Some Problems Concerning Power Management System for More Electric Aircraft

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***Abstract*— This paper aims to present some problems concerning the electric power management systems of aircraft. In the first sections are presented some converters topologies used on aircraft, principles and digital control schemes for these converters. In the next sections there are presented architecture principles of power management systems using these kinds of converters. Converters are mainly used to adapt the power parameters of the on board sources to the aircraft consumers necessities. On More Electric Aircraft, with VSVF generators, these converters are used to feed the aircraft power buses, each consumer being coupled to the corresponding power bus. Taking into account the great importance of some consumers, it is necessary to ensure its feeding even a part of the on board power sources fails. In this purpose one use by one hand redundant power buses and by other hand the electric power management systems. These systems ensure both the coupling of the power sources to the power buses according to the power necessities and also commute the consumers feeding between the buses using different control strategies. The control strategies consider the available power sources at a time, the consumers it has to be fed and priority order of the consumers.**

I. INTRODUCTION. DIFFERENT CONVERTER TOPOLOGIES

A total number of five different types of DC to DC converters are known into literature, which can increase or decrease the amplitude of the output voltage for DC current and/or to invert polarity. The output voltage control and regulation it's made by width modulation of the impulses (PWM – pulse width modulation). This width modulation is used in both DC-DC converters and DC-AC converters [1]-[14].

The block schema of a Buck Converter is presented into figure 1. The switch from figure 1 is connected to the input voltage V_g; the switch output voltage $v_s(t)$ is equal to V_g when the switch is on position 1 and equal to 0 when the switch is on position 2. The switch position is periodical, thus $v_s(t)$ has a rectangular wave form of period T, and the duty cycle of the impulse $D=\frac{t}{T}$, $D\in[0,1]$ [1]-[11].

The switching frequency f is equal to $1/T$. In practice this switch is made using semiconductor devices like: MOSFET power transistors, IGBT, BJT and thyristors. The commutation frequencies are up to 200 kHz, depending on the switching speed commutation of the semiconductor devices and the output power.

The functioning of the switch modifies the DC component of the output voltage, the waveform of the DC component is given by the average value and some ripples can appear. The average value of $v_s(t)$ (Fig. 1) is given by the following expression [1]-[4]:

$$V_s=\frac{1}{T}\int_0^T v_s(t)dt=D\cdot V_g \quad (1)$$

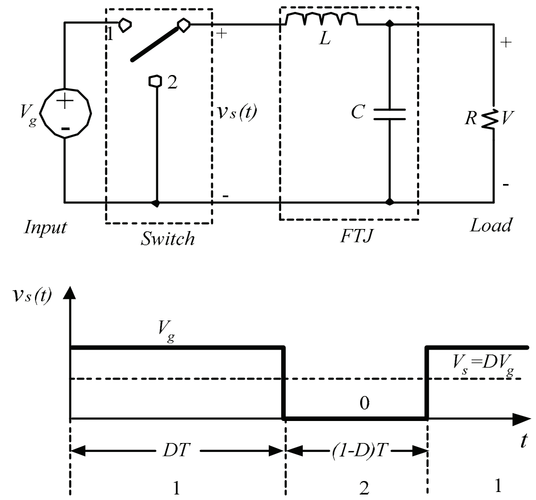

Fig. 1. Buck converter.

The Buck converter reduces the DC component voltage by a factor equal to the value of the duty cycle D, because $D\in[0,1]$, the V_s voltage is smaller or equal to V_g.

The dissipating power into the ideal switches is equal to 0. When the switches contacts are closed, the contacts voltage is equal to 0 and thus the dissipating power is equal to 0. When the switches contacts are open, the current is equal to 0 thus the dissipating power is equal to 0. Thus, the ideal switch is capable to modify the DC component without dissipating power. The $v_s(t)$ waveform contains unwanted coupling frequency harmonics, and for removing those harmonics we will use a low-pass filter, so the output voltage of the converter $v(t)$ is equal to the DC component $V=V_s$. The converter from figure 1 contains a low-pass filter LC. The resonating frequency of the filter is

$$f_0=\frac{1}{2\pi\sqrt{LC}}. \quad (2)$$

The conversion rate in stationary state $M(D)$ is defined by the DC output voltage V and input voltage V_g thus

(3)For the Buck Converter, M(D) is

$$M(D)=\frac{V}{V_g}. \quad (3)$$

For the Buck Converter, M(D) is

$$M(D)=D \quad (4)$$

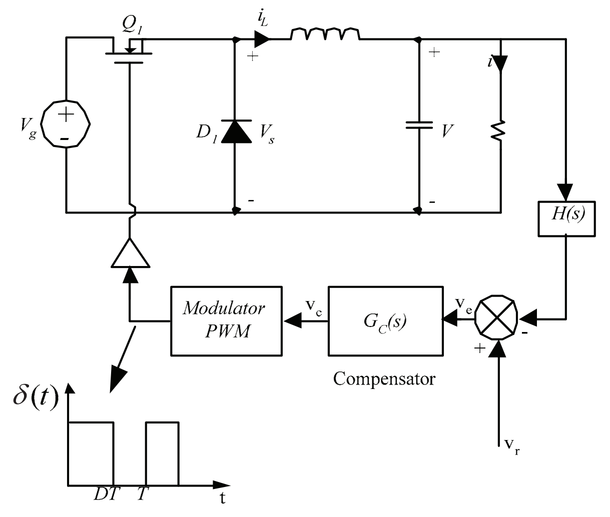

Fig. 2. The block schema of a Buck converter in close loop [11].

Figure 2 presents a way of building the switch into the Buck Converter using a MOSFET power transistor and a diode [2]. The power transistor is commanded through an electronic circuit by the logical signal $\delta(t)$ for its conducting (ON) and blocking (OFF) state. When $\delta(t)$ is greater, for $(0 < t < DT)$, then the Q_1 transistor is ON, the drain-source voltage is insignificant. Thus $v_s(t)$ is approximate equal to V_g and the diode is inverse polarized. The inductor positive current $i_L(t)$ passes through the MOSFET transistor. At $t = DT$ moment, $\delta(t)$ is equal to 0 (on falling), and commands the transistor to block itself, the $i_L(t)$ current passes through D1 diode which is direct polarized, and $v_s(t)$ is approximately equal to 0. The $i_L(t)$ current stays positive and D1 diode is ON for the rest of the commutation period.

The $v(t)$ output voltage is function of D duty cycle; so we can design a voltage control system using a reference voltage v_r. Figure 2 presents a block schema of a converter in close loop. The output voltage is measured using a voltage divider and it's compared with a reference voltage v_r. The error signal which results $(v_e = v - v_r)$ is applied to a controller. The controller output voltage $v_c(t)$ is applied to a block called modulator (pulse width modulation – PWM). The modulator produces a waveform (δ) which commands the Q1 transistor.

The duty cycle of this wave form, D is proportional with the control voltage $v_c(t)$. Design a control system leads to modification of the duty cycle D automatically, thus the output voltage of converter v traces the reference voltage v_r and it is essentially independent of v_g variations or the loads current.

Another variant of the converter is the Buck-Boost converter, which has some transformation ratio, it can switch polarity of the source, and it can increase or decrease the voltage amplitude. The Cuk converter contains inductors in series with its inputs and the outputs. The switch alternately connects a capacitor to the input and inductors to output. The conversion ratio is identical with the one of the Buck-Boost Converter, but it performs reverse source polarity. The SEPIC Converter is similar to the Buck Converter; it can either increase or decrease the source amplitude, but it does not reverse the source polarity. The conversion ratio is $M(D) = D / (1\text{-}D)$.

II. DIFFERENT CONTROL SCHEMAS FOR DC TO DC CONVERTERS

In essence, to command converters and to obtain the desired output parameters it is necessary to generate impulses that have a stable frequency and to modulate these pulses using PWM. The control of the converter can be analog or digital. For analog control it is used an oscillator, which generates the switching frequency (see figure 3), and then the variable linear voltage is generated with the same frequency of the oscillator. A differential amplifier determines the difference between the real and the desired voltage, and then this is processed with a controller, most of the times a P.I. controller. The PWM pulses are obtained using a comparison between the variable linear voltage and the controller output voltage.

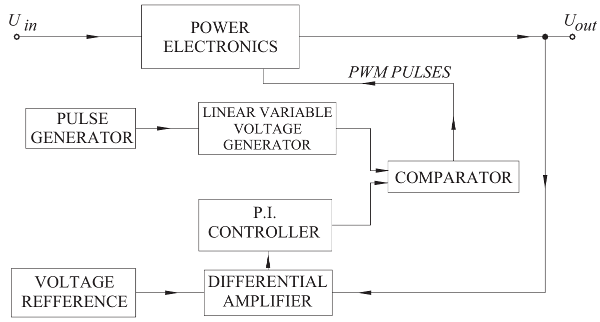

Fig. 3. The analogic version for command schema of a DC to DC converter.

When the blocks are realized with discrete components, there are needed a lot of components to realize the blocks from figure 4. There are special integrated circuits which incorporate the entire control schema of the converter, but these have small possibilities for modifying the output voltage within the users' needs.

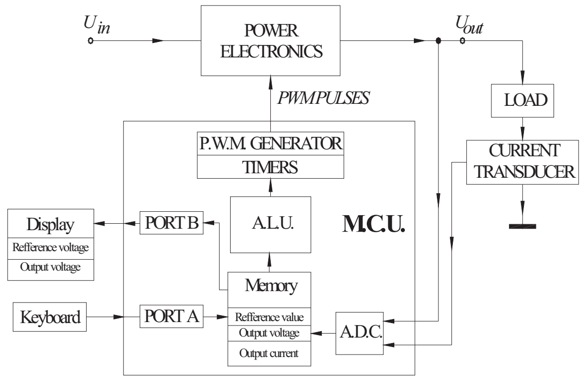

Fig. 4. Microcontroller command schema of a converter.

A more flexible alternative is the use of a microcontroller to command the converter. Using its timers it can be done both the switching frequency and also PWM of the output pulses. Because we're talking about digital control we don't need any more the reference voltage. This is integrated into the control program as a numerical value which is then compared with the output voltage using the analog-digital converter (ADC) of the comparator. The reference voltage may be fixed by the program, in which case one cannot make adjustment, or can be read from a keyboard and can thus obtain an output voltage desired by the user. Converter control scheme in this case is shown in figure 5.

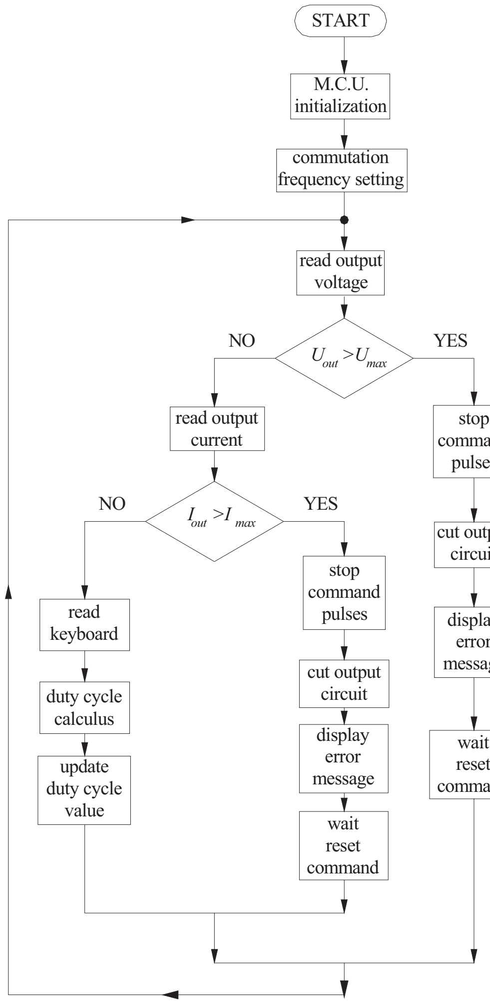

Fig. 5. Digital control algorithm of the converter.

For permanent monitoring of its functionality one may use a LCD display which shows the desired voltage and the real output voltage. Also, using a microcontroller we can implement the overvoltage and overcurrent protection system. When the algorithm detects the exceed of admitted limits, the PWM pulses are blocked and converter is stopped. After detecting one of the abnormal conditions, an error message is shown on the LCD and then the converter waits to be reset.

III. Multistage Converters

On board AC or DC generators feed with electrical power the corresponding AC and DC consumers and the power conversion systems such the Transform-Rectifier Units (TRU), DC to DC converters or DC to AC inverters.

One problem of the static power converters of the aircraft is the output voltage ripples increase with the load, and so the power quality on board gets worst. Another important aspect concerning the functioning of the static power converters is the efficiency increase with the duty cycle of the control pulses. The duty cycle is function of conversion factor and the load. At small duty cycle the efficiency get worst and increases at high duty cycles. That means when the load decreases also the converters efficiency decreases. So it is suitable to maintain the duty cycle as constant as possible and near the optimum value.

A solution to this problem is to use instead a big, simple converter, a multistage converter (see figure 6). This is in fact composed of many smaller converters disposed in parallel. The main advantage in this situation is the possibility to make an interleaved command of each smaller functioning stage. Each MOSFET is commanded with a $2\pi/n$ phase shift, where n is the number of functioning stages. One obtains by this way an important ripples diminishing. Furthermore, taking into account the dimensions and weight of the power circuit components increase substantially with the rated power, it is possible the entire ensemble to be less heavy and less bulky relative to one single powerful converter. The reliability of the distribution system also increases. If one stage fails, the other stages may work further. If one powerful converter fails, all de consumers are dropped. In [15] is presented one study concerning the possibility to reduce weight and volume of the conversion system by using many smaller converters. One assesses also the possibility to improve by this way the efficiency of the conversion system. By successive putting in operation of supplemental stages once the power necessity to the bus increases, one can maintain all the stages at a duty cycle value near to the optimum. The converter efficiency is optimized and will less depend on the power conveyed by the bus.

A difficulty in case of interleaved multistage converters is the necessity to modify each converter phase shift once more stages are entered into the circuit. The MOSFETs command of the interleaved converters presented in [16] are realized in analogical form, using monostable circuits to obtain the phase shifts. This version do not allows modifying the phase shifts once supplemental stages are on. A viable variant is to use a microcontroller to command the MOSFETs. By software one can manage at once the number of the functioning stages and the phase shift for each stage.

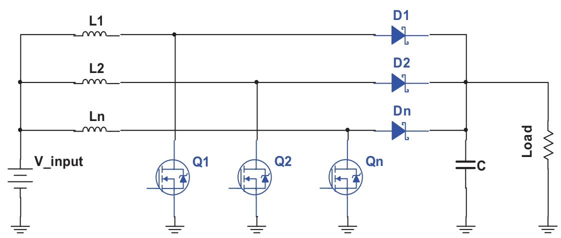

Fig. 6. Multistage converter.

The microcontroller command make easier the multistage converter integration into an intelligent power management system, as it is presented in figure 7. By the side of the converter commands management, the microcontroller can receive from the power management system information concerning the power request on the bus and can transmit to the power management system information concerning its healthy functioning. The communication with the power management system can be implemented on the aircraft data buses.

IV. Implementation of the Multistage Converters in Power Management Systems

Taking into account the necessity of a high reliability for the on board power supply system, the distribution systems are provided usually with two main power buses and one emergency power bus in the DC power system.

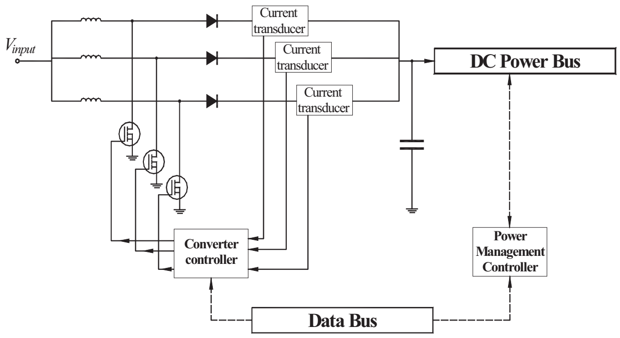

Fig. 7. Intelligent power management system.

The main power busses are supplied by the on board generators driven by the engines. The emergency power bus is supplied by the on board batteries, auxiliary power unit (APU) and super-capacitors if the power system is equipped with these devices. A simplified architecture of an electric power system is presented in figure 8 [17]. It contains two AC main power buses fed by the main generators. For the emergency cases the APU is equipped also with a AC generator which can be connected to any AC main power bus.

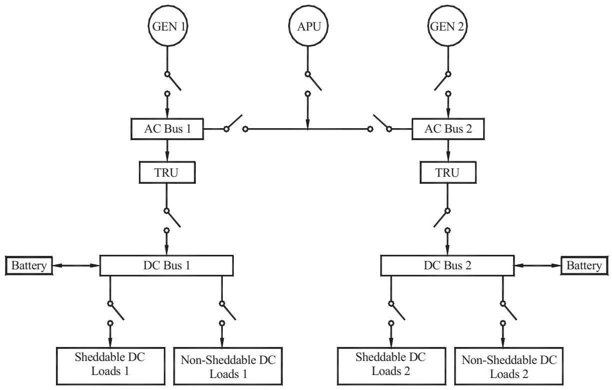

Fig. 8. Simplified diagram of an electric power system [17].

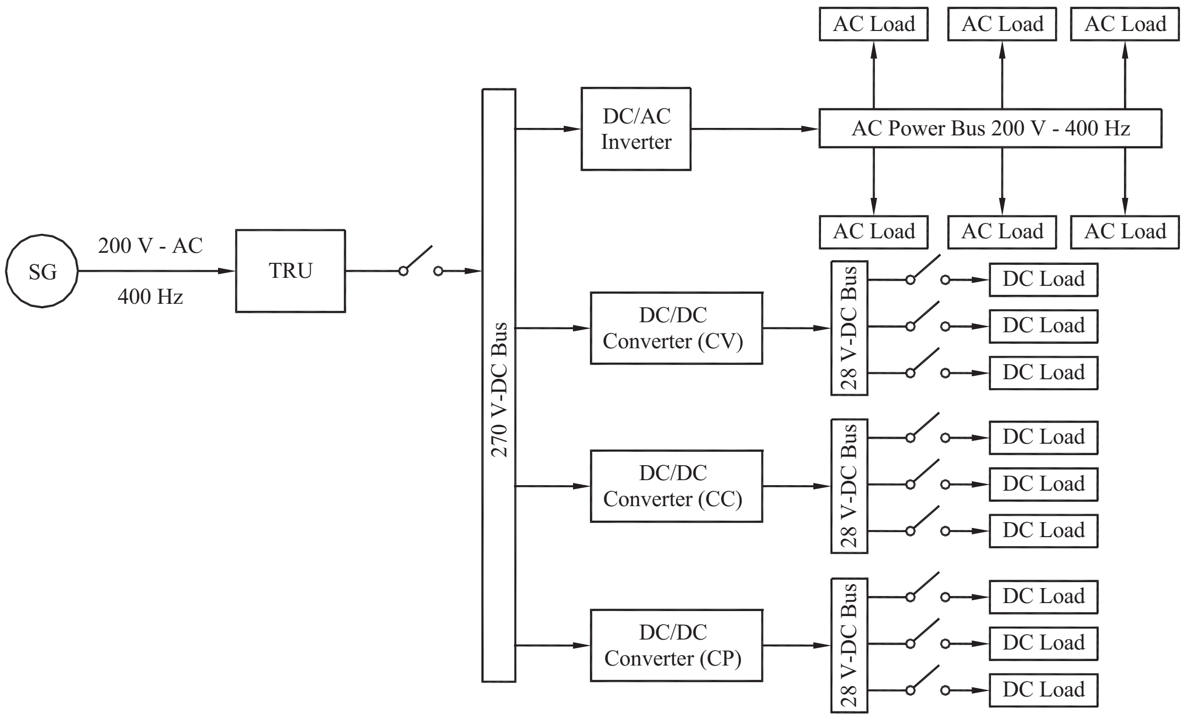

Fig. 9. Aircraft electric power system (AEPS).

Another architecture for the electric power system of a passenger aircraft is presented in figure 9 [18]. It contains the main power source, the starter/generator (SG) which supply 200V AC with variable frequency between 400 and 800 Hz, the transformation-rectifier unit (TRU) which obtains 270 V DC at its output and feed the main power bus, many DC to DC converters in order to obtain the 28 V DC for the secondary DC bus and one inverter for the 200V AC bus, with constant frequency 400 Hz.

In figure 10 is presented an architecture for de Advanced Aircraft Electric Power System (AAEPS). The main power sources are the generators with switched reluctance (SRG), used as starter in the start sequence. The energy fed by the SRG is processed by a DC to DC

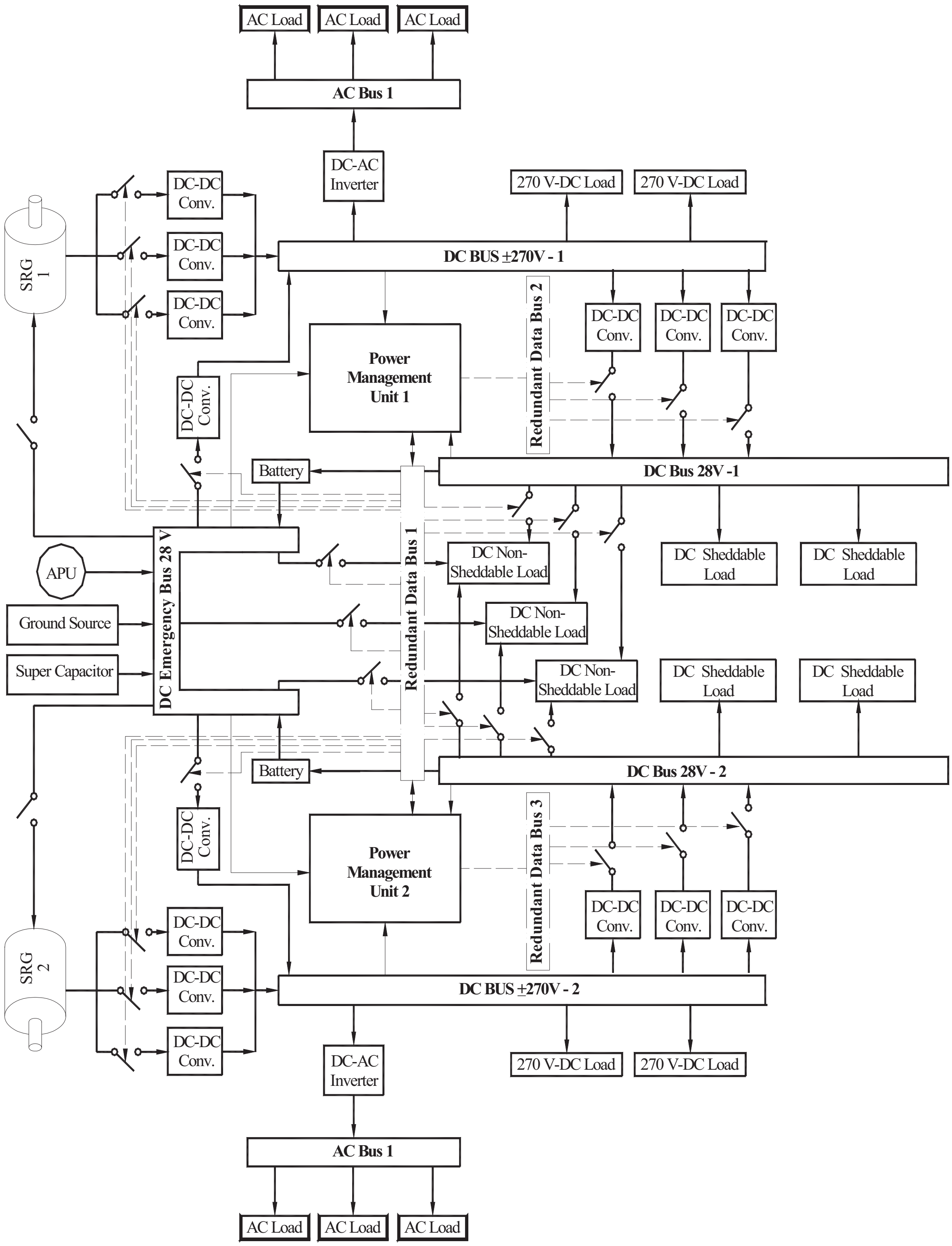

Fig. 10. Advanced aircraft electric power system (AAEPS).

converters ensemble and is sent to the ±270V DC main power buses. The number of the converters used at the time depends on the power request on each bus. One can use either several separated converters, either a multistage converter, like figure 7.

The ±270V DC main power buses feed mainly the command surfaces servo-actuators which are electro-hydrostatic actuators (EHA) or electro-mechanical actuators (EMA) on more electric aircraft (MEA). For smaller DC loads there are provided the 28V DC buses. A part of these loads are vital importance for the aircraft and it has to be fed regardless any failure appeared in the electrical power system: flight control computers, aerodynamic central, data buses drivers and so on. In order to ensure its permanent feeding there are provided two 28V DC buses powered by the ±270V DC main power buses through several converters which can be also separated or multistage converters. Further, it is provided the emergency power bus which is fed by the APU, ground source, super-capacitors and batteries. The vital importance loads can be fed by this bus if the other two 28V DC buses fails. The DC loads with less importance are connected direct to one of the 28V DC buses. Its loss of feeding does not threat the aircraft safety. Between the vital loads and the low importance loads are also others loads which ensures the good flight. They are ranked on different priority levels. Typically they are fed by one of the power buses, but in failure cases, the power management system can decide to interrupt feeding some of them. The order to interrupt feeding is set by the load priority level. AC loads are fed by AC buses powered by DC to AC inverters. They receive power from the ±270V DC main power buses. In order to simplify the drawing, in figure 10 it is not presented how the power management system act upon these loads.

The emergency power bus is responsible also with the starters feeding from the batteries, ground sources or from the APU. In this case the SRG are in motor regime. If the main SRGs fail the ±270V DC main power buses can be energized by the emergency power bus by several converters.

The converters management (both those power the ±270V DC main power buses and 28V DC) is performed by two redundant Power Management Units (PMU). Its receive information concerning the voltages and the currents on the busses at the time and depending on its evaluate the power request and the bus health an also switch on the necessary number of converters (or stages of a converter). If a converter or stage fails it can be replaced with another one. Also, the PMU manages the vital importance load relocation on the functioning buses, cut order or relocation of the non-vital loads in failure case.

PMUs are redundant and communicate by the data buses. The switches on/off commands to the loads and to the converters are sent also by the data buses. The converters health information is sent to the PMUs also by the data buses.

V. Conclusions

DC to DC converters are widely used in the automotive industry in general and on aircraft in special. Its allow to adapt the energy parameters provided by the generators to the parameters required by the standardized loads. According to the energy parameters modification, different converters topologies are used. All these topologies are well suited to be digitally commanded by a digital control system. Unlike the analogical control system, the digital one offers a higher flexibility and allows the implementation of advanced control strategies. Further, a digital control system based on a microcontroller permit the converter to communicate on the digital buses of the aircraft. By this way one can develop digital power management systems for aircraft, their actual evolution being very fast. The central element of the power management system is the Power Management Unit which receives information concerning the power requirements at the moment and buses health, it send commands to the generators control systems, to the converters and load switches in order to maintain the power balance in the aircraft power system.

Multistage converters are a solution in the power management systems. They provide a higher reliability with respect the high power single stage ones. Also, as it is stated in different works, its can provide a weight and volume saving, which is very important on aircraft. Using digital control for this kind of converters, one can use interleaved control the functioning stages. By this way the ripples on the DC buses diminish severely and the power quality is improved.

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