with a new class of smart sensors. The ECB will serve as an electrical load health sensor, in addition to its primary function, as a circuit protection device. The SCIU, as the central interface and system brain, will be the final repository or router for on-aircraft health data between the aircraft maintenance computer and ground base station.

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BACKGROUND

According to the Integrated Vehicle Health Management (IVHM) Plan [1], “fatal accidents in the worldwide commercial jet fleet from 1987-2005 were due primarily to controlled flight into terrain, loss-of-control in flight, and system/component failure or malfunction (non-power plant, power plant)”.

“FAA and NTSB are clear: subsystem, component failures and hazards together contribute 24% to onboard fatalities, and are underlying factors in many of the 26% of the accidents caused by loss-of-control in flight. However, with the projected increase in departure rates, it is estimated that the accident rates will increase significantly. Accidents due to controlled flight into terrain have been virtually eliminated through the addition of various safeguards, but the same cannot be said for accidents due to loss-of-control in flight and system/component failure or malfunction. System/component failures and malfunctions are recognized as contributing factors to aircraft loss-of-control in flight, so safeguarding against them will reduce the number of fatal accidents in the two top accident categories. Safety risks due

to hardware and software-related failures and malfunctions will increase with the complexity that comes with more sophisticated capabilities and the greater reliance on automation.”

Thus, it is necessary to develop new capabilities that will provide accurate on-board detection, diagnosis, prognosis, and mitigation of adverse conditions during flight.

INTRODUCTION

Over the last 20 years, the aviation industry has been in process of migration away from electro-mechanical system elements, in favor of solid-state technology, in all areas, particularly regarding electrical power distribution. The solid state electronic circuit breaker (ECB) has earned credibility, given enhanced circuit protection capabilities (i.e arc fault protection), as well as orders of magnitude increase in reliability.

Driven from the IVHM need, a more holistic view of aircraft system design is presented. An effectively networked electrical power and control system will be proposed to provide enhanced system health awareness, data concentrator

functions and enhanced safety through reduced system complexity. This distributed architecture EPDS/IVHM system will serve as a total aircraft health management framework.

This paper will include a deeper investigation of optimized EPDS/IVHM integration with data management, interfacing needs and communication, followed by discussion of the ECB's application, as a sensing element and the additional diagnostic, prognostic and communication support it can provide.

It is reasonable to suggest that the ECB can do much more than provide circuit protection. After all, it is inherently a sensor and a power switch coupled with a resident microprocessor. Active switch control, health monitoring and data communication are all viable capabilities to leverage. As [Figure 1](#) suggests, an ECB has four resident capabilities: protect, communicate, diagnose and control. These capabilities will be explored herein, relating to aircraft health management.

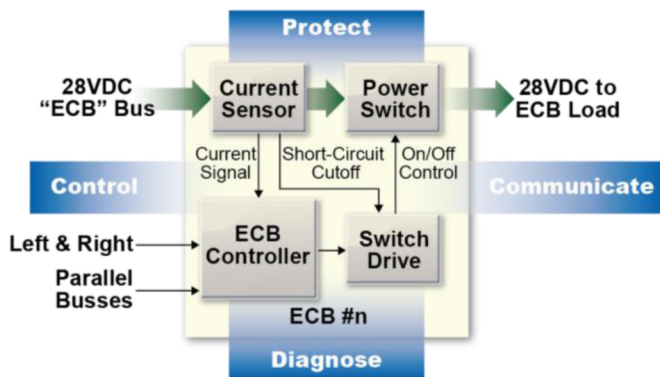


Figure 1. ECB Core Building Block

To meet the IVHM need, the ECB can be scaled as a pervasive element in the aircraft, within a networked power system, and appropriately distributed throughout the aircraft, as remotely operated control, logic and data management devices.

BODY

The electronic power distribution system: Baseline framework:

If an aircraft rated microprocessor is combined with latest generation power MOSFET switch, appropriate switch drive, conditioning/EMI filtering circuitry, and current sense circuit, the ingredients are present for the electronic circuit breaker/solid state switch. This is a device with no inherent wear-out mechanism and the central building block of an electronic power distribution system ([Figure 2](#)).

This programmable system element can be combined into logical card-level groupings of electronic circuit breakers (ECBs) and packaged in a manner that allows them to be operated remotely in the aircraft near their respective electrical loads. Each grouping of ECBs, referred to as electronic circuit breaker units (ECBUs) has local processing/

data storage capability to manage necessary sub-routines, initially, as circuit protection algorithms, fault redundancy management and reporting functions. ECBUs can be best placed in the aircraft in a distributed manner to manage large quantities of breaker and switch functions, supporting system separation & redundancy requirements. This dramatically reduces system weight, cost and touch labor, given that power feed wire and load wire lengths are shortened, leaving only digital data bus wire to be routed to the "head-end" unit. Management of the entire network of ECBUs is accomplished via a common data bus either to the primary avionics suite or to dedicated system control interface units (SCIUs). The SCIU provides data bus conversion between avionics suite and ECBUs. It has processing power to provide logic functions, such as load shedding and many utility functions to be discussed herein.

Inherently, the EPDS system can eliminate the switch, thermal breaker, relay/contact, significant wire content, intermediate data acquisition LRUs, as well as legacy logic circuits and power conversion/conditioning functions on federated LRUs. This can be accomplished in a manner that provides simplification and increases fail safe redundancy.

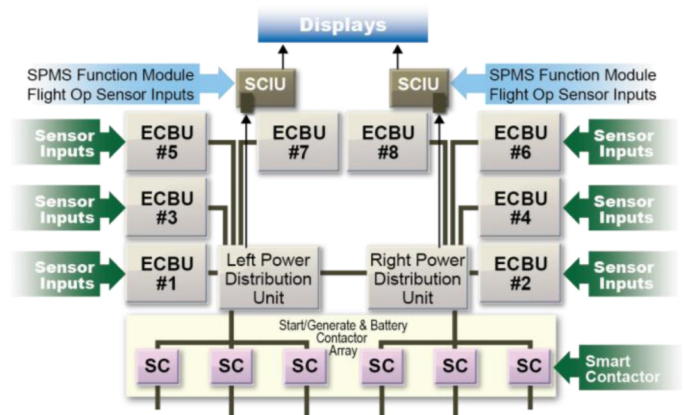


Figure 2. EPDS Building Blocks

EPDS expansion as a network health management framework:

The EPDS can be used as a sensor data acquisition device to replace special purpose data acquisition systems. Already, EPDS is being used to manage numerous utility functions (i.e. window heat, de-icing, thrust reversers, etc.) formerly, governed by federated LRUs. It is a natural evolution to include sensor interfacing, in support of aircraft health management. An example ([Figure 3](#)) of this outgrowth might be a windshield temperature control system. The EPDS supplies the power to be used to heat the windshield, so it can also be made to modulate that power in response to windshield temperature, thus eliminating the windshield temperature control system LRU entirely. The EPDS has to acquire the windshield temperature sensor information in some way to accomplish this function, which it does to execute a closed loop control function. As a closed loop

control system or as a monitoring device, the EPDS must gather information from sensors. The sensors can be of any type that measures a physical parameter, such as a position, temperature, pressure, level, or etc. Sensors can have either an analog or digital output.

In this windshield temperature case, EPDS quickly evolves, conceptually, into an EPDS/IVHM system. Inherently, the system provides:

- On/off system control
- Closed loop PWM logic
- Circuit protection
- Sensor I/O, formatting, data concentration and routing

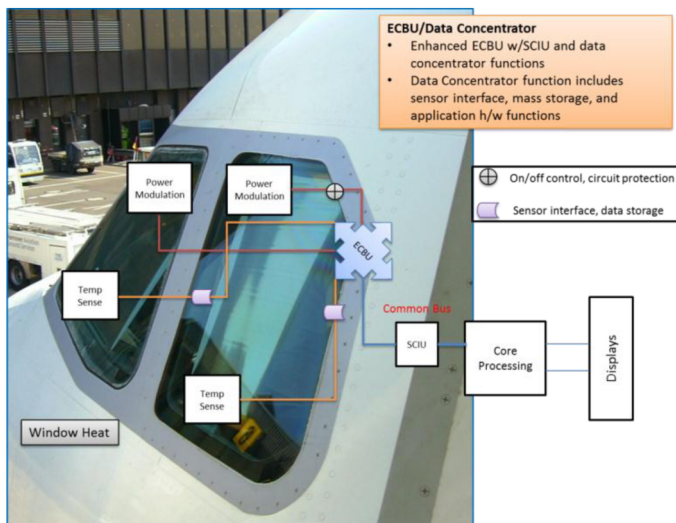


Figure 3. Window Heat Control and Health Management

Additionally, the ECB itself will take on an expanded role to provide health status of the load (i.e. window heating element) and wire fault location.

EPDS/IVHM System Architectural Discussion

A notional EPDS/IVHM system might be configured as shown in [Figure 4](#). This is one half of a complete system showing an SCIU and two ECBUs. A complete system would have left and right sides for redundancy and fault isolation.

The portion of a complete system shown here incorporates interfaces between the ECBUs and external sensors located on the aircraft or in other sub-system components. Some of the external sensors are multiplexed by an element external to the ECBU while other sensors may interface directly with the ECBU, either in analog or digital formats. Electrical load parameters sensed within the ECBU by the individual ECB's are combined with external sensor data, pre-processed and transferred to the SCIU via a serial data bus to the SCIU. Formatted data and alert messages are then ready for crew and/or maintenance disposition.

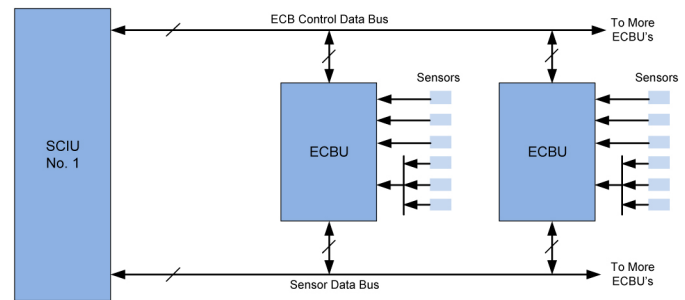


Figure 4. Sensor Interfaces in Integrated Diagnostic/Prognostic/EPDS System

Integrating numerous sensors within an EPDS system requires a unique architectural approach to alleviate complexities of sensor networking and avoiding certification issues. With sensors distributed throughout an aircraft, a multitude of data will be required to be captured, processed and stored all while not interfering with the normal flight critical operation of the system. While simply capturing this data is important, it is paramount to ensure the entire system is synchronized to enable correlation between sensors within different locations yielding a look at the entire aircraft's health. System time correlation will be handled by the primary SCIU and will periodically broadcast time synchronized information to the pertinent ECBU's within the system. This will allow for every sampled data point to be correlated to the same time-line.

The overall data path requires transducer information to be transferred from the monitored load to the SCIU, which has adequate processing available to handle real-time monitoring/storage and possesses a direct communication link to the flight computer for error identification/download to a fleet wide database once at a hangar. Potentially there is an extremely large amount of data that needs to be transferred from the various transducers throughout the aircraft to the area where the information is to be processed/stored (SCIU). This limits the options of how the overall interface can be configured due to theoretical maximum data rates that can be achieved. [Figure 5](#) shows a generalized data flow from sensor to data storage.

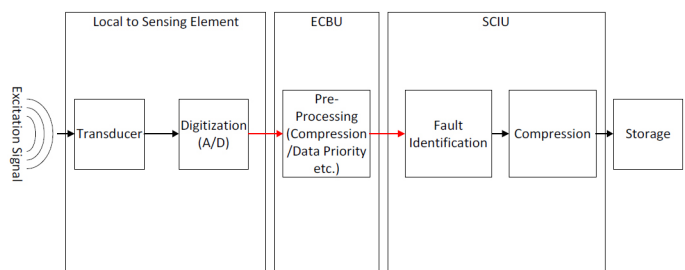


Figure 5. System Data Flow