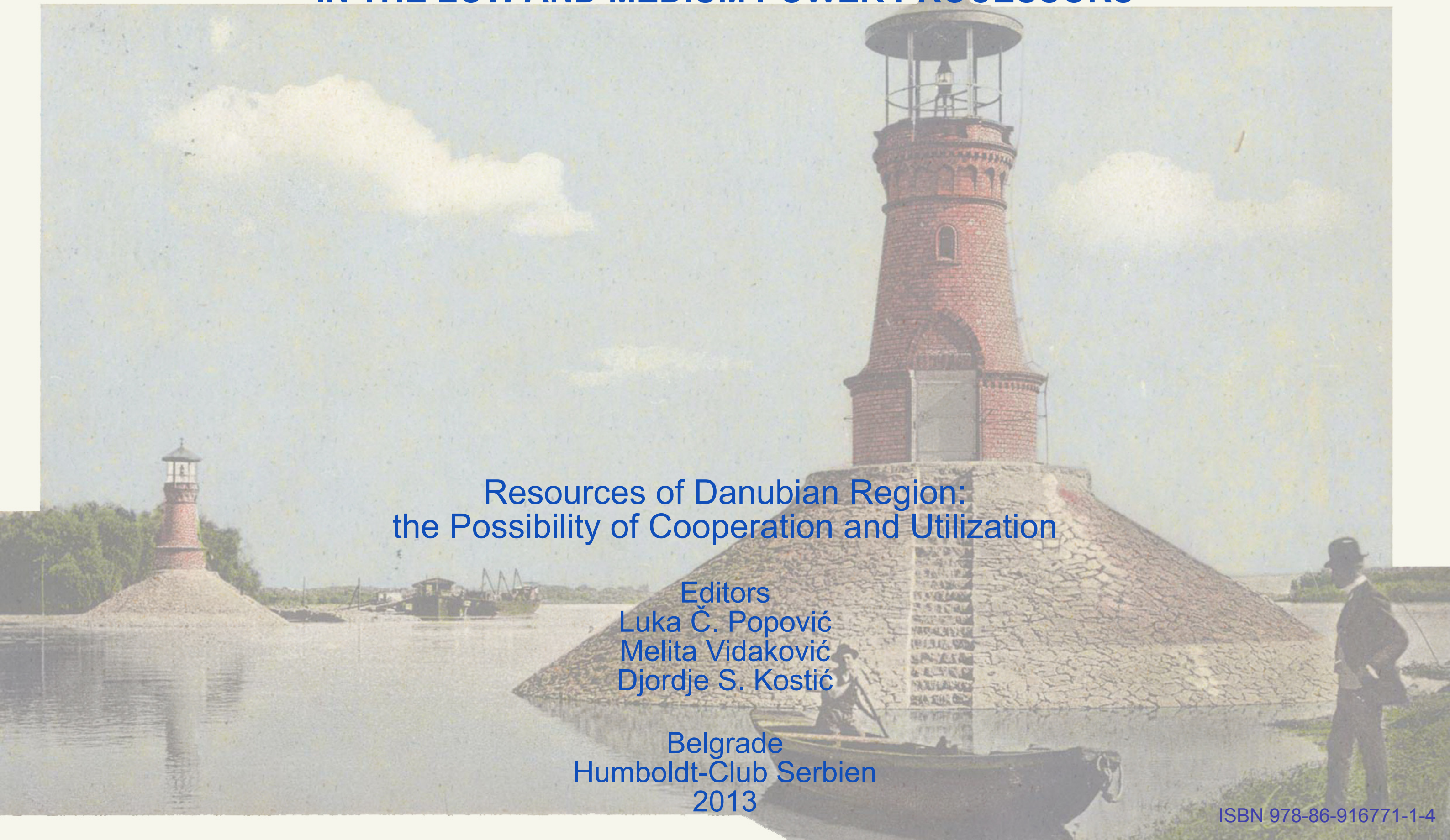
Richard Marschalko
Technical University of Cluj, Romania
Fodor Dénes
University of Pannonia, Veszprém, Hungary
László Kovács
TDK-EPCOS Szombathely, Hungary

COOPERATION IN THE DANUBE REGION FOR IMPROVEMENT OF ENERGY STORAGE ELEMENTS IN THE LOW AND MEDIUM POWER PROCESSORS



Resources of Danubian Region:
the Possibility of Cooperation and Utilization

Editors
Luka Č. Popović
Melita Vidaković
Djordje S. Kostić

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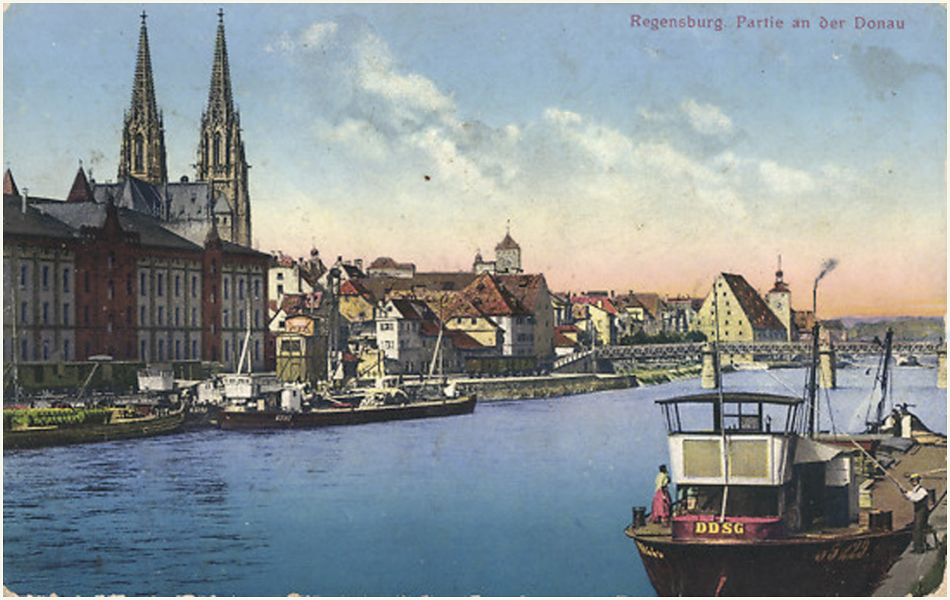

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Abstract. Aluminum electrolytic capacitors are applied in most of power electronic systems. The current shape of the DC-link capacitors in the PWM converters is similar to a bipolar square wave signal. The standards of Aluminum electrolytic capacitors doesn't contain electrical tests such kind of stress caused by the PWM control methods. The paper briefly presents the construction and structure of Aluminum electrolytic capacitors for power electronics and describes the actual generally applied test methods. Afterwards the real stress of the Aluminum electrolytic capacitors in PWM applications is investigated. According to the simulation results a test bench is proposed and presented.
Keywords: Passive electronic components, Aluminum electrolytic capacitor for PWM converters, Test standards for electrolytic capacitors, New square-wave current test.

1. Introduction

The power electronic conversion of the energy isn't possible only with the use of the power electronic devices. The presence of the reactive energy storage elements, coils or capacitors is conditioning the power conversion processes.

Unfortunately, a lot of papers supposes the passive electronic devices as ideal. As a result it is lost basic information concerning the operation mode of the converter. In this way a simplified image about the transient processes imposes itself and difficult problems appear frequently in the design of the power electronic circuits.

Within the framework of the cooperation agreement between the Technical University of Cluj and the University of Pannonia, associated with the TDK-EPCOS concern, the researches presented below investigate the operation mode of the so called "smoothing condenser" in the power applications controlled with the help of pulse width modulation.

The aluminum electrolytic capacitor is the most important passive component in numerous power applications and systems, for example PWM DC or AC converters, inverters, traction motor drives, smoothing dc bus voltage, etc. The lifetime of these applications significantly depends on the lifetime of the active and passive electronic components, among them the capacitors. The data sheet of applied circuit elements includes the lifetime. These elements are verified by test standards which contain different kind of test methods. The current waveforms of the capacitors during these tests are essentially different from the current of DC-link capacitors used in PWM based power electronic applications.

This paper presents some applied test methods which were used during the validation process of

Aluminum electrolytic capacitors and it describes the properties and characteristics of the capacitor current in these tests. The current of the DC-link capacitors in the PWM DC or AC converters is similar to a bipolar square wave signal [1],[10]. The standard does not define a method where the current of the capacitor is square waveform. The paper proposes a modified Two-Quadrant Chopper test circuit which generates the same shaped current waveform. In addition this paper presents simulation about the voltage and current waveforms of the test circuit's elements and the Aluminum electrolytic capacitor.

2. The structure and construction of the aluminium electrolitic capacitor.

The winding of an aluminium electrolytic capacitor [2], [3] contains two foils and an impregnated (a tissue soaked in electrolyte) paper. These are rolled together tightly into a winding. This winding can be seen on Fig. 1. The material of the anode, positive foil is aluminium with purity higher than 99.9%. The foil has been etched [4] to increase the effective surface area (and thus the capacitance of the capacitor) that is typically 20–40 times larger than the plain area. On it an aluminium oxide layer [5], [6] has been generated electrochemically. The cathode foil is also aluminium and itself has a thin oxide layer. The negative pole of the capacitor is a combination of high-absorption paper impregnated and the cathode foil in contact with it. The electrolyte is necessary to make good contact with the anode by permeating its etched structure and also to repair any damages in the oxide layer.

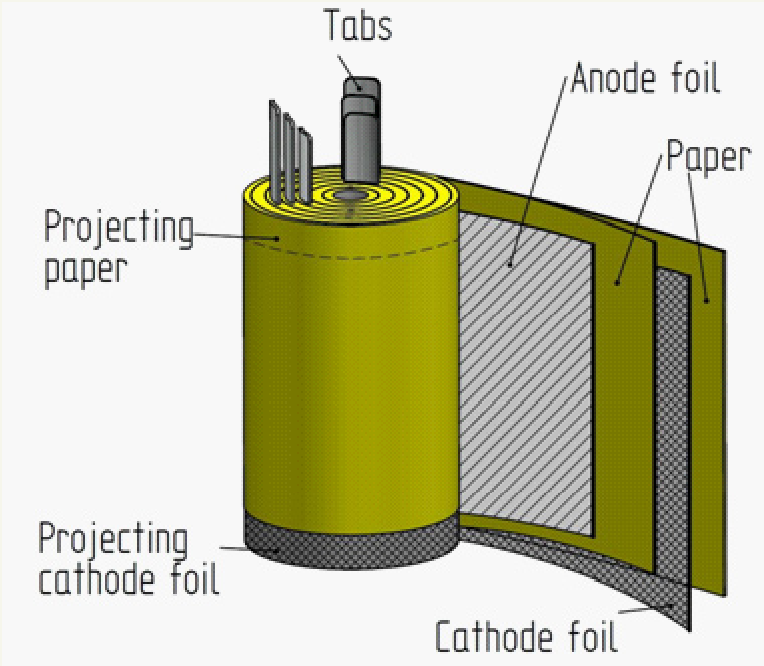

Fig. 1.
Winding of Aluminum electrolytic capacitor

The foils are connected to aluminium tabs that are coming out from the winding and are riveted to the aluminium terminals of the cover disk. Before being housed in a suitable container, the complete winding is impregnated with electrolyte. After housing the edges of the can are curled back. Before being sleeved and packed, capacitors are first aged. The purpose of this stage is to repair any damage in the oxide layer and thus to reduce the leakage current to very low levels.

3. Validation tests of the aluminium electrolitic capacitors.

There are numerous standards, which include the test procedures of Aluminum electrolytic capacitors like: AEC-Q200, CECC 30301-801 or IEC 60384-1. The aforementioned standards contain detailed description about the test -process and -environment. The role of these processes is to simulate the default operation and the stress in different environments (rapid temperature change, high humidity, etc.). There is not a test defined in any standard that puts the capacitor under the same stress as in a PWM DC or AC converter.

This paper describes the processes of general standards [7]-[9] in which the tested capacitor elements are under voltage and current stress. The most important tests methods are the following:

A. Charge and discharge test

A million, 0.5 sec-long charge and discharge cycles must be carried out usually on room temperature. The voltage of the test is equal to the capacitor rated voltage. Voltage and current waveform of the tested capacitor can be seen on Fig. 2.

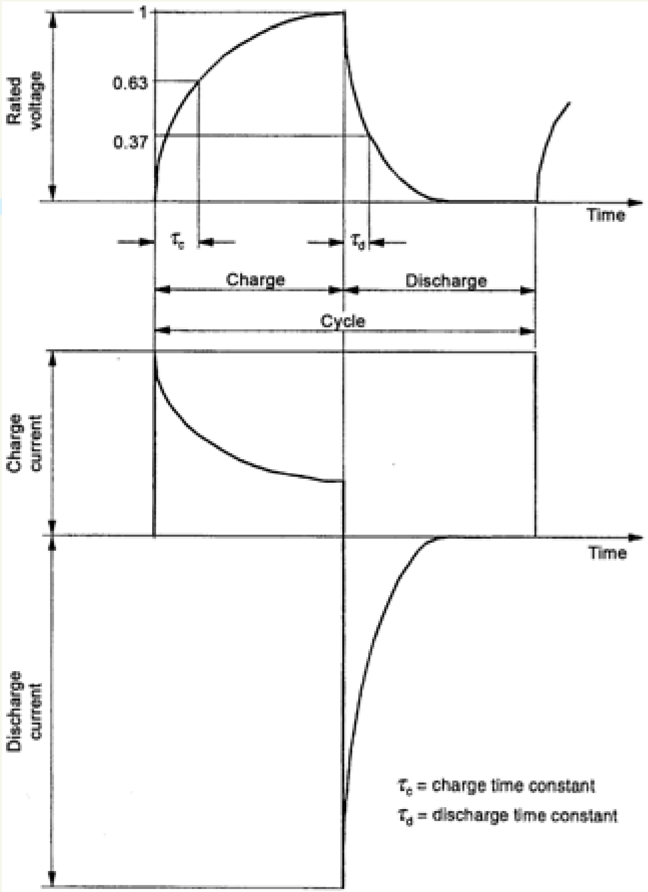

Fig. 2.
Voltage and current waveform of capacitor during the charge and discharge test

B. Endurance test

This test shall be carried out at an upper category temperature and rated voltage. The duration of the test depends on the type of the capacitor. For Snap-in capacitors it is 2000, for multi pin capacitors it is 3000-4000, for Screw terminal capacitors it is more than 5000 hours usually. The current of capacitor has a peak at the beginning. It starts decreasing exponentially until it reaches and sets at a low constant value which depends on the capacitance of the capacitor and the temperature of the examination.

C. Endurance test with sinusoidal current

This test is carried out the same way as a simple endurance test (temperature, voltage and duration). However, the shape of the current wave is different. The waveform is sinusoidal and the applied power supply works as a current generator.

D. Surge test

A thousand, 30-second-long cycles must be carried out at an upper category temperature. During a cycle the capacitor must be charged to 1.1 or 1.5 times its rated voltage. The coefficient depends on the capacitors rated voltage (if it is above 315V the multiplier is 1.1, else it is 1.5). The voltage and the current waveforms are similar to the Fig. 2.

E. Voltage transient overload

The test circuit can be seen on Fig. 3. The capacitor under test C_X is charged from the power supply 1. The auxiliary capacitor bank C_A is charged to the high test voltage from the power supply 2. On triggering the thyristor Th, the capacitor bank C_A is discharged through the inductor L charging the test capacitor C_X to the voltage of power supply 2. When the thyristor turns off the test capacitor C_X is discharged through the resistor R from the voltage of the power supply 2 down to the voltage of the power supply 1. The shape of current waveform can be seen on Fig. 4 with purple.

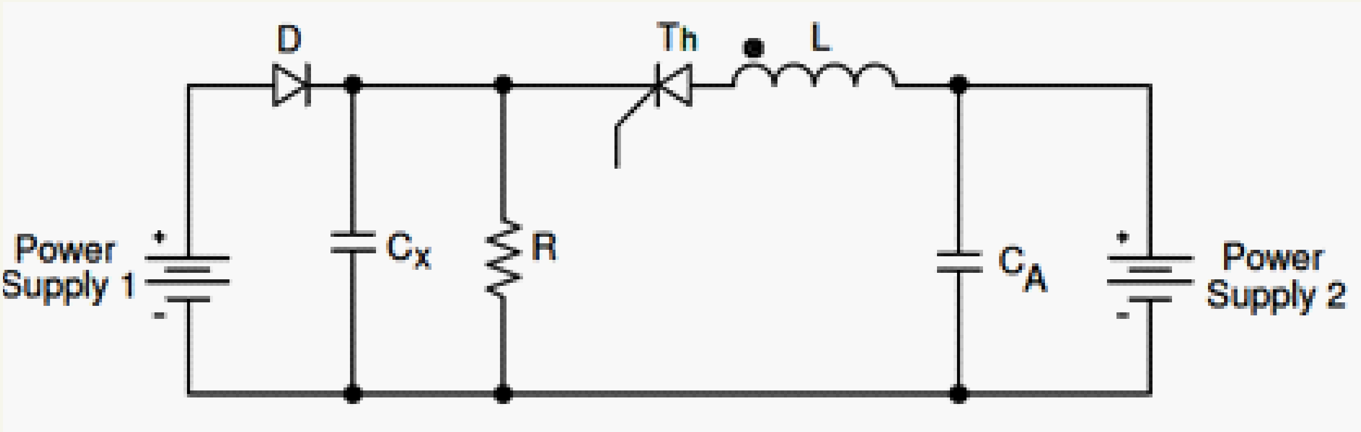

Fig. 3.
Electrical circuit of Voltage transient overload test

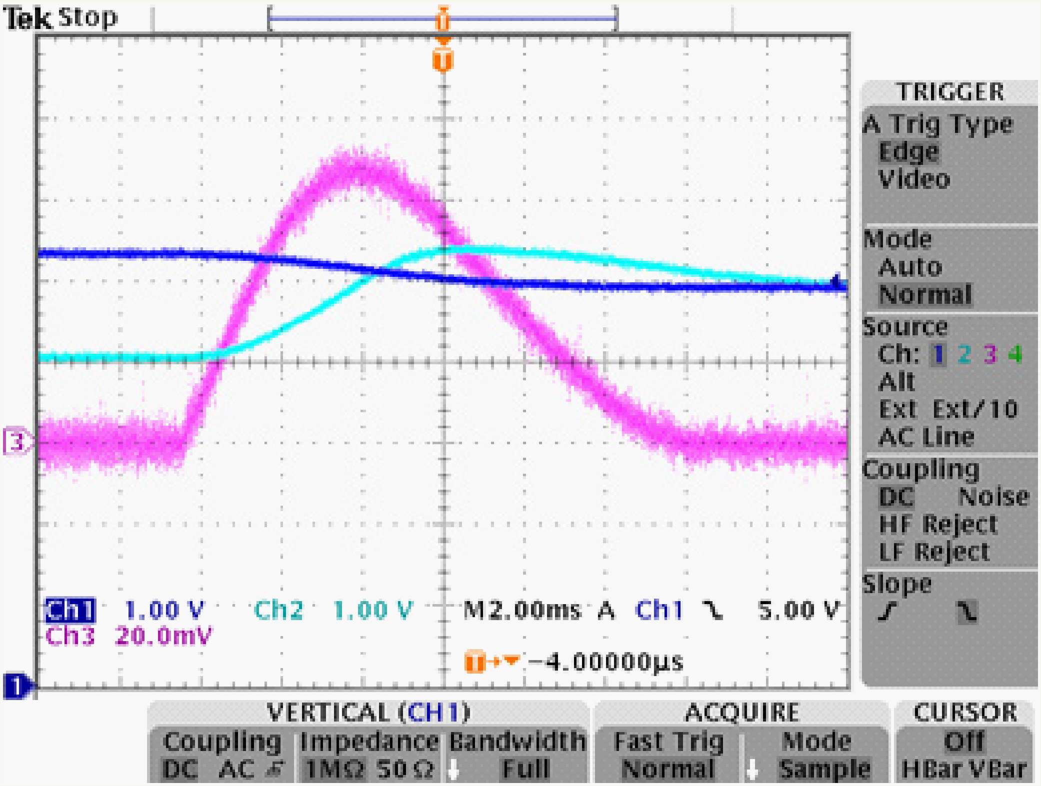

Fig. 4.
Current waveform of capacitor during voltage transient overload

4. The capacitor current in PWM converter applications

The shape of the DC-link capacitor current in a PWM AC or DC converter is presented by a number of papers [1], [10]. During this kind of operation the current of the DC-link capacitors changes dynamically according to the PWM commutation frequency, as it can be seen on the Fig. 5.

This variable current presents an important stress for the DC-link capacitor. The previously presented almost rectangular current is not specified in any standards. It is relevant to capacitor development to study the observed effects caused by this waveform. A test environment has been implemented which takes into account the above presented phenomenon.

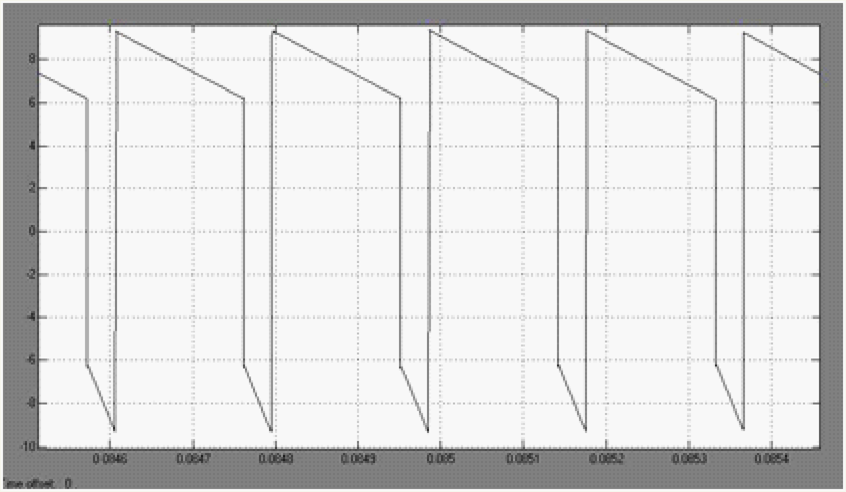

Fig. 5.
Capacitor Current waveform of PWM DC converter

5. Implementation of the new test bench.

The base of the test bench is a modified Two-Quadrant Chopper that contains the examined capacitor. The block diagram of the circuit can be seen on Fig. 6.

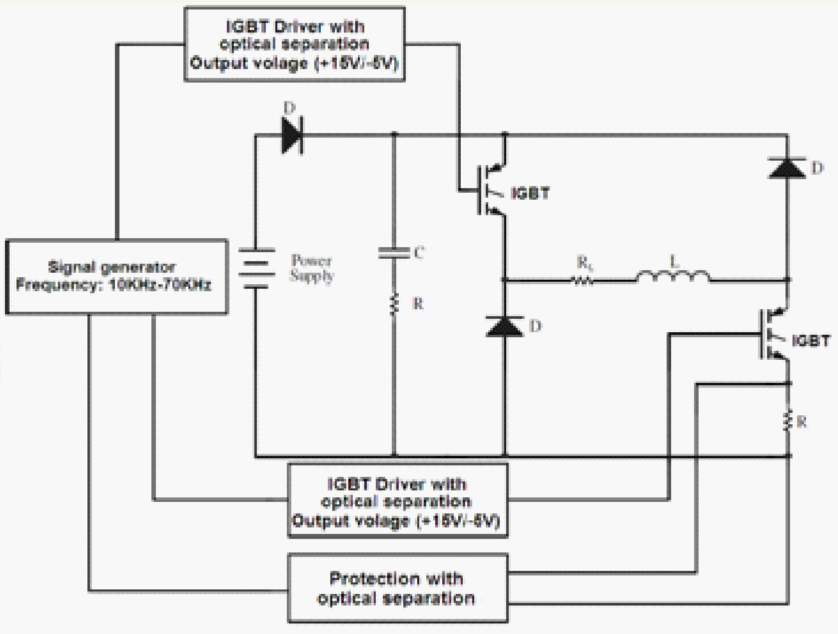

Fig. 6.
Block diagram of the Chopper circuit.

a) Design of the circuit. The next step of the development was the design of the test circuit elements. At the start the following parameters concerning the investigated capacitors were available: C_R=4700uF, U_R=400V, ESR=23mΩ, Z=28mΩ, d=76.9mm, l=105.7mm; $I_{AC,R}$=13,8A.

The characteristics of the proposed circuit are: fs=10KHz, T=10usec; the operating current and changing I_{op}=27.3A, ΔI_{op}=2.7A. (The operating current of the capacitor was calculated from the $I_{AC,R}$), U_T=400V.

The circuit design has two phases. The first one is the design of the power stage and the second one is the design of the drive circuits. The signal generator, based on SG3524 IC can generate really precise square waveform and is possible to change the duty cycle. The driver stage of the IGBT modules (SEMIKRON SKM 195GB126D) was developed and implemented with the help of two circuits which provides +15/-5V gate drive signals. At the design of the power electronics parts was important the minimization of the losses. For this reasons, the R_L resistance must be the lowest possible. During the design process was chosen the value of 1Ω. As results the power losses during the test are:

$$P = R * I_{op}^{2} = 1\Omega * 27.3^{2} A = 745.3W \qquad (1)$$

It can be seen that in spite of the low resistance, relative high power dissipation appears. To the perfect current waveform two parameters were really important, the exact duty cycle and the inductivity of the current smoothing coil. The following equations were used to calculate the above:

$$T_C^{*} = \frac{T_C}{T} = \frac{1}{2} * \left(\frac{U_T}{U_d} + 1 \right) \qquad (2)$$

$$L \geq \frac{R}{f_s} * \left[2\ln \frac{2U_T + R\Delta I_{op}}{2U_T - R\Delta I_{op}} \right]^{-1} \qquad (3)$$

The calculated duty cycle in percent is 0.534125 and the inductivity of the coil is 7.3mH.

b) Simulation of the circuit. After the OrCAD modeling of the test circuit the current stress of the capacitor has been simulated. The current curve on Figure 7 is very similar to the one seen on Figure 5.

It means that the circuit works as it was expected and it can generate the needed current stress for the device under testing. During the simulation it was possible to analyze the voltage and current stress of the other electrical components too. It is important to highlight the voltage of the capacitor: high voltage impulses are present. These are caused by the parasite inductance of the circuit.

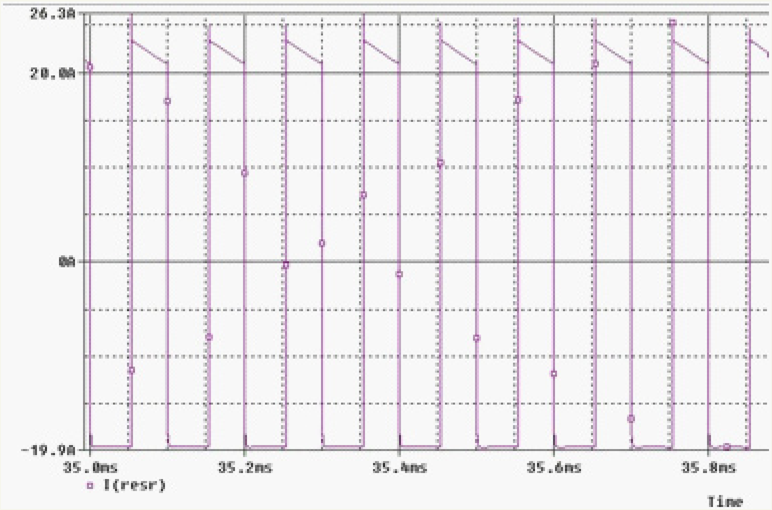

Fig. 7.
Capacitor current during the simulations of the test bench operation

c) Test circuit implementation. The next step was the implementation of the circuit. Technically, minimizing the parasitic inductivities was one of the most important challenges. The complete circuit can be seen of Fig. 8.

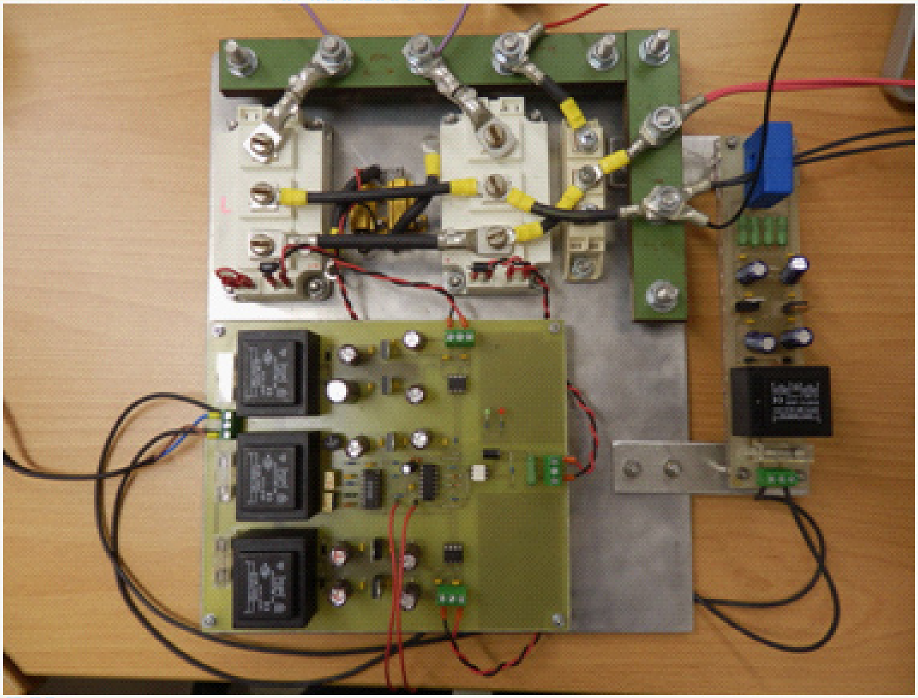

Fig. 8.
The implemented circuit.

6. Conclusions

In the introduced paper, actual tests used during the validation of an Aluminum electrolytic capacitor have been presented. The general set of Aluminum electrolytic capacitor test does not cover all the aspects concerning the operation in PWM converters. For this reason, a special test environment was developed and implemented. This paper presents the design method of the test bench and the first experimental results. With intensive use of the above presented test-bench we expect a more detailed insight into the internal physical-chemical behavior of the electrolytic capacitor in PWM converter applications. With deeper understanding of these processes a new type of capacitors for power electronics should be developed.

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