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Polarity Determination of Electrolytic Capacitors in Power Supplies from external terminals

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***Abstract*—This paper presents the extension of the method previously developed, concerning the identification of the correct assembly in an electronic circuit of a polarized capacitor [1]. The method is upgraded to in-circuit testing readiness for switched-mode power supplies and represents an efficient and very low-cost alternative to the "classical" Automated Optical Inspection (AOI) techniques. The charging – discharging technique can be applied to the external terminals of a switched-mode power supply without requiring additional testing points on the electronic assembly.**

Keywords*— *Electrolytic capacitor, polarity, in-circuit testing, charging, discharging

I. Introduction

Electronic power assemblies, especially switched-mode power supplies (SMPSs) and power drivers in automotive industry widely use aluminum-based electrolytic capacitors for energy storage purposes. Often these capacitors have either large values (hundredths to thousands of μF) with medium nominal voltages (35V to 50V), or, in the case of AC/DC SWPS, smaller capacities, but large nominal voltages (hundredths of V). Therefore, the size of the capacitors is usually larger than the size of other passive components in the circuit, making them suitable for trough-hole technology (THT) mounting. THT components are often assembled by human operators. Consequently, mounting the energy storage capacitors in the correct polarity is subject to human error.

It is well known that a reverse polarized electrolytic capacitor can lead to the destruction of the electronic circuit. The gas generation, ignition or explosion, can cause severe accidents [2]. Studies shown that the electrolytic filter capacitor is the primary component leading to SMPS failure, accounting for 60% of all SMPS components [3]. However, the reverse polarized capacitor failure usually does not happen in the first minutes of operation, under any condition. Studies concerning reverse biased behavior of electrolytic capacitors shown that the capacitor can resist for hours or even tenths of hours without noticeable physical damage [4], [5]. Upon the experimental result presented in [1], where a 680μF/35V capacitor is reverse biased with 12V for the current limited to 100mA by a constant current source, the same conclusion can be drawn. The figure represents the voltage across the capacitor along with the temperature, in adiabatic conditions. The thermal runaway occurs in Fig. 1 only after 2.3 hours of reverse biased condition, and the capacitor breakdown (explosion) happens after about 3 hours of reverse biased condition.

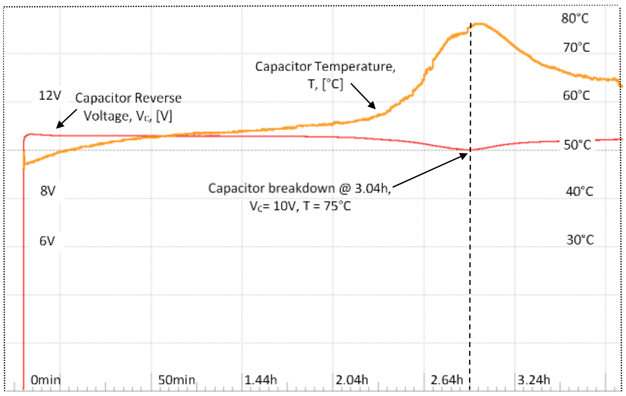


Fig. 1. Reverse biased 680μF/35V electrolytic capacitor voltage and temperature behavior over time

Moreover, [6] concludes that the experimental results suggest the existence of a threshold voltage, above which reverse installed capacitors would fail within seconds, and below which they would withstand hundreds and thousands of hours enduring relatively high leakage currents but without hard failures. According to his experiments, this threshold voltage is expected to be somewhere within 15% and 25% of the rated voltages. Although the study in [6] was done on tantalum capacitors, our experimental results shown a similar behavior for aluminum electrolytic capacitors too.

Thus, for reverse mounted capacitors the defects/ accidents can occur either at the testing phase, or during the operation phase. Consequently, a testing procedure that focuses on the correct assembly of the electrolytic capacitors, especially those used for energy storage purposes on power assemblies becomes essential.

II. In-Assembly or In-Circuit Testing Methods Focusing on Electrolytic Capacitors

Obviously, the In-Circuit Testing (ICT) methods such as the bed of nails or flying probe testing deals with all board defects such as bad solder joints, missing or defective components, incorrect analog signature etc., not only on electrolytic capacitors. Thus, research on flying probe testing methods is mostly concerning testing effectiveness by optimizing probe motion or cost path [7], [8]. Concerning in-circuit capacitor testing, research focuses on capacitor parameter measurements

[9], [10], especially capacitance, leakage current and Equivalent Series Resistance (ESR).

Increase in ESR is the clearest indicator of an aged electrolytic capacitor. Therefore, extensive research is targeting in-circuit ESR evaluation of SMPS filter capacitors. The evaluation methods are usually based on the output ripple voltage increase measurement, [11]. In the case of digitally controlled SMPS, research is also done on ESR increase evaluation by examining the stability of the digital control loop [12]. The main goal in this field is failure time or lifetime prediction of the electrolytic capacitors.

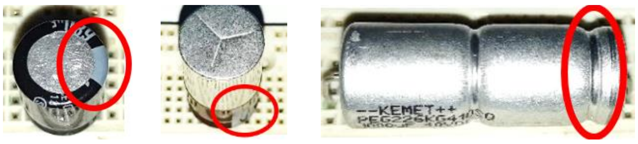
However, all the methods for capacitor parameter testing, or lifetime estimation mentioned above assume that *the electrolytic capacitor(s) are correctly assembled and forward biased.*

The most widespread solution for testing the component placement correctness, thus, the electrolytic capacitors polarity is the visual inspection, especially the Automated Optical Inspection (AOI) methods. Initially the acquired image of the electronic assembly was compared to a reference (ideal) image, highlighting the differences. The main difficulties of this approach are the requirements for precise alignments and well-designed illumination on images. Therefore, the image processing techniques developed by including artificial neural network and support vector machine (SVM) classification methods [13], [14], are quite complicated, evolving to Machine Vision-based systems.

Beside of the very high costs of an AOI system, another major drawback is that AOI was conceived for surface-mount technology (SMT), where component assembly and alignment is machine-based rather that in THT, where trough-hole components are usually assembled by humans, introducing both larger component misalignment, or, in the case of electrolytic capacitors, capacitor mounting is done with a polarity mark hidden from the camera.

Fig. 2 shows some comparative examples of aluminium electrolytic capacitors in THT case. Fig. 2 a) shows the usual electrolytic capacitor, where polarity mark is visible both from the top and the side views. However, during our experiments we encountered capacitors shown in Fig. 2 b), where the polarity mark is visible only at the side view, or, in Fig. 2 c), where the polarity mark might not be visible under improper illumination conditions.

The correct polarity can be ambiguous in case of capacitors in Fig. 2 b) and c), not only for an AOI system (even 3D) but also for human. The proposed method overcomes these drawbacks and provides a simple an cheap testing solution.



a) b) c)

Fig. 2. Aluminium electrolytic capacitor types with polarity marks shown in ellipses. a) Radial THT case, polarity mark is clearly visible from the top for an AOI system b) Radial THT case, polarity mark is shown only on the side c) Axial THT case, polarity mark might be missed in the case of a bad illumination.

III. The Proposed Method

A. Overview of the method principle

The method principle, presented in [1] consisted in a constant current source and a switch controlled by a pulse signal that charges the capacitor for an imposed time, followed by the switch opening and leaving the capacitor under test in open circuit. The self-discharge behavior of the capacitor voltage determines whether the capacitor is direct or reverse polarized.

The electrolyte changes in a reverse biased capacitor causes an increased leakage current compared to a forward biased one. Therefore, a reverse biased capacitor will self-discharge faster. Consequently, the reverse biased capacitor in any circuit will show smaller equivalent time constant than in the case it would be forward biased. Fig. 3 is the reproduction from [1] showing this behavior, for a 470µF/35V aluminium electrolytic capacitor charged by a 100mA, 500ms current pulse, then left in air.

Note that the strength of the electrolytic dissolution effect in the reverse biased capacitor is strongly dependent on the applied reverse voltage ratio versus the capacitor nominal voltage. The same voltage charge (up to maximum 12V) applied to a 50V rated capacitor shown smaller yet measurable differences between the forward and reverse bias behavior. This also confirms that the statement in [6], suggesting the existence of a threshold voltage, is valid for aluminium electrolytic capacitors too.

This should be considered when choosing the charging voltage limit. The voltage limit should be larger than the suggested 15...20% of the capacitor nominal voltage. On the other hand, the voltage limit should be as low as possible to avoid undesired destruction of the capacitor. In addition, the voltage limit shall be under the power supply nominal voltage in order to avoid destruction of other components

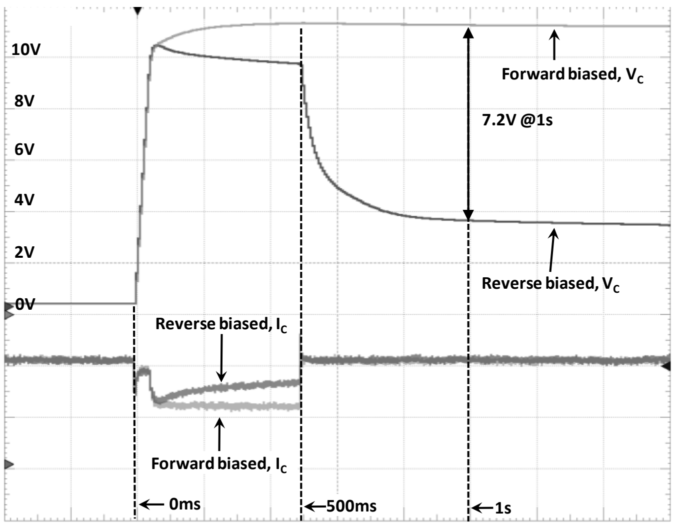


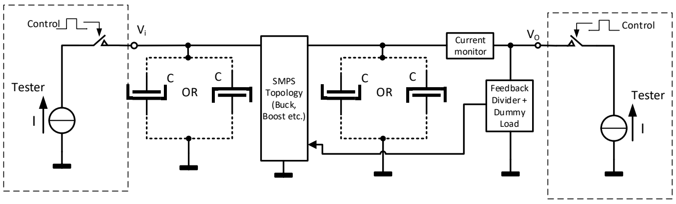
Fig. 3. Timing diagram of the charge-self discharge behavior for a 470µF/35V capacitor, reproduced from [1].

B. Applying the tester to the SMPS external terminals

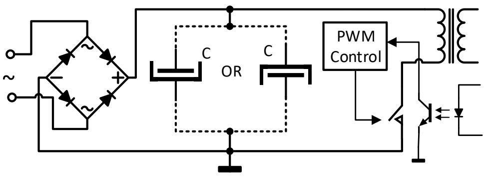
If the tested circuit is a DC-DC converter, regardless the topology, the filter capacitors are connected practically in parallel with the input respective output terminals, e.g. in Fig. 4

a). Note that the current monitor usually consists of a very low (<<1Ω) resistance.

In case of an AC/DC converter with a flyback topology, as shown in Fig. 4 b), the input AC voltage is rectified first. Therefore, in order to access the input filter capacitor terminals, extra connections would be necessary. This requirement complicates and further delays the testing procedure.



a)



b)

Fig. 4. a) in a typical SMPS architecture, filter capacitors are practically connected in paralell with the input and output terminals, respectively b) In the case of an AC/DC flyback converter, acces to the capacitor terminals needs extra connections.

The proposed solution was found by applying a charging current pulse at the input of a bridge rectifier in order to charge the capacitor, simultaneously monitoring the charging current. Hence, it was expected that in the case of a capacitor connected in reversed polarity, the occurrence of an increased leakage current which rapidly discharge the capacitor. In order to check this, a second charging pulse is to be applied after a silence time period. Fig. 5 presents the experimental results for a 470µF/35V electrolytic capacitor charged from a 100mA current source for 2 seconds. After a 4-second pause, another 1 second pulse charge is applied. The capacitor is discharging much faster when is reversed charged than when is forward charged.

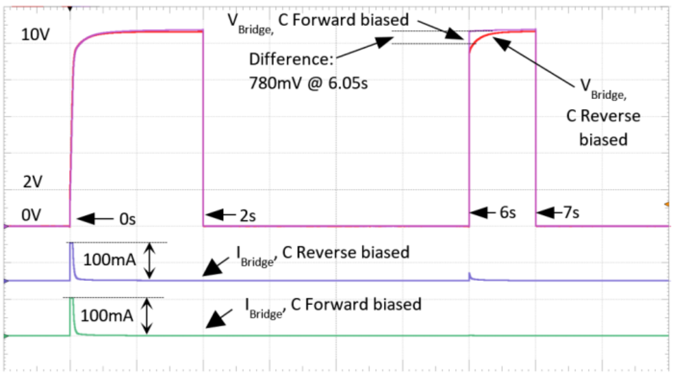
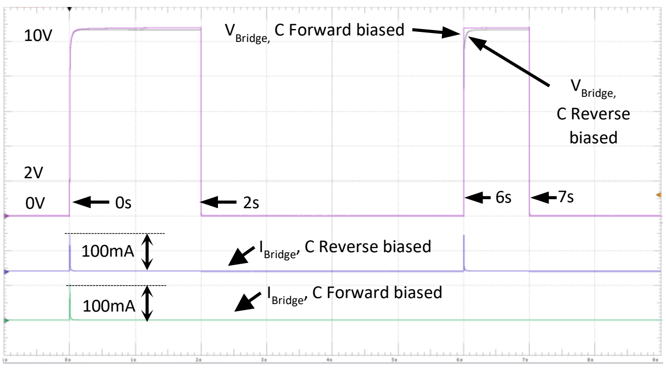


Fig. 5. Experimental results for the two-pulse charging 470µF/35V aluminium electrolytic capacitor, forward and reverse.

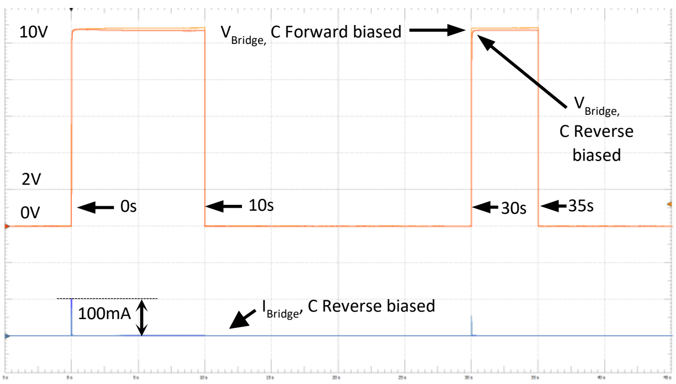
Therefore, 50ms after the second charge pulse is applied, the voltage on the bridge drops 0.78V versus the case when it was forward charged. At the same time the reverse charge current presents a peaking at the second charging pulse, when the capacitor is reverse connected, while the forward connected capacitor charging current is not peaking. This behavior gives the possibility to follow any of the two parameters in order to determinate whether the capacitor was forward or reverse mounted: the comfortably measurable voltage difference or the existence of the second current peak. Note that the second charge pulse is only used to check the voltage drop on the capacitor, so its length can be shorter (e.g. 50ms) in order to further reduce the stress on the reversed mounted capacitor. One second pulse length was used only for better graph visibility purposes.

C. Testing large voltage rated capacitors

The AC input of an AC/DC flyback SMPS is usually the power supply network with the voltage ranging from 110V to 240V. Therefore, the energy storage capacitors in the primary stage shall have high nominal voltage (e.g. hundredths of V). These capacitors have usually small capacitances (e.g. varying from tens of µF to few hundredths of µF). For these conditions it is expected that the charging voltage limit of 12V, used in the previous experiments is not enough to clearly differentiate between the forward and reverse charged behaviors. The experiment result in Fig. 6 a), made on a 100µF/250V capacitor, shows only small differences between the forward and reverse biased capacitor voltage behavior.



a)



b)

Fig. 6. a) Two-pulse charging at 12V charge limit of a 100µF/250V capacitor forward and reverse connected does not give clearly differentiable results b) Increasing the charge and silence times with a factor of 5 does not solve the issue.

Nevertheless, the reverse biased capacitor charging current still presented a peaking when the second charge pulse was applied. Hence, this behavior can be used to differentiate between forward and reverse connected capacitor. However, monitoring the current and testing the current peaking presents some drawbacks. Monitoring the charging current must be done under the conditions of the rectifier bridge voltage changes from 0 to the charging limit. It means that a floating current monitor is needed, hence, increasing the circuit complexity. On the other hand, the moment when the peaking must be detected is very close to the moment when the charge current is applied. Hence, at that moment transient effects in the circuit might alter the measurements, resulting in false forward/reverse connected decisions

In order to use the more convenient difference between the forward and reverse charging/discharging voltages as the tested parameter, that finally concludes about the forward or reverse connection decision, the charging voltage limit must be increased. Fig. 7 presents the experimental results for a 100 µF/250V, capacitor two-pulse charged with different charging voltage limits: 20V, 30V, 40v and 50V. Due to reasons regarding maximum voltage rating limit on the current source components, the charge current in the experiment is resistively limited. Voltage difference was measured at 100mS after the second pulse was applied. From Fig. 7 results that a comfortably measurable difference (1.29V) is found at 30V charging voltage limit. This value represents 12% of the capacitor nominal voltage, V_{NOM}.

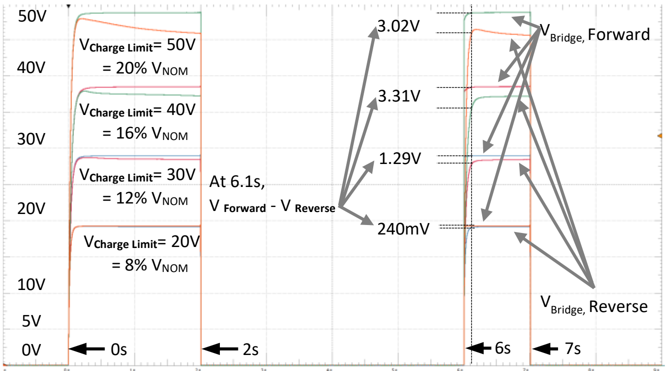


Fig. 7. Two-pulse forward and reverse charging at 20V, 30V, 40V and 50V charging voltage limit of a 100µF/250V capacitor.

IV. CONCLUSIONS

In this paper the extension of the method previously developed in [1], regarding the identification of the correct assembly in an electronic circuit of a polarized capacitor is presented. The method is upgraded to in-circuit testing readiness for switched-mode power supplies. The method represents an efficient and very low-cost alternative to the Automated Optical Inspection (AOI) techniques. The testing method is demonstrated for the capacitor assembly correctness in case of a DC-DC converter input and output filter, by accessing to the power supply input and output terminals, without requiring extra testing connection. Extending the testing method with the two-pulse approach allows testing an AC/DC converter input stage filter capacitor - isolated by the rectifier bridge, only from the AC side input terminals.

The experiments targeted the high voltage rating capacitors, used in AC input stages provided information about the optimal value of the charging voltage limit. At this value the possibility of capacitor destruction in reverse connected mode is minimum, while the voltage value allows clear differentiation between the forward and reverse mounted behavior.

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