

Research Article

Effect of Asymmetrical Edge Disconnection on Equivalent Series Resistance of Metalized Polypropylene Capacitors

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Abstract: In order to investigate the effect of asymmetrical partial edge disconnection on the Equivalent Series Resistance (ESR) of Metalized polypropylene capacitors an experimental study has been made. Theoretical analysis made using PSPICE simulation package reveals that electrode resistance of individual turn rises from 10 to 30% depending on the location of the turn. This rise is not measureable at all the frequencies as ESR is frequency dependent and it includes resistance due to electrodes and dielectric losses. Metalized polypropylene capacitors were made with partial edge disconnection at one end (asymmetrical) with different magnitudes of edge disconnection by masking during the process of zinc spraying. Measurements of ESR have been made in a wide range of frequencies from 20 Hz to 50 MHz and the theoretical results are validated through the experimental data. A short time step stress test was conducted on the capacitors, which can be further developed as a type test to identify the capacitors with partial edge disconnection.

Keywords: Asymmetrical edge disconnection, current density, dissipation factor, Metalized Polypropylene Film (MPPF), schooping

INTRODUCTION

End connections of self clearing metalized film capacitors are made by plasma sprayed metal on the ends of capacitor winding (Fuchang and Xin, 2003). In MPPF capacitors, total disconnection of sprayed ends is one of the most frequent causes of capacitor failure, but even partial disconnection has negative consequences as it occasions an increase in dissipation factor (Pirani, 2003). Electrical stress and mechanical stress resulting from it play a very important role in the degradation mechanism of the end edge contact. Literature is available on symmetrically edge disconnected metalized polypropylene capacitors (Robert, 2007a). In general literature says edge disconnection causes increase in ESR and dissipation factor which sometimes may lead to catastrophic failures. So far no work is found in literature on asymmetrical edge disconnection of MPPF capacitors. In this study partial edge disconnection and its role on the ESR are quantified theoretically and the results are validated through the experimental data. A short time step stress test to identify the capacitors with partial edge disconnection (asymmetrical) is conducted.

MPPF CAPACITORS

The polypropylene capacitors are used in industry due to their low production cost, high reliability and

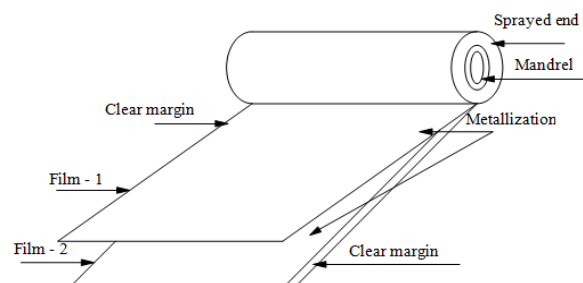


Fig. 1: Construction of MPPF capacitors

good electrical characteristics. These capacitors have gained wide usage for the unique capability of self healing. Polypropylene films are metalized on one face with clear margin of few millimeters on one side. Two such metalized films are wrapped around a cylindrical mandrel with clear margins at the opposite sides to make metalized capacitor. After winding, the sides are sprayed with metal particles (normally with zinc) establishing a connection between each turn of the foil (Siami *et al.*, 2001; El-Husseini *et al.*, 2002; Reed and Cichanowski, 1994). This process is known as schooping (Vuillermet *et al.*, 2007). On the clear margin there is no metallization for few mm and hence no contact is made there. Clear Margin (CM) lies at the opposite side of Contact Edge (CE). Electrode of thin metal evaporated on to the film is in the order of 300 Angstrom.

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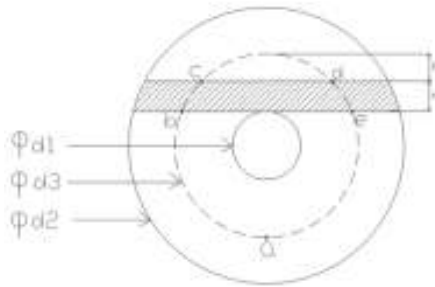


Fig. 2: View of sprayed end with partial edge disconnection

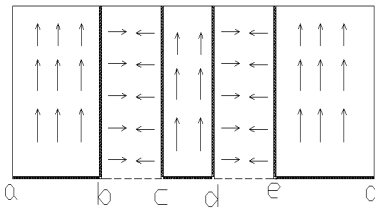


Fig. 3: Spread view of the electrode

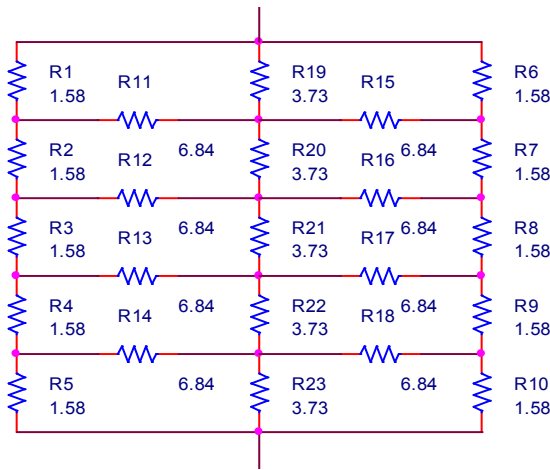


Fig. 4: Electrical model of electrode



Fig. 5: Photo graph of sprayed end with partial edge disconnection

Table 1: R and R' for x = 2 mm

d3 (mm)	x (mm)	y (mm)	R (ohms)	R' (ohms)	Ratio R/R'
15	2	1	4.37	3.81	1.14
17	2	2	3.73	3.37	1.10
19	2	3	3.28	3.01	1.08
21	2	4	2.92	2.72	1.07
23	2	5	2.63	2.49	1.05

Table 2: R and R' for x = 6 mm

d3 (mm)	x (mm)	y (mm)	R (ohms)	R' (ohms)	Ratio R/R'
23	6	1	3.25	2.49	1.30
25	6	2	2.85	2.29	1.29
27	6	3	2.57	2.12	1.24
29	6	4	2.38	1.97	1.19
31	6	5	2.15	1.84	1.16

Table 3: Specifications of manufactured capacitors

Group	1	2	3	4	5	6
Width of disconnection (mm)	0	2	4	6	8	10
Disconnected area (%)	0	7.6	14.8	22.5	27.4	32.3

Thickness of polypropylene dielectric is in the range of few micrometers. The metal used is aluminium, zinc or zinc-aluminium alloy (Rehmatollahpur *et al.*, 2010; Borghetti *et al.*, 1995). For AC voltage applications, Zinc rich zinc-aluminium alloy electrode is used to avoid AC corrosion problem. Figure 1 shows the construction of Metalized polypropylene film capacitor.

Equivalent series resistance due to metal electrode:

Theoretical analysis: For theoretical analysis, capacitor of 8 μ F was taken with inner and outer diameter of 9 and 34 mm, respectively. Width of the film is 30 mm. Figure 2 shows one end of wound capacitor with partial discontinuous edge disconnection for the width of x mm. In the figure, d₁ and d₂ are the diameters of mandrel and wound element respectively. Dotted circle shows the turn taken for analysis with diameter d₃.

In the turn, regions a-b, c-d and e-a are edge connected and regions b-c and d-e are edge disconnected. Since the edge disconnection is asymmetrical, one of the electrodes is healthy. Figure 3 shows the spread view of electrode shown in dotted circle in Fig. 2. With the values d₃ = 15 mm and x = 2 mm, calculated values of ab = 16.6 mm, bc = 3.04 mm, cd = 7.82 mm, de = 3.04 mm and ea = 16.6 mm. In edge connected part current flows in the axial direction and in edge disconnected part current flows in radial direction as shown.

Electrode shown in Fig. 3 is electrically modeled by dividing each part into five small sections as shown in Fig. 4 (Kong and Lee, 2004; Robert, 2007b). Calculation of resistances are made using (Xiaguang and Steven, 2004):

$$R = R_{\square} \times w/l \tag{1}$$

where R is the resistance of each small section, R \square is the resistance per unit square, w and l are the width and length of each section. In the dotted circle, with x = 2 cm, y = 1 cm and d₃ = 15 cm, the resistance value computed using PSPICE is 4.37 Ω for the partially edge disconnected electrode of turn. For the same turn the resistance is 3.81 Ω when fully connected.

Table 1 and 2 show the computed resistance of turns at different positions for x values 2 and 6 mm,

respectively. R and R' denote resistances of electrode of partially edge connected turn and resistance of equivalent fully connected turn.

As the capacitor with partial discontinuous edge disconnection becomes hybrid model with disconnected part and connected part, it is a complicated process to calculate the total resistance of the electrode. With the computed resistances, ratio of resistances of partial edge connected turn and fully connected turn varies from 1.05 to 1.14 for $x = 2$ mm and from 1.16 to 1.30 for $x = 6$ mm for turns at different locations. As all the

turns are actually connected in parallel, net resistances of electrode further gets reduced.

Measurement of ESR and dissipation factor of partial edge disconnected capacitors: Six groups of capacitors were manufactured with different widths of edge disconnection on one end (asymmetrical) as given in Table 3. Artificial disconnections are made by suitable masking during the process of zinc end spraying. Parameters of the manufactured capacitors are:

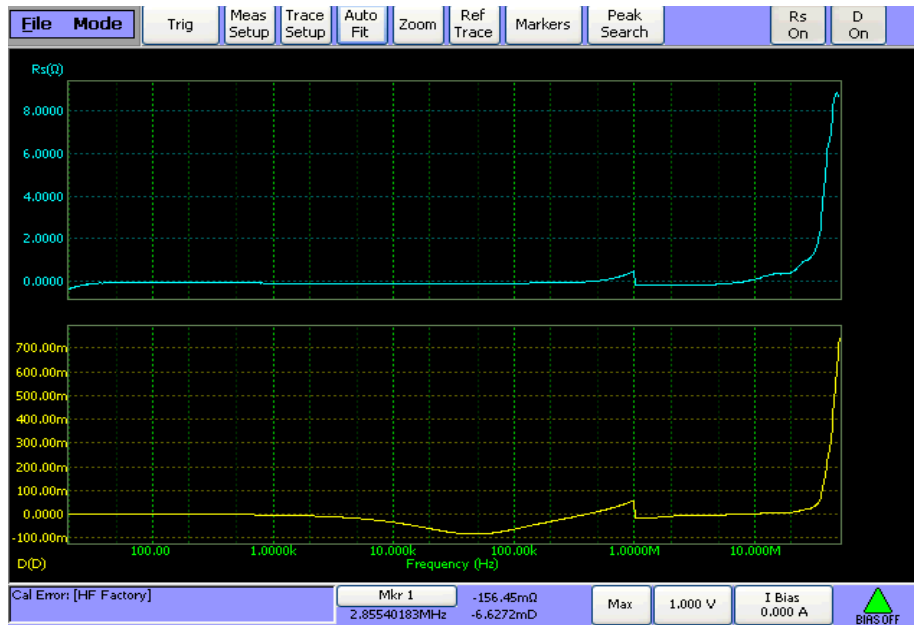


Fig. 6: ESR and DF for group 1 capacitors

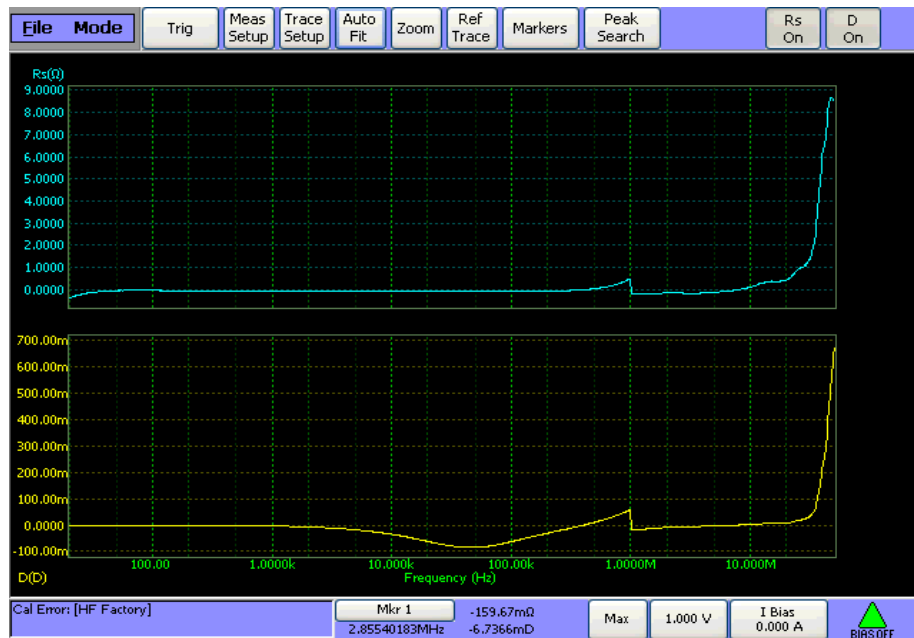


Fig. 7: ESR and DF for group 6 capacitors

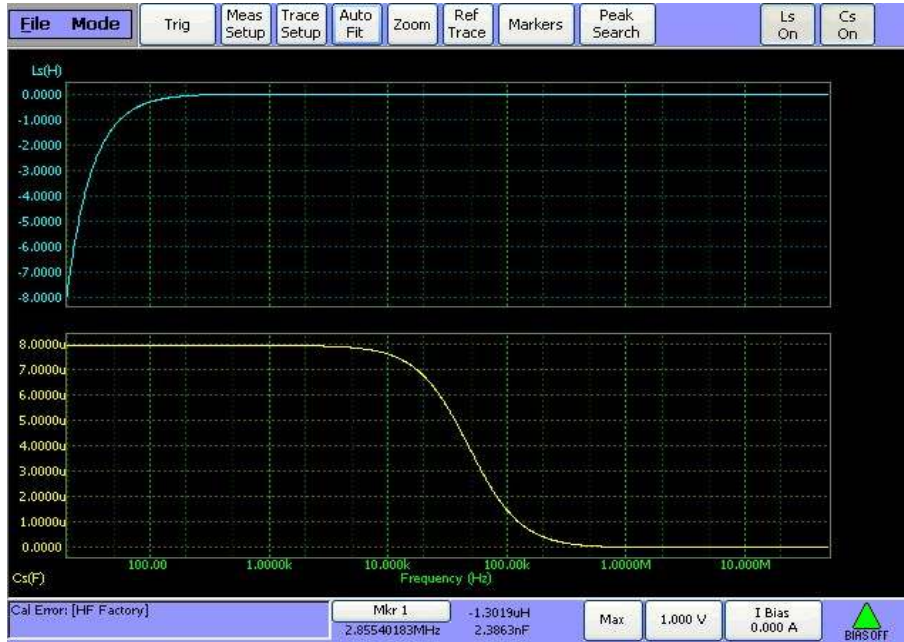


Fig. 8: L and C for group 1 capacitors

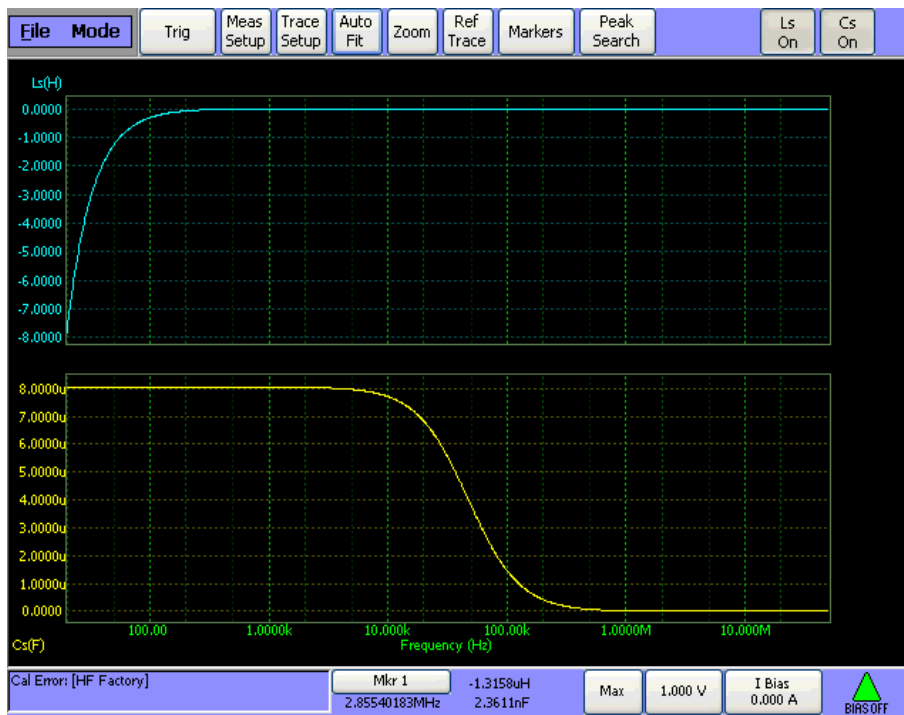


Fig. 9: L and C for group 6 capacitors

Table 4: ESR values measured at different frequencies

Frequency	Equivalent series resistance in ohms					
	Group 1	Group 2	Group 3	Group 4	Group 5	Group 6
1 KHz	0.0663	0.0664	0.0663	0.0062	0.0064	0.0063
10 KHz	0.0686	0.0701	0.0684	0.0702	0.0683	0.0685
1 MHz	0.3861	0.3874	0.3901	0.3864	0.3852	0.3862
10 MHz	0.1145	0.1209	0.1327	0.1452	0.1558	0.1597
50 MHz	8.5985	8.4263	8.4251	8.6412	8.5452	8.4845

Table 5: Dissipation factors

Group	1	2	3	4	5	6
DF	0.002084	0.002269	0.002392	0.002684	0.002794	0.002963

Capacitance: 8 μ F
 Rated voltage: 350 V
 Thickness of Polypropylene film: 7 microns
 Thickness of metalized electrode: 300 A°
 Diameter of mandrel: 9 mm
 Diameter of wound element: 34 mm
 Effective width of Polypropylene: 30 mm
 Length of winding: 49 m

Figure 5 shows the photograph of capacitor manufactured with partial edge disconnection on one end by suitable masking during the process of plasma spraying.

All the capacitors made with edge disconnection were tested for equivalent capacitance, equivalent resistance, dissipation factor and inductance at wider range of frequencies from 20 Hz to 50 MHz using high precision impedance analyzer Warner Kerr 6000 B. Figure 6 and 7 show equivalent series resistance and dissipation factor of group 1 and 6 capacitors respectively. Figure 8 and 9 show inductance and capacitance of group 1 and 6 capacitors, respectively. (Group 1 capacitors are healthy and Group 6 capacitors are with maximum edge disconnection).

Equivalent Series Resistance of the capacitor (ESR) is measured for ten capacitors in each group and average is given in Table 4 at selected frequencies. In general at low frequency spectrum resistance of the electrode is negligible and loss is predominately in the dielectric. In the upper frequency spectrum the major loss occurs in the series resistance of the metal elements which, owing to skin effect. In the mid frequency range the total sum of the equivalent series resistance is due to electrodes and the series resistance due to skin effect (Lafferty, 1992).

Referring to Table 4, the effect of partial edge disconnection can be observed at 10 MHz and at any other frequency range the partial edge disconnection is not observable. Similarly only around 10 MHz the increase in dissipation factor could be observed. Table 5 shows dissipation factor for different groups of capacitors at 10 MHz.

DISCUSSION

Previous studies reveal that, in case of symmetrical edge disconnection (where disconnection occurs concurrently on both layers), the part still connected directly to the scooping will have good high frequency characteristics and low loss where as the edge disconnected part will have poor frequency characteristics and high losses. Pole frequency for equivalent capacitance of the edge disconnected part reduces with the square of length of edge disconnection. As little as 5% edge disconnection of the

length of the two overlaid strips caused the pole frequency for that part to fall from radio frequency to audio frequency (Robert, 2007a). Five percent symmetrical edge disconnection causes 65 times increase in dissipation factor. This present study on asymmetrical edge disconnection reveals that capacitors with even 33% of edge disconnection (group 6) show the increase in dissipation factor of only 1.39% compared to the healthy capacitor and no change in pole frequency is noticed.

STEP STRESS TEST

Step stress testing is intended to reduce the test time and to assure that failures occur quickly enough. Starr and Endicott proposed equivalent damage to estimate the life at constant stress from that on linearly progressive stress. Wayne (1980) developed a short method of estimating the life time using step stress test using the equivalent damage concept. Step stress test is relatively short. Inverse power model is the simplest form represented by the equation:

$$tv^n = k \tag{2}$$

where, t is the time to failure at voltage v and k and n are constants. Under step stress test voltage is raised in steps and held constant at each step for some interval. The cumulative damage is then simply the sum of damage at each voltage level. This relation is represented by:

$$t_k (v_k)^n = \sum t_i (v_i)^n + \sum t_{i+1} (v_{i+1})^n \tag{3}$$

where,

- t_k : Equivalent time to failure at voltage stress v_k
- $t_i v_i$: The product of time and voltage at each fully completed step
- t_{i+1} : The time to failure on the uncompleted v_{i+1} step

In the past, step stress tests were conducted on various electrical equipments. But no work was found in literature on step stress test of metalized polypropylene capacitors. Normally, in step stress test, starting stress is chosen nearer to normal operating stress. The step time varies from minutes to hours depending on the material under test (Lahari and Cygan, 1990; Robert and Wayne, 1983; Gaetano and Antonio, 1986).

In the present study, the capacitors were step stressed starting from the voltage of 350V with time interval of 30 min. The voltage was raised in steps of 50 V up to 900 V. Table 6 gives the results of step stress test.

Table 6: Percentage reduction of capacitance under step stress test

Group	C _{initial}	C _{final}	Reduction (%)
1	8.10	7.84	3.20
2	8.09	7.52	7.04
3	8.10	7.42	8.39
4	8.12	7.40	8.86
5	8.17	7.15	12.40
6	8.07	Failed catastrophically	

When we initially chose higher step voltages and lower step time, the results deviated very much from the results of accelerated step stress test which may be due to the change in failure mechanism.

CONCLUSION

- Effect of asymmetrical discontinuous edge disconnection of Metalized polypropylene capacitors was analyzed.
- Analyzing the turns at different locations, resistance contributed by the partially edge disconnected turn rises from 1.05 to 1.30 times that of fully connected turn depending upon the location of the turn and width of edge disconnection.
- Capacitors were manufactured with partial edge disconnection. Measurement of equivalent series resistance and dissipation factor reveals that ESR of 33% partially edge disconnected capacitor is 1.3 times that of healthy capacitor in the frequency range of 10 MHz. In any other frequency range the ESR of partially edge disconnected capacitor is at par with that of healthy capacitor.
- Dissipation factor of partially edge disconnected capacitors is observable only around 10 MHz. For 33% asymmetrical edge disconnection rise in dissipation factor is around 1.3 times.
- A step stress test was conducted for a short period which helps to identify the capacitors with partial edge disconnection.
- The step stress test conducted in this study may further be developed and a type test may be defined for the MPPF capacitors.

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