ACTIVE RECTIFIER COMBINED WITH AN ENERGY STORAGE DEVICE FOR AN ELECTRICAL SUBNETWORK

J-J Simon, R. Casimir, R. Meuret,
HISPANO-SUIZA

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Abstract

The paper presents new solutions using power electronics to manage high transient power loads required by embedded aeronautical systems, such as landing gear and braking systems, leading to network quality improvement and alleviating peak power request at generation and distribution level.

This solution has to be compared with the architecture in which stored energy is only used for back up.

1 Introduction

The challenge of more electric aircraft requires developing innovative solutions for providing tailored answers to each system requirements.

In [1] the authors highlight the main issues that remain to be solved.

Many loads request high transient power levels, leading to over sizing the electrical drives, the protection devices, compromising the electrical network quality (high level of harmonic rejection, inrush current, reactive power).

This paper describes how a local sub-network dedicated to such loads can address the problem when applied to different electrical actuation architectures like landing gear and breaking systems.

The main function of an energy storage device for these architectures is to provide a back up solution, in case of emergency breaking for instance.

A further step discussed in the paper, should be to use the stored energy, when available, for supplying the peak power required by the loads.

In the first part, a short description of the product under development is given.

The second part describes typical electrical drive architectures that could be applied for systems like landing gear and braking.

The last part explains the trade off when using the active rectifier and energy storage device in those architectures.

2. Product description

2.1 Product Breakdown

The active rectifier is the interface with the aircraft main electrical network, currently three phases 115Vac steady or variable frequency. This design can evolve in the future towards a three phases 230Vac network.

Therefore, the topologies under development address this evolution. We consider the 3Ph-230Vac for main network voltage, for which a Buck topology ([2] Fig. 1) should be used in the active rectifier design.

The energy storage device is used for supplying the peak power, whereas the active rectifier would supply the mean power. The latter will be used in steadier load, alleviating its design constraints, thus leading to efficiency and reliability increase.

The most attractive solution envisioned for the energy storage, is the use of an ultra capacitor bank [3].

The energy storage device needs to incorporate a bi-directional converter for power to be sourced out or be sunk in it.

A trade off on mass, ESR, reliability has led to a 100V voltage choice. The characteristics of the ultra capacitors device bank were determined with the help of the landing gear power profile.

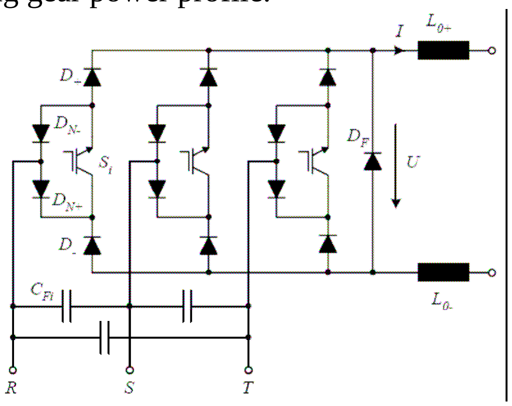

Fig. 1. Topology of the power supply unit (PSU)

The Fig. 2 describes this profile, and shows retraction phase and extension phase. During retraction phase, one can see the desired power limitation of the active rectifier

Above this threshold the aim is to use the energy storage.

2.2 Specification

2.2.1 The bi-directional converter

The bi-directional converter selected topology should be an interleaved buck-boost converter (Fig. 3– [4],[5]). Its main features are:

- Low voltage side: 50 – 100 V
- High voltage side: 340 V
- Peak power sourced by storage device: 3kW max, 2,5 kW typ.
- Peak power sunk in storage device: 2 kW
- Estimated weight: 1 kg
- Efficiency requirement: 95%

Reliability requirement: $\lambda \approx 0{,}2.10^{-5}$ F/FH

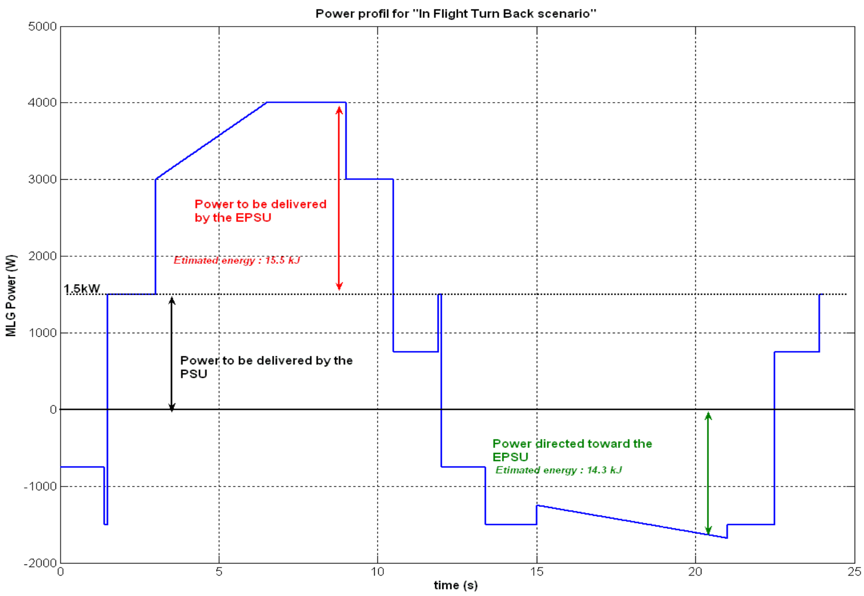

Fig. 2. Load's profile for one Main landing gear

Besides the back-up mode, the maximum operation time in generation mode or in recovery mode is 10s max. This represents 20% of the landing gear actuation time.

A fail-safe protection will be added at the output in order to insulate the DC/DC converter in case of failure.

In case of open circuit in one leg, the converter remains working on the safe two other legs, by simply changing the converter control. Therefore the converter is fault tolerant [6].

The converter's weight objective seems ambitious. But if we consider the limited operational time, the heat sink size can be reduced.

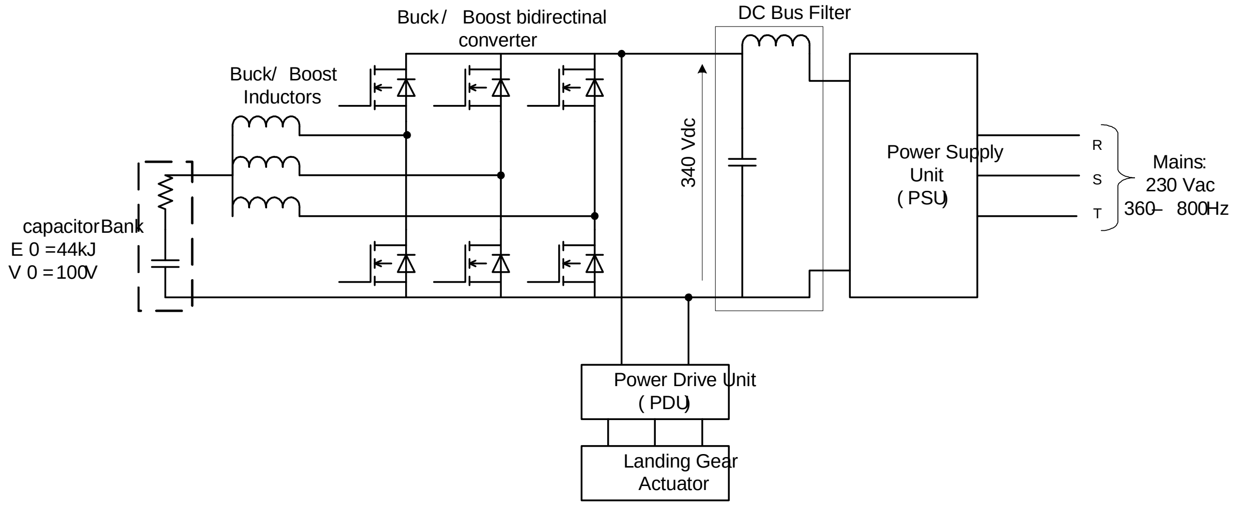

Fig. 3. Local sub network for one landing gear and bi-directional converter topology

Furthermore, Coolmos transistors are suitable for high switching frequency. Therefore the size and the weight of the Buck-Boost inductors can be reduced. No galvanic isolation is required.

The optimum values of the inductors were found to be about 50µH (weight < 0.5kg).

2.2.2 The storage device

The main characteristics of the storage device are:

- Nominal voltage: 100V.
- Stored Energy: 44 kJ.
- Maximum energy used: 25 kJ
- ESR: 0,13 Ohms
- Capacitor: 8,75 F (370F per cell)
- Number of cell: 40.
- Mass (package and electronic balancing included): 3,4 kg.

The estimated weight of the ultra capacitor bank is 2,4 kg for 45 kJ. If we include the package and electronic balancing, the weight could reach 3.4kg.

For extended lifetime reason, cell voltage shall not decrease fewer than 50% of nominal voltage, thus limiting the available energy.

In terms of lifetime, current technologies have demonstrated a 1000 h – 100A discharge capability at 60°C, with a loss of capacitor less than 15%. This figure allows 350 000 cycles.

2.2.3 The active rectifier

The active rectifier is the local sub network main power supply unit ; its main features are:

- AC side: 230 V 3ph 360 – 800Hz.
- DC side: 270 V – 340 V
- Power: 4 kW typ –5,5 kW peak
- Efficiency requirement: 95%
- Estimated weight: 6 kg
- Fail-safe protection at the output
- Reliability: $\lambda \approx 0{,}5.10^{-5}$ F/FH

2.3 Control

The controls of the active rectifier and the bi-directional converter are segregated.

The active rectifier controls the DC bus voltage (voltage mode control), while the bi-directional converter is engaged if the load power exceeds a predefined threshold (*i.e.* 1.5kW one Fig. 2).

When the load voltage is lower and the load supplied current higher than predefined thresholds (resp *Vloadth*, *IloadM*), the current loop of the bi-directional converter will be activated.

The excess amount of current is thereby the input current of the boost converter loop. In that mode, the converters work in parallel.

The active rectifier works in voltage mode control, and the bi-directional converter works in current mode control.

In Buck configuration, the Bi-directional converter's current loop will allow energy recovery in the storage device, either from the load side in the gear extraction mode, or from the active rectifier in the pre-charge mode. The latter mode occurs when the current supplied to the load is zero or negative.

In that mode converters are serial combined.

The energy recovery from the load side occurs if the load voltage is higher than the related threshold and the active rectifier does not supply current anymore.

The different working modes are activated by a state machine control (Fig. 4).

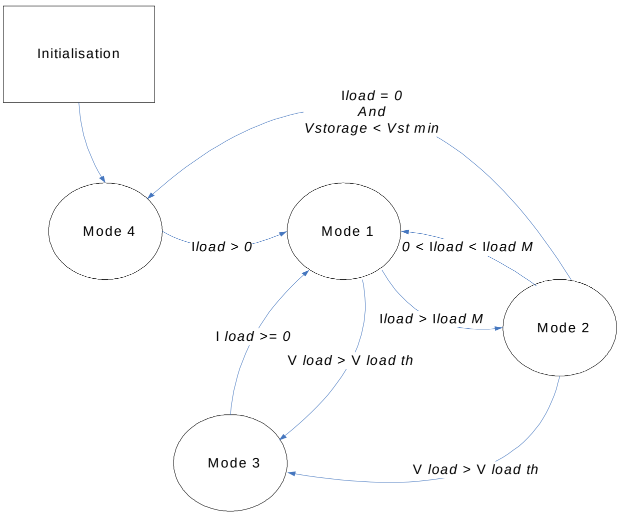

Fig. 4. Functioning modes and conditions of transition

The mode's descriptions are the following:

- Mode 1: Active rectifier sources power to load (voltage mode) control
- Mode 2: Active rectifier and Energy storage converter source power to load
- Mode 3: Energy storage sinks power from load
- Mode 4: Active rectifier sources power to Energy storage (bi-directional converter in buck mode)

3. Power profile of typical drive architectures

In electrical landing gear and braking system, the drives act sequentially and ensure the functions:

- Gear door opening and closing
- Gear retraction and extension
- Breaking requires power peak cycles during 50s (Main landing gear).
- Wheel steering (Nose landing gear)

In order to achieve the reliability data and be compliant with the safety analysis, each electrical drive needs to be redundant.

The electrical architecture is represented on the Fig. 5.

Redundancy modes include both "Active – Active" mode and "Active – Standby" mode.

In "Active –Active" mode, the two electrical channels are working in parallel, each providing half of motor power. In Active-Stand by mode, the overall power is supplied by one of both channels.

In case of failure of one channel, the second one is activated either at full power or at half power (active-active mode, if de-rating on movement duration is acceptable).

The energy storage could be designed with the same redundancy organization, with the possibility of crossing the peak power supply from one channel to the other.

Let us consider the main landing gear retraction phase as the most energy-consuming phase:

In the active-active mode, the needed energy is about 15,5 kJ. We assume the energy device is fully charged before the take off phase.

In the extension phase, the recovered energy from the drives is about 14,3 kJ and can be used to charge back the ultra capacitors.

For both main gears to be driven, the required energy during the retraction phase is 24,5 kJ peak, and the energy returned back from the actuators is 29 kJ peak. That will allow the storage energy device to recover its charge. The excess of energy will be dissipated in the drive brake resistor.

Whatever the scenario, the simple conclusion is that a large part of energy is recovered in the storage device. Therefore, the last one remains available for its main purpose: back up braking.

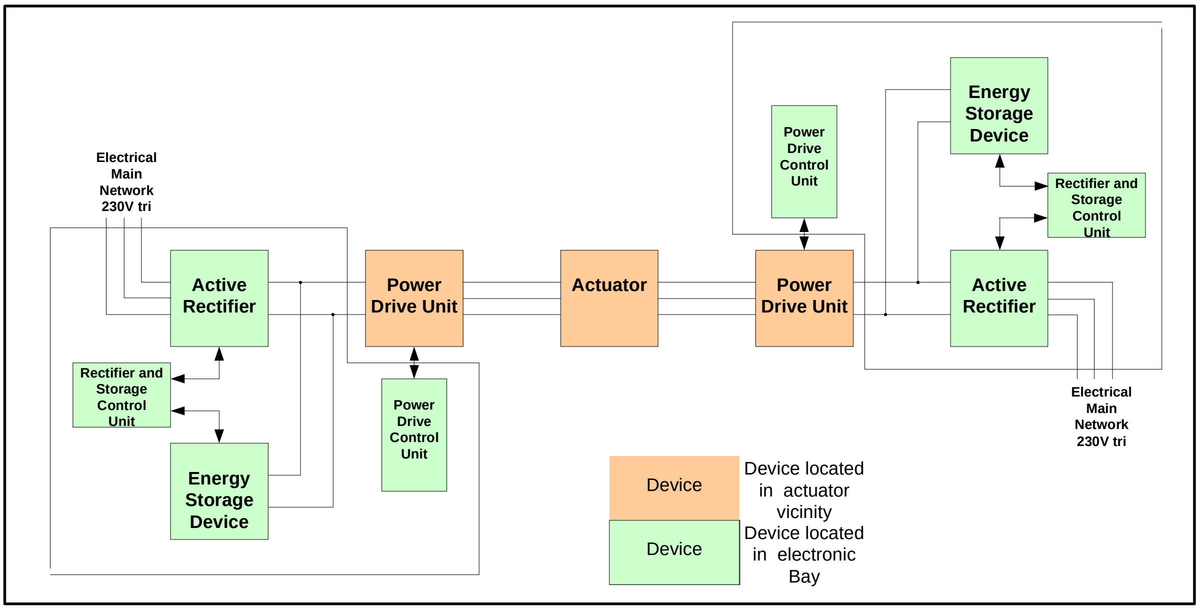

Fig. 5. Electrical architecture for one main landing gear actuation

4. Simulation results

The product depicted in part 2 will comply with the electrical landing gear drive in the Active – Active mode stated in part 3.

The most demanding peak energy is related to the gear retraction phase.

The voltages and the currents are represented on the Fig. 6. These waveforms concern the retraction mode. In this mode, the bi-directional converter is in the Boost configuration. The bottom figure illustrates the correct interleaving of the boost inductors.

The demanding energy for the back up braking is 25 kJ. This energy is to be supplied by the ultra – capacitors bank.

Therefore, the goal is also to be sure that after being used in the retraction phase, the ultra-capacitors will recover enough energy. By this way, the back-up mode would be available.

The Fig. 7 shows, the battery behaviour in recovery mode during 3sec. The bi-directional converter is then in step-down (Buck) mode.

The sequence in Fig. 8 shows the power to be delivered or sunk by the storage device, in time in both concatenated phases (a), the current flow in and out the storage device (b), and the voltage across it (c).

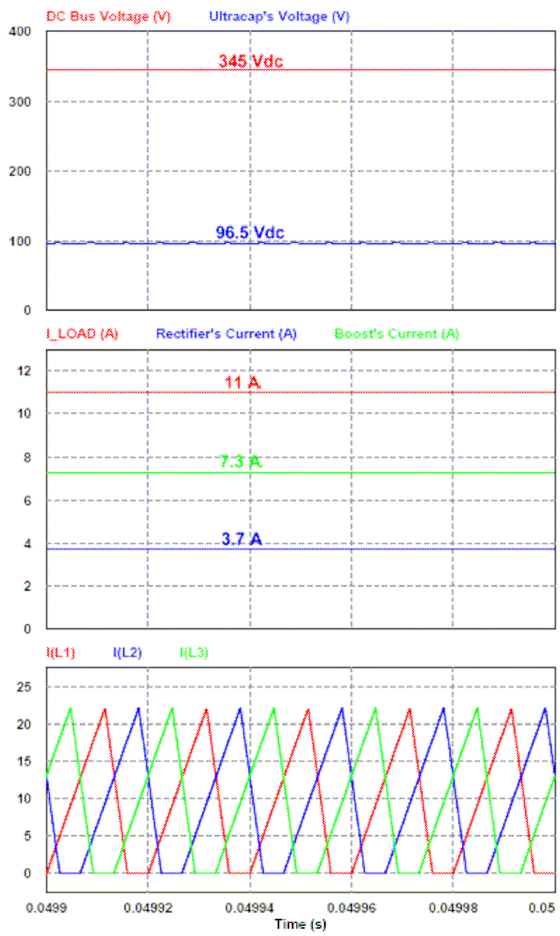

Fig. 6. DC Bus and ultra-caps voltages (top); currents mean values for the load, the boost converter and the active rectifier (middle); boost inductors currents (bottom).

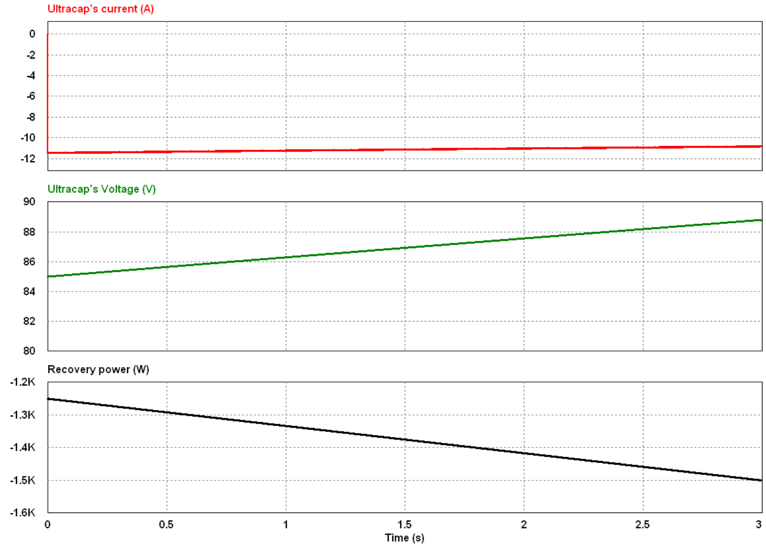

Fig. 7. Storage device behavior in recovery mode

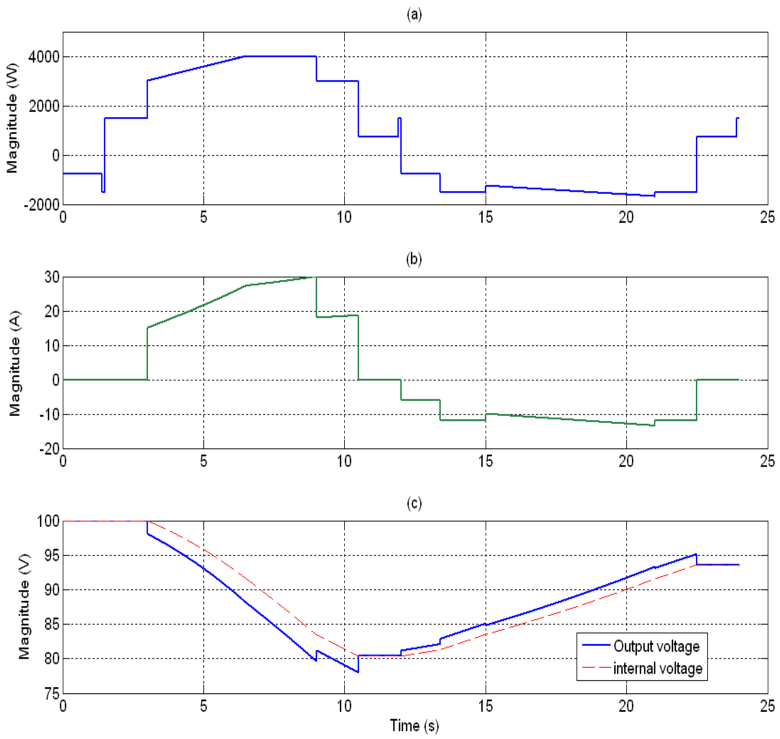

Fig. 8. Load profile and storage device behavior

5. Conclusion

In the frame of More Electric Aircraft challenge, a local electrical subsystem incorporating an energy storage device has been presented. The storage device is used mainly for backup purpose.

A working mode has been detailed, allowing the energy storage to smooth the transient power requested by the loads. This led to:

- Stress reduction at active rectifier side and electrical drive side.
- Charge and discharge current control at energy storage device side.

When applied on landing gear and breaking system, as an example, the power recovered during extraction phase could balance the major part of the power spent during retraction phase.

Two architectures can be derived depending on the use of the energy storage device:

- A: Use for back up only
- B: Use for back up and power transient delivery.

The main benefits of B versus A are:

- Electronic converters reliability improvement: the active rectifier does no more sink the whole required power but only 40%, therefore its reliability is increased.

- The power generation and distribution system will provide no more the transient power. Thus quality of the electrical network will be improved.

- Energy recovery during the reverse phase of actuator kinematics, reducing the size of the braking resistor included in the electronic drives.

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