Modeling, Ageing and Health Monitoring of Metallized Films Capacitors used in Power Electronics Applications

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***Abstract*— Capacitors are one of the most widely used forms of electronic components. A careful choice of a capacitor for a particular application and an adequate installation in the circuit will assure a good life service. Since half of the electric equipement failures are caused by capacitors degradation, interest for capacitor "Health monitoring" function reveales to be very strong. Eventhough metallized polymer films capacitors proved to be more reliable components than cheap electrolytic capacitors in aerospace applicatitions, given the risk of infalamation in the case of a default, improving the dependability of these components and monitoring their health conditions are fundamental to the availability of systems in which they are employed. Two approaches should be considered: reliability and diagnostic. The major concern in the 'reliability' process is to monitor and analyze the degradation modes which requires knowledge of in-service use and life cycle environmental and opperational conditions. Diagnostic, through adequate measurements must ensure analysis of the component aging, an essential step to predict tolerances and capacitor performance and its remaing lifetime. The final interest has been growing in monitoring the ongoing health of the system in order to predict failures and provide warnings in advance of catastophic failure. Thus, the goal of these studies is to provide a basic understanding of the degradations modes of metallized films capacitors and to develop new techniques of health monitoring to enable pronostics for power electronics systems.**

***Résumé*— Compte tenu de leur capacité à stocker de l'énergie électrique sous forme de charges électrostatiques, les condensateurs sont utilisés dans de nombreuses applications de l'électronique de puissance. Le choix d'un condensateur bien adapté au système peut s'avérer primordial car il est responsable, dans certaines applications, de la majorité des défaillances et donc d'arrêts intempestifs de systèmes très critiques. Malgré que les condensateurs à films métallisés s'avèrent des composants plus fiable que les condensateurs electrolytique dans les applications aeronautiques, mais compte tenu du risque d'inflammation en cas de défaut, l'amélioration de la sureté de fonctionnement de ces composants et la surveillance de leurs états de santé sont donc fondamentales pour la disponibilité des systèmes dans lesquels ils sont employés. Deux approches en interaction forte afin de concourir à l'objectif d'amélioration de la sûreté de fonctionnement de ces composants, sont considérées : la fiabilité et le diagnostic. La préoccupation majeure dans la démarche 'fiabilité' est de suivre et d'analyser les défauts et le vieillissement des composants. Le diagnostic par l'intermédiaire de mesures et de méthodes adéquates doit assurer la détection des pannes ou du vieillissement des composants ; la finalité recherchée étant de prévoir les défaillances grâce à l'application d'une maintenance prédictive. Par ailleurs, l'analyse du vieillissement des composants est primordiale pour prévoir les tolérances et les performances du condensateur ainsi que sa durée de vie. Les axes majeurs de cette thèse s'avèrent être l'identification des mécanismes et modes de défaillances des condensateurs films métallisés d'une part et la surveillance de leur état de santé d'autre part.**

I. INTRODUCTION

A. Project background

Aerospace industry is slowly moving towards a more electric airplane, where electrical systems are gradually replacing hydraulic technologies. Electrical technology offers some strong advantages such as cost, efficiency, power on demand as well as relative ease of maintenance. The inverter constituting the subject of our study (cf. Fig. 1), is not dedicated to a particular application. It can be placed into the airplane cabin subjected to well known environmental conditions (electrical, thermal), as well as outside the plane (wing for example) which imposes more stringent conditions of use (humidity, electromagnetic interferences …) not known accurately. Our inverter is supplied with an HVDC network +/- 270 V, which requires an AC power generation, rectification and filtering blocs.

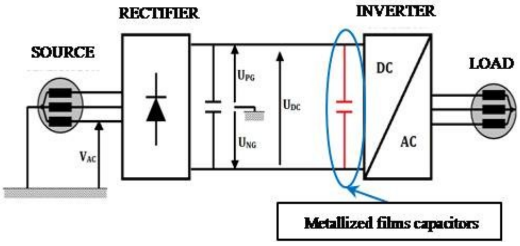

Fig. 1. Scheme of the inverter under test

Our work focuses on the metallized films capacitors used as DC-link capacitors.

B. *Why the choice of metallized films capacitors?*

Capacitors are widely used in power electronic applications and the need nowadays is increasingly growing to have more robust devices, compact and able to withstand more stringent conditions of use. Although each type of capacitor has its own limitations, advantages and disadvantages, the films capacitor has the blend of proprieties that make it well suited for these applications. Unlike electrolytic capacitors, plastic films capacitors do not require a given polarization and behave well under high current and voltage conditions. Metallized films capacitors are a very interesting alternative to electrolytic capacitors and present higher reliability, higher RMS currents and small capacitance change regardless of applied voltage. Metallized films capacitors have been used since the 1950's and were coveted for their abilities of self-healing; defects such as pinholes, embedded foreign particles or even micro flaws in the dielectric material can lead to a localized breakdown of the film. Such a breakdown event results in the discharge of a portion of the stored charge with the development of a sudden localized temperature and pressure build-up. During this intense discharge, a puncture is developed in the dielectric material and the thin metallization layer near the defected site is rapidly vaporized and blown away and the site becomes electrically isolated. Thus, metallized film capacitors can undergo a large number of breakdowns with as only visible impact a slight drift of its electrical parameters. Polymer films are the preferred materials of choice for capacitive energy-storage applications thanks to their high dielectric breakdown strengths, low dissipation factors and good stability over a wide range of frequencies and temperatures. The most common plastic used as dielectric are respectively the polypropylene (*PP*) and the polyethylene Tereftalate also known as polyester (*PET*). Capacitors using these two different materials as dielectric should be tested in order to determine the most reliable type for our application.

II. CHARACTERIZATIONS AND AGEING PROTOCOLS

A. *Temperature dependence*

Metallized films capacitors are components whose characteristics vary with temperature and have a measurable influence on the entire circuit behavior. The ambient temperature considered for avionic applications extends over a range of -40°C to 70°C (up to 85°C in the component). This temperature sweep should be taken into account within the limits of possible for the metallized films capacitors studies.

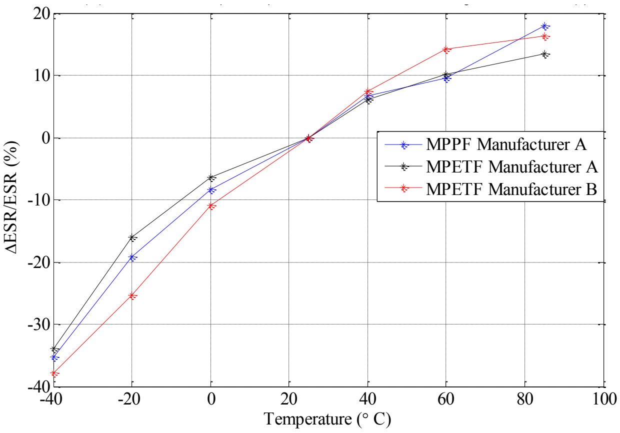

Fig. 2. Evolution of the equivalent serial resistor with the ambient temperature

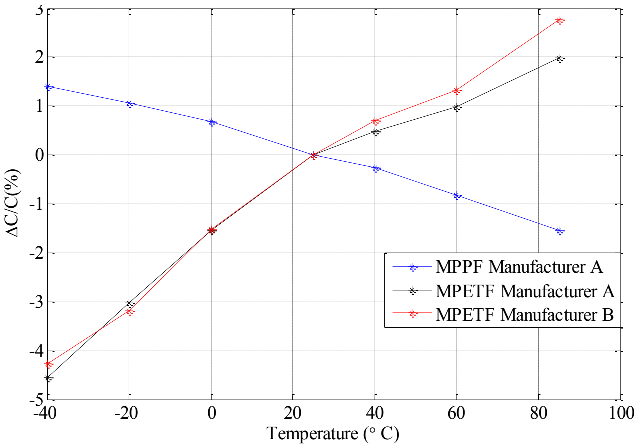

Fig. 3. Evolution of the capacitor capacitance with the ambient temperature

Fig. 2 and Fig. 3 show the evolution of the capacitor parameters with respect of the ambient temperature. It is of interest to note that as seen in Fig. 3, the capacitance do not behave the same according to the dielectric material that have been used. This difference is the mainly due to chemical composition of the material itself. Polymers are separated into two main categories, polar and apolar dielectric; *PP* belongs to the apolar type, while the *PET* belongs to the polar group.

B. *Ageing protocols*

Ageing protocols have been defined, and are listed as follow:

- 'Floating ageing', at fixed temperatures and voltages. This kind of tests will allow us to deduce the accelerating ageing factors in function of the ambient temperature and the applied voltage.
- 'Ageing through cycling tests' – High current. This test constrains mainly the connection 'electrode-schoopage' of the capacitor.
- 'Ageing by superposing a ripple current with a DC voltage'. This test aims to characterize the individual impact of the amplitude and the frequency of the ripple current on the capacitor lifetime. It also subject the component to similar constraints encountered during a normal operation.

C. *First Ageing Results*

The first ageing test (1,1.U_N-85ºC) was launched for both types of metallized films capacitors (*PP* and *PET*). The components of test were selected to have the same ratings (0.68 µF-630V, 1µF-630 and 15µF-400V) but whose type (PP, PET) and/or manufacturer are different.

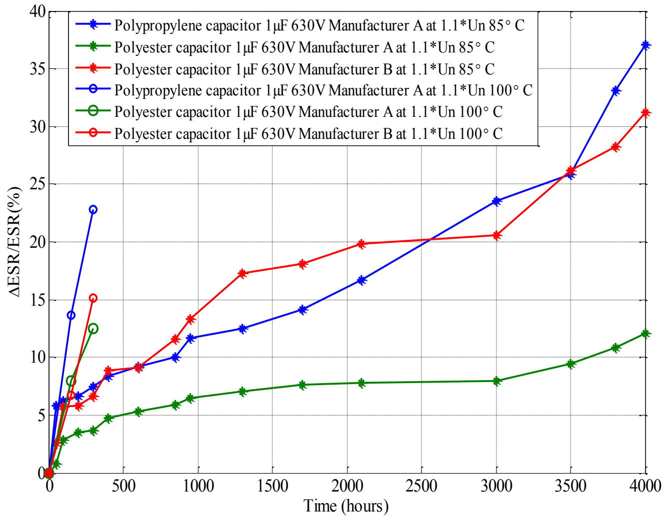

Fig. 4. Evolution of the ESR with ageing time

To study the influence of temperature and voltage on the lifetime of the capacitors, a second aging test was lunched (1,1.U_N-100ºC) for the types of cited previously. Fig. 4 and Fig. 5 show the evolution of the capacitor parameters in function of the ageing time. In fact, a capacitor is considered as inoperative when its equivalent serial resistance (*ESR*) reaches the double of its initial value and/or when its capacitance decreases of 20% from its original value. At this point, as seen in the Fig. 4 and Fig. 5, the ageing tests affect mainly the capacitor equivalent resistor; its capacitance remains almost constant. These evolutions are mainly due to the self healing properties of the metallized films capacitors as described in the previous section.

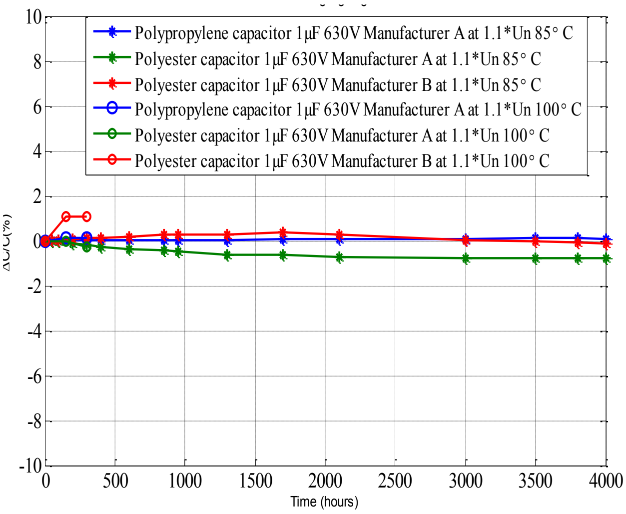

Fig. 5. Evolution of the capacitance with ageing time

'Ageing through cycling tests' and 'ageing by superposing a ripple current with a DC voltage' requires the use of a specific test bench and is described in the Fig. 6.

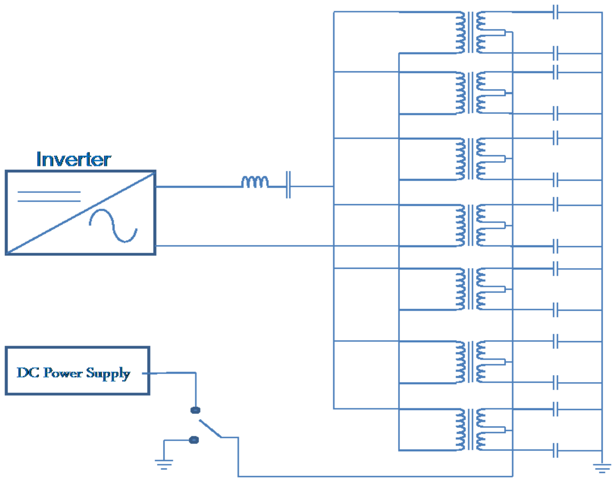

Fig. 6. Accelerated ageing test bench

This test bench is in the realization phase, and it should be operative at the end of July 2012.

III. METALLIZED FILMS CAPACITOR MODEL

Proper deign of metallized films capacitors requires an understanding of all parasitic parameters sources and their impact on circuit operation. Parasitic parameters could occur at low frequencies as well as at high frequencies and disturb substantially the behavior of the component. Many models have been developed in literature within frequency variation; Nyquist plot showed an imprecision in the parameters identification. Since the capacitor impedance is constituted of a real and an imaginary part, our proposed approach consists on applying the fitting algorithm on the complex expression of Z; Nyquist diagram reflects well this approach.

Two different models have been developed depending on the dielectric material that has been used. Fig. 7 and Fig. 8 present the models thus developed respectively for metallized polypropylene and polyester films capacitors.

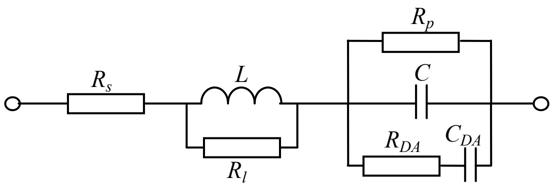

Fig. 7. Metallized polypropylene films capacitor model

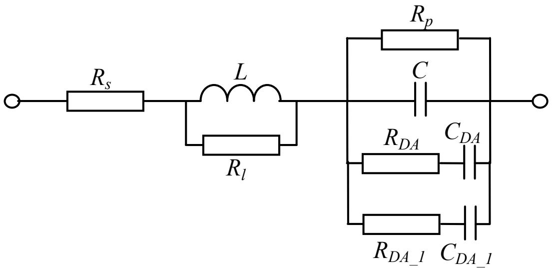

Fig. 8. Metallized polyester films capacitor model

Where R_s represents the contact and electrodes resistance; R_p is the parallel resistance taking into accounts the dielectric losses and leakage between the electrodes. *C* represents the nominal capacitance of the capacitor, while the inductance *L* in parallel with R_l represents the contribution due the skin and proximity effect. R_{DA}-C_{DA} refers to the dielectric absorption (DA) in the capacitor. DA is also called 'Capacitor Soakage, dielectric relaxation, or even residual charges, and is related to the remnant polarization trapped on dielectric interfaces, and is highly dependent on the dielectric material itself. In addition, some polarization of the dielectric may be due to physical charges accumulating on grain boundaries of polycrystalline materials, charges tunneling to the surface states at the plate interface, or the formation of electric domains. From an electrical circuit point of view, the extra polarization behaves like a set of additional series RCs time constants connected in parallel with the main capacitance. If a capacitor is charged for a long time and then briefly shorted, a residual voltage slowly builds up across its terminals and reaches a fixed percentage of its original value. This percentage referring to the DA of the capacitor can range from 0.02% for polypropylene up to 0.5% for polyester dielectrics. This phenomenon can affect in some cases the operation of some particular electronic devices and should be taken into account. Fig. 9 and Fig. 10 represent respectively the Nyquist diagrams of a metallized polypropylene (MPPF) capacitor 1µF-630V and a metallized polyester films (MPETF) capacitor 1µF-630V. The continuous line represent the experimental measurements, while the dots are the theoretical points calculated with respect to Fig. 7 and Fig. 8. The agreement between experimental points and theoretical plots is quite good which proves the accuracy of the model.

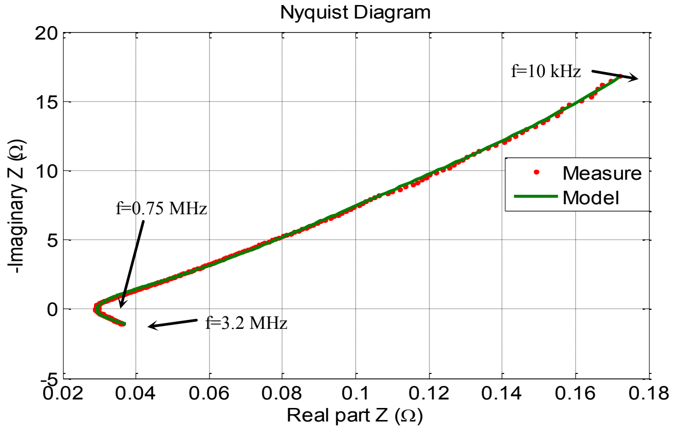

Fig. 9. Nyquist plot of MPETF capacitor 1µF-630V

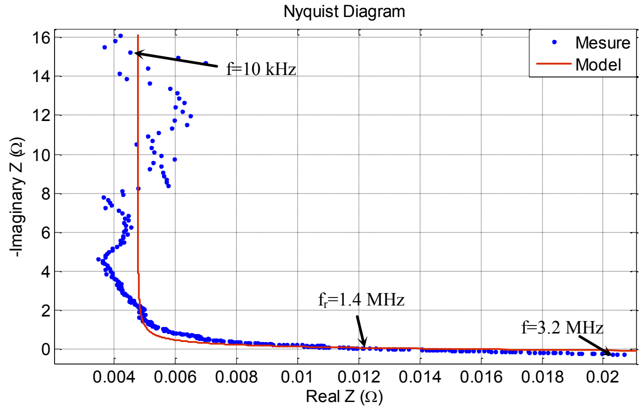

Fig. 10. Nyquist plot of MPPF capacitor 1µF-630V

IV. CONCLUSION AND PERSPECTIVES

Identification results obtained with the proposed approach induces an accurate and simple technique for determining the capacitor parameters for a wide range of frequency and temperature. The results obtained are quite satisfactory and give a good idea about the DA in capacitors. Different phenomena, not taken into account in the described model, could occur at high frequencies and disturb substantially the capacitor behavior. Modeling at high frequencies should be the next step to do in our future work. Furthermore, as the ageing tests progress, the capacitor parameters will degrade, and thus we would be able to analyze and determine the failure modes taking place into the component. Once the capacitors reach their end of life, we can determine the ageing lows of the metallized films capacitor, and integrate them into the health monitoring phase.

REFERENCES

[1] M. MAKDESSI, A. SARI and P. VENET, *'Modeling of Metallized Films Capacitor Impedance', IEEE – IECON 2012*