Approach to Implementation of Power Management with Load Prioritizations in Modern Civil Aircraft

Brice Nya, Detlef Schulz

***Abstract*—**Any use of energy in industrial productive activities is combined with various environment impacts. Withintransportation, this fact was not only found among land transport, railways and maritime transport, but also in the air transport industry. An effective climate protection requires strategies and measures for reducing all greenhouses gas emissions, in particular carbon dioxide, and must take into account the economic, ecologic and social aspects. It seemsimperativenow to develop and manufacture environmentally friendly products and systems, to reduce consumption and use less resource, and to save energy and power. Today'sproducts could better serve these requirements taking into account the integration of a power management system into the electrical power system.This paper gives an overview of an approach ofpower management with load prioritization in modernaircraft. Load dimensioning and load management strategies on current civil aircraft will be presented and used as a basis for the proposed approach.

***Keywords*—**Load management, power management, electrical load analysis, flight mission, power load profile.

I. Introduction

NOWADAYS, load and power management in electrical power systems play an essential role in energy utilization with highest efficiency of energy conversion and use. Initially, it is necessary to make a comprehensive analysis of the operating power supply and energy use, in order to reduce the power consumption and relate the accruing costs. In airplanes, the motivations to apply a rational energy use and implement power management systems can be diverse:

- compliance of requirements, which meet the aviation guidelines
- reduction of operating costs due to low fuel consumption and the reduction of maintenance costs
- revaluationof the company's image and thereby improvement of the competitiveness of the company in context with the national and international increasing importance of the climate protection
- prevention with regard to long-term non avoidable regulatory basic approaches or tax measures

Fig. 1 shows an example of the amount of electrical power during a flight mission in a conventional aircraft [1]. This is referred to as load curve and is used to plan the electrical power needs to supply the loads sufficiently at any flight phase.The power demands vary in accordance with the load activities. Variation in power demands result in non-constant load curves.

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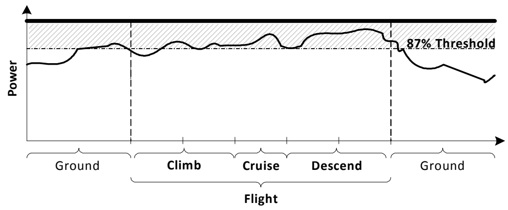

Fig. 1 Typical conventional aircraft load curve with power dimensioning

II. Power Dimensioning

Basically, the overall aircraft electrical power system is designed to deliver the maximal electrical energy in each flight phase. This maximal electrical energy is equal to the total sum of energies of all installed electrical systems.

$$P_{total} = \sum_{i=1}^{n} P_i \qquad (1)$$

Where n = number of installed loads and P = electrical power.

The equation (1) shows that the available total electrical power remains the same in each flight phase. Not all systems need their maximal power in each flight phase, so that the electrical network is oversized.
So there is,

$$P_{total} > \sum_{i=1}^{n} P_i \qquad (2)$$

in each flight phase!

An optimized electrical system architecture may be achievedby integration of electrical loads and power management system onboard an aircraft.

III. Load Management System

Load management is the process of changing the load profile in an electrical system in order to reduce the total system peak load, increase load factor and improve utilisation of sources like fuels or generation, transmission and distribution capacity [2]. Many advantages to be achieved by practising load management are listed in the following:

- avoidance of the requirement to increase transformer, cable sizes and generator capacity
- controlling peaks by more efficient load profile
- effective use of resources.

Except in electronic engine control, the electrical load management system in aircraft shall be defined to ensure for all electrical configurations the best adequacy between AC power and the electrical loads connected to the AC network. Automatic load shedding has to be ensured in case of power source overload, whereas automatic reconnection of loads should be established, when enough power is available on power source [3].Fig.2 portrays the algorithm of a load management system as described previously.

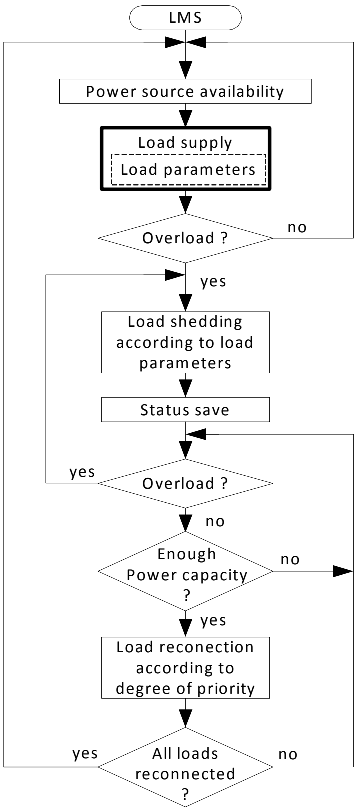

Fig. 2 Algorithm of load management system in current aircraft

In order to define an accurate model of the load management system, it is necessary to define exact parameters for each electrical load.A managed load may be either a physical load (e.g. Galley) or a group of loads (e.g. Lights), with their characteristics as mentioned in Fig. 3, such as load priority, current type, maximal power, connected busbar and load status.

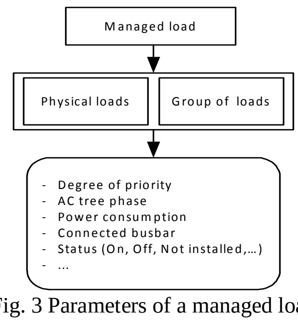

Fig. 3 Parameters of a managed load

IV. Power management system

On the other hand, power management system is a process to direct power efficiently to different components of a system. Power management is especially important, when loads are connected to different power sources such as generators, batteries, fuel cells etc. It ensures reliable and efficient energy use by reducing power to components that are not being used [4]. Fig.4 shows the synopsis of a typical power management system that is able to manage a highly dynamic aircraft electrical network.

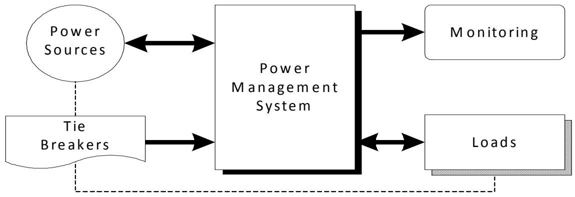

Fig. 4 Synopsis of a power management system

The power management system comprises controls and monitoring of electric power generation and loads. The system controls and monitors all power sources, tie breakers and load status. In case of an electrical system fault the power management system restores power in a minimum of time, in order to guarantee a safe function.In current aircraft the load and power management is implemented in one unit. This type of management is referred to as*centralized power management*. In future aircraft architecture, where more electrical systems could be installed, a decentralized power management could be beneficial because of the avoidance of the “single point of failure” (SPOF) presented by a centralized power management [5].

A. Centralized Power Management

With a centralized power management a virtual power plant ideally results in the combination of several power sources together with energy storage and loads. This exhibits the characteristics of a large power station, in which the power demand can be controlled at a central point. In a conventional civil aircraft, all power sources focus towards a single point called“primary electrical distribution center” (PEPDC). The electrical systems are then supplied from the PEPDC through feeders. In this type of configuration,in which the point-to-point cabling architecture exists, a centralized power management as shown in Fig. 5is preferred.

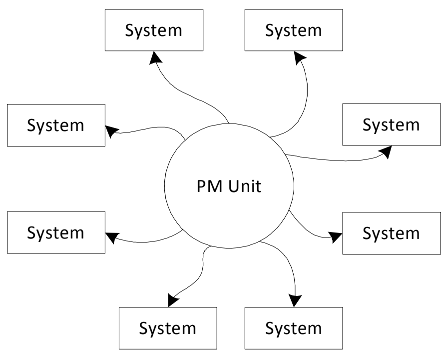

Fig. 5 Centralized Power Management

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The centralized power management has some drawbacks: the control center presents a SPOF and therefore needs to follow a redundant design. In addition, the complexity increases exponentially with the number of power sources and loads. Decentralized power management may be chosen for systems, where on the one hand the power source can be optimized and on the other hand the loads can be disconnected and reconnected.

B. Decentralized Power Management

In opposition to a centralized power management, a decentralized power management has more than one SPOF and thus is more robust and less complex. This is referred to as "multiple points of failure" (MPOF).In addition, a centralized power management is a fault-tolerant system, because having MPOF would imply that no one failure of any component would fail the whole system. Thus, the system remains operational even after a component has failed. Current aircraft have a distributed electrical architecture as shown in Fig. 6 [6]. Now there is the possibility that a decentralized power management could be implemented by integrating small power management units (PMUs) into the secondary power distribution boxes (SPDBs), so that each PMU controls loads or group of loads supplied from the SPDB, in which it is integrated (see Fig. 7). This type of power management is not focussed on in this paper, only the case of a centralized power management system with load prioritizations has been studied.

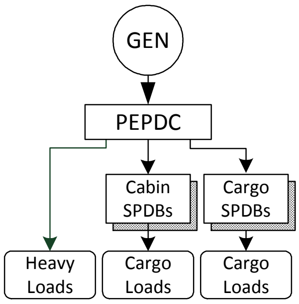

Fig. 6 Distributed Aircraft Electrical Power System [6]

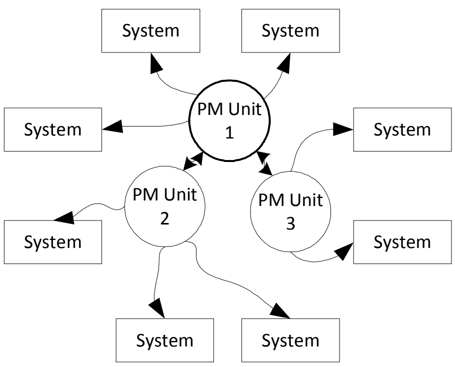

Fig. 7 Decentralized Power Management

V. LOAD PRIORITIZATION

In this type of power management algorithm, each feeder load will be assigned a priority level and a status ON/OFF. When the total power capacity is less than the total load (plus a tolerance limit), the feeder load with the lowest priorities are preselected for shedding. If the power capacity is greater than the total load, loadscan be reconnected. In current aircraft power management loads are not only classified by priorities (P1, P2, P3), but also by groups (G001,G002, …). In practice, loads do not change their priorities during the flight phase; meaning the load priorities remain the same on ground as well as in-flight. Systems with high priority level (P1) must not be disconnected, because they are mostly flight relevant systems.A general framework for organizing the load priorities in an aircraft electrical power system is shownin Table 1 [7]. Aircraft's vital systems (e.g. flight controls) have typically the highest priority while some aircraft's passenger comfort systems (e.g. cabin lighting, galley systems) are the most easily sacrificed dependent on the threat level. Generally, systems with the highest priorities must not be turned off. In case of a total engine flame out (TEFO) or a total loss of main electrical system (TLMES) the power management system does not react, since the emergency system will be established in order to supply the critical loads, so that a safe landing is assumed.

Table I shows the load priority assignments in current aircraft. It is a matrix which the following data:

- *#*: number of the load
- *Load* group: groups associated with the indexes
- *Name*: name of the system with maximal 16 characters
- *Busbar*: name of the connected busbar
- *Power*: estimated mi and max electrical power
- *Priority*: load priority on the ground and in the flight
- *Installed*: load status (installed or not installed)

TABLE I
LOAD PRIORITY ASSIGMENT

#	Group	Name	Busbar	Power	Priority (Ground)	Priority (Flight)	Installed ?
1 … n	G001, G002, …,Gn	Name of the system (max 16 characters)	Connected busbar	Estimated min/max electrical power	1 (high), 2 (medium) 3 (low)	1 (high), 2 (medium) 3 (low)	0 (not installed) 1 (installed)

In this paper an optimum load management strategy is proposed, where loads are classified into three priorities with a strategy to retain the highest priority load to the detriment of the less critical loads.

VI. GENERAL FRAMEWORK

This section deals with a mathematical approach to the load management with priority. Table II gives the proposed load classifications and their priorities based on a number of height loads.

The power management implementation is based on this Table. However the algorithm can be simply adapted to an arbitrary number of loads.

TABLE II
LOAD CLASSIFICATION AND PRIORITY

Index	Load type	priority
1	IFE (In-Flight Entertainment)	3
2	ECS (Environmental Control Systems)	1
3	Wireless Local Area Network	3
4	Galley System	2
5	Water Pumps	2
6	Water Heating	2
7	Cabin Heating	1
8	Wastewater Systems	2

The solution of the problem addressed is based on the maximum of the weighted objective function that depends on the load priorities and is subject to the availability of power supply [8]. The proposed power management enables load (re)connections and disconnections in accordance with the power supply availability. This can be expressed mathematically by two functions, for load disconnections and (re)connections respectively.

A. Load disconnections

The aim of the disconnection is to minimize the load shedding schedule under certain conditions, in accordance with the load priorities in order to clear an overload in the whole electrical system. Load disconnections can be expressed mathematically by

minimize

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i} Switch_{ij} \tag{3}$$

subject to

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i} I_i Switch_{ij} \geq Overload \tag{4}$$

Switch ∈ {0,1}, for all i, j. 0 ≡ OFF and 1 ≡ ON
$Switch_{i=1} = 1$, for all i

where

i=priority index; n = 3 since three priorities are defined
j= load index (1 to m_i)
m_i=number of loads of priority i
I = load currents.

B. Load (re)connections

Similarly, the load (re)connection is the process to switch on the loads after they have been disconnected, when the power capability permits it. Contrary to the load disconnections, here it is attempted to reconnect the maximum of the disconnected loads, according to the available power capability. This can be mathematically expressed by

maximize

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i} I_i Switch_{ij} \geq Overload \tag{5}$$

subject to

$$\sum_{i=1}^{n}\sum_{j=1}^{m_i} I_i Switch_{ij} \leq I_{Capacities} \tag{6}$$

with the same boundary conditions for switches as defined in the equations (3) and (4).

VII. SIMULATION STUDY

An example is provided here to demonstrate the applicability of the implemented approach. The number of loads is limited to eight in this example. Fig. 8 illustrates the schematic of the studied power management system.

A. Power Management Schematic

The studied power management system consists of four blocs:

- The *Feeder Currents Subsystem,* which contains each feeder current and the sum of them
- The *Power Management Subsystem* which integrates the *Embedded MATLAB Function* for the switching decisions
- A *Monitoring* to visualize the load current flows and verify, if the system operates properly
- A *switch Subsystem* which connects or disconnects the loads.

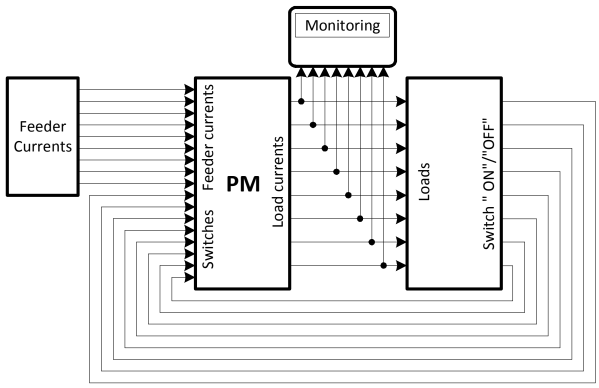

Fig. 8 Power Management Schematic

B. Simulation Results

The following Fig. 9 to Fig. 11show the load feeder currents for the systems with the three priority types 1, 2 and 3. The upper wave forms show the current characteristics before the power management actions, whereas the wave forms on the bottom indicatethe characteristics after the power management actions.

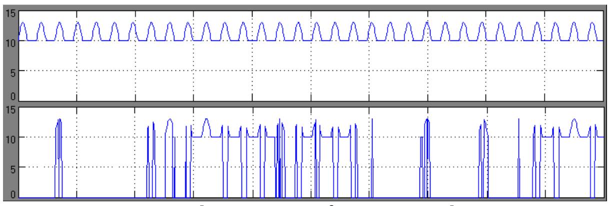

Fig. 9 Current characteristic of a system with priority 3

The wave forms of a system with priority 3 are illustrated in Fig. 9. An example of such a system is the IFE as listed in Table II. Although this system has the lowest priority, it will be decided, in which passenger classes (first, business or economy class) the availability of this system firstly will be provided.

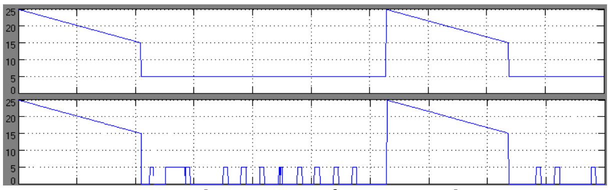

Fig. 10 Current characteristic of a system with priority 2

An example of a system with priority 2 is the galley system. Fig. 10 reveals in this case that the galley system is managed well, when its power demand is muchmore moderated.The proper operation of the whole system is maintained, despite the disconnection and (re)connection sequences due to the power management actions.

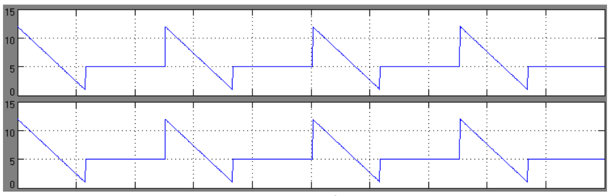

Fig. 11 Current characteristic of a system with priority 1

Fig. 11 shows that the characteristic of a current of a system with priority 1 remains the same before and after the power management actions. This assumes that in a total loss of the main electrical generation, the emergency power takes over the electrical generation and has sufficient capacities to supply the loads with highest priorities.

VIII. Conclusion

In this work a model to manage power in an aircraft electrical systemis proposed, taking into account the load priorities. Proper power management techniques should lead to better utilization of the power sources and then enhance their efficiencies.

A case study is presented for a system, which includes eight loads.This example shows that the switching algorithm must be improved, in order to avoid to make the power management “nervous”. This aspect will be taken into account in the further implementation. The next implementation stage is to integratethe developed power management function into a real setting.

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