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SELF HEALING ANALYSIS AND PERFORMANCE APPRAISAL OF METALLIZED POLYPROPYLENE CAPACITORS

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ABSTRACT

In Metallized Polypropylene Film [MPPF] capacitors, the erosion of thin metal coating is due to self healing which leads to the loss of capacitance. In practice, it is found that beyond 5% reduction in capacitance, loss of capacitance is rapid when stressed further. In MPPF capacitors excessive power dissipation on metal electrode and associated temperature rise play vital role in loss of capacitance. Power dissipation of metal electrode of self healed MPPF capacitors increase much from that of normal one. In this present work a theoretical study is made to investigate the reason for the rapid increase in the loss of capacitance beyond 5% reduction in capacitance, using PSPICE simulation package.

Index Terms — Metallized polypropylene film (MPPF), Self healing (SH), Schooping, Power density, Resistor Centric Transmission line model.

1 INTRODUCTION

AGING process in metallized capacitors causes a slow decrease in the value of capacitance due to self healing taking place in metal coating. After the capacitor loses about 5% of its capacitance, the loss of capacitance accelerates rapidly when stressed further. Hence in practice, 5% of capacitance loss has been chosen as the normal end design life for this class of capacitors[1]. The aim of this paper is to investigate the effect of self healing on the performance of MPPF capacitors. A simplified single layer film capacitor equivalent circuit is illustrated by Kong and Lee [2]. Resistor Centric Transmission line model of cross width healthy strips of MPPF capacitors has been developed and voltage, current density and power profiles related to the cross width metal layer were reported by Brown[3]. In this study, transmission line model of cross width MPPF capacitors is analyzed incorporating the effect of self healing. Behaviour of MPPF capacitors with various magnitudes of self healing occurring at different locations of metallized film is reported by computing power distribution which is the key factor playing dominant role in the deterioration process. Rate of rise of power density of the electrodes of MPPF capacitor as a function of magnitude of self healing is presented. PSPICE simulation package is used for circuit simulations and computations.

2 MPPF CAPACITORS

The polypropylene capacitors are used in industry due to their low production cost, high reliability and good electrical characteristics. These capacitors have gained wide usage for the unique capability of self healing.

CONSTRUCTION

Polypropylene films are metallized on one face with clear margin of few millimeters on one side. Two such metallized films are wrapped around a cylindrical mandrel with clear margins at the opposite sides to make metallized capacitor. After winding, the sides are sprayed with metal particles (normally with zinc) establishing a connection between each turn of the foil[4]-[6]. This process is known as schooping[7] . 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 300Angstrom. Thickness of polypropylene dielectric is in the range of few micrometers. The metal used is aluminium, zinc or zinc–aluminium alloy[8]-[10]. For AC voltage applications, Zinc rich zinc–aluminium alloy electrode is used to avoid AC corrosion problem. Figure 1 shows the construction of metallized polypropylene film capacitor.

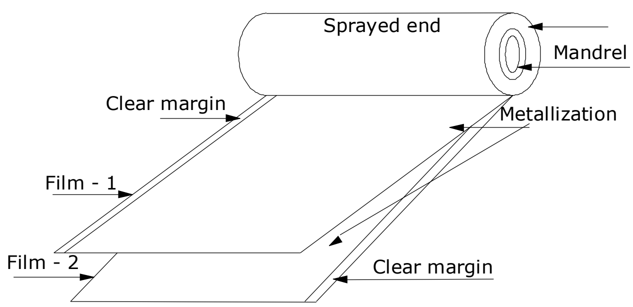

Figure 1. Construction of MPPF capacitors

2.2 SELF HEALING

When there is a fault(short circuit due to pin holes etc.,) in the dielectric, fault current flows through both upper and lower electrodes surrounding the faulty area. As the fault current attempts to go through metal conductor which is very thin and translucent, electrode in the area of fault will get eroded and the current will be safely interrupted. Once the fault has been cleared, the capacitor will continue to function but with a little loss of capacitance[11]. One of the aging mechanisms of metallized polypropylene capacitors is because of reduction in capacitance due to erosion of the metal coating [12].

2.3 PHYSICAL PARAMETERS

The capacitance of a wound capacitor is given by

$$C = 2\ \varepsilon o \varepsilon r\ A / d \quad (1)$$

where εo is the absolute permittivity in F/m, εr is the relative permittivity of polypropylene dielectric, A is the area of metal plate excluding clear margin in m^2 and d is the thickness of dielectric in meter. Polypropylene dielectric has relative permittivity of 2.2, maximum operating temperature 105 °C, breakdown voltage strength 640 V/µm, dissipation factor less than 0.002 at 1kHz and the energy density 2 J/cm^3 [13]. The total resistance of the metallization from one edge of capacitor film to other is given by

$$R = R_{\square}\ w / l \quad (2)$$

Where R□ is the resistance of metallization per unit square, l and w are the length and width of capacitor winding in cm respectively[14].

3. MODELING

Figure 2 shows model of capacitor where the films are divided into number of mini squares [15]. Sum of the capacitances of individual mini squares gives the total capacitance.

3.1 MODEL OF TWO HEALTHY STRIPS

Figure 3 shows view of two adjacent healthy strips across the width of upper electrode of film capacitor with ten mini squares in each strip. Each mini square is of 0.35cm x 0.35cm size. Thickness of polypropylene film is 6 micrometer and thickness of aluminium electrode is 30 nanometer. Figure 4 shows the electrical model of two adjacent healthy strips with upper and lower electrode and dielectric in between. R1 – R10 are the resistors in upper electrode and R11 – R20 are the resistors in lower electrode of strip 2. R21 – R30 are the resistors in upper electrode and R31 – R40 are the resistors in lower electrode of strip1. C1 – C22 represent capacitance of mini squares. Each mini square contributes a capacitance of 80pF, resistance of 6 ohms in upper electrode and 6 ohm in lower electrode. In upper electrode section 1 is closer to contact edge, section 10 is closer to clear margin and it is the other way in the lower electrode.

3.2 MODEL OF SELF HEALED STRIPS

Figure 5 shows two adjacent strips with metal erosion caused by self healing at the tenth mini square of first strip. In the eroded area of metallization, resistance becomes infinity and capacitance becomes zero. Due to erosion at 10^{th} mini square of strip -1 the related parameters change as $R_{30} = \infty$; $R_{40} = \infty$; $C_{21} = 40$ pF and $C_{22} = 0$.

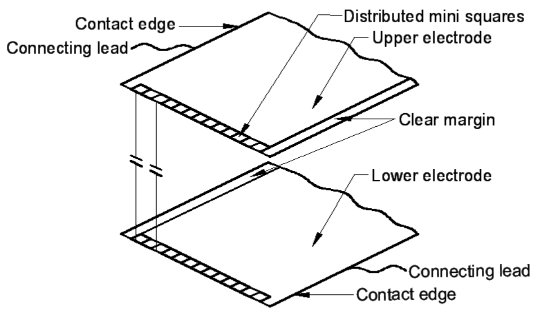

Figure 2. Three dimensional view of film capacitor divided into mini squares

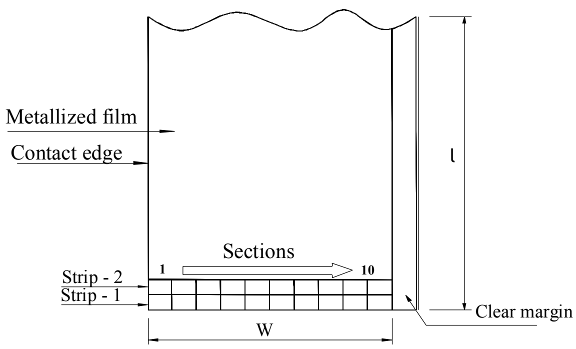

Figure 3.Two healthy strips across 3.5cm width with 0.35cm x 0.35cm mini squares. w – Effective width of metallized film; l – length of metallized film.

3.3 MODEL TAKEN FOR ANALYSIS

In this study, 10 parallel strips with ten mini squares in each strip are taken for analysis incorporating self healing of various magnitudes (from 1to 9%) at different locations from sections 1 to 10. Physical parameters taken are width of the film 35 mm; size of each mini square 3.5mm x3.5mm; metal film resistance 6 ohms per square; thickness of polypropylene dielectric 6µm and metal electrode thickness 30 nm. As an example, Figure 6 shows 10 strips with 5% of SH at section-6.

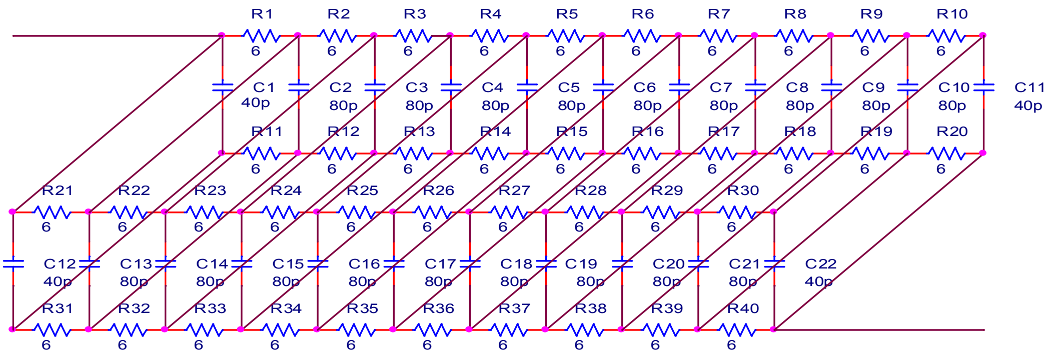

Figure 4. Electrical model of two adjacent healthy strips with 10 mini squares in each strip.

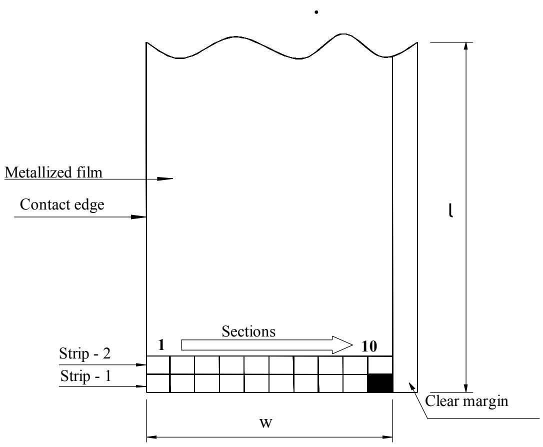

Figure 5. Two strips with metallic erosion at 10th mini square of first strip

Analysis made with 10 strips and results obtained hold good for any length of capacitor film. For computations of power distribution, PSPICE simulation package is used.

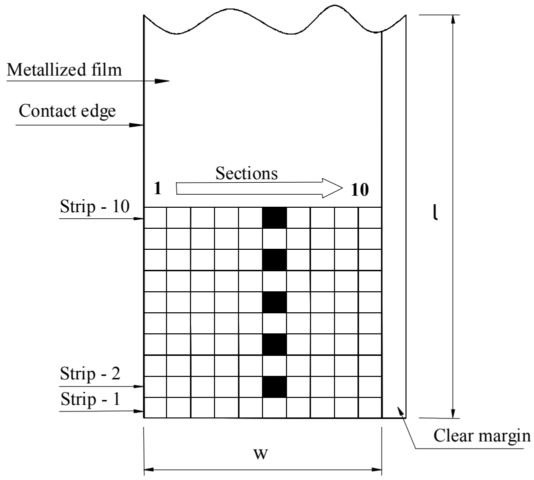

Figure 6. Electrode with 5% erosion at section 6 due to self healing

4 RESULTS AND ANALYSIS

4.1 POWER PROFILE UNDER HEALTHY AND SELF HEALED CONDITION

Table 1 shows the power density at the remaining healthy area of eroded section for different magnitudes of self healing occurring at various locations(sections) in the upper electrode. Calculations are made with 100 Vac and 1 kHz frequency. For the lower electrode results are sectionally reverse to that of upper electrode. In the eroded sections power density increases as the actual current carrying area decreases. Figure 7 gives 3D plot of power density at the remaining healthy area of eroded section as a function of magnitude and location(section) of SH for the upper electrode. For the lower electrode power density plot is spatially reversed. Fig.8 gives percentage increase in power density when SH occurs at different magnitudes compared to healthy case at sections 3, 5 and 7. Percentage rise in power density with respect to the healthy case is calculated as

$$\% P_d = \{ (P_{dsh} - P_{dh}) / P_{dh} \} \times 100$$

Where $\%P_d$ is the percentage rise in power density, P_{dsh} is the power density in the remaining healthy area of self healed section of electrode and P_{dh} is the power density under healthy condition.

From the power density analysis it is inferred that

a. Power density remains minimum and constant independent of magnitude of self healing when SH occurs at the section nearer to clear margin

b. Power density is found maximum when SH occurs at the section nearer to contact edge.

c. From Fig 8, it is observed that beyond 5% SH, percentage rise in power density increases rapidly. Upto 5% of SH rise in power density curves are nearly lying on the x axis.

d. For 5% of self healing percentage increase in power density is 279% where as it is 8975% for 9% self healing at the section nearer to contact edge. (i.e. at section 1 for upper electrode and at section 10 for the lower electrode)

Table 1 Power density for different magnitudes of Self Healing occurring at various sections on upper electrode at 100 Vac and 1 kHz. SH – Self Healing PdSn – Power density at the remaining healthy area of n^{th} self healed section of electrode.

	Power Density (µw/cm²)									
Condition of strip	Pds1	Pds2	Pds3	ds4	Pds5	Pds6	Pds7	Pds8	Pds9	Pds10
Healthy Strip	11.05	8.85	6.89	5.17	3.70	2.48	1.50	0.77	0.28	0.03
1% SH	13.50	10.79	8.39	6.29	4.49	2.99	1.80	0.91	0.32	0.03
2% SH	16.91	13.50	10.48	7.84	5.58	3.70	2.21	1.10	0.38	0.03
3% SH	21.85	17.42	13.50	10.08	7.15	4.73	2.80	1.38	0.46	0.03
4% SH	29.42	23.43	18.13	13.50	9.55	6.29	3.70	1.80	0.57	0.03
5% SH	41.91	33.34	25.74	19.13	13.50	8.85	5.17	2.48	0.77	0.03
6% SH	64.78	51.46	39.67	29.42	20.69	13.50	7.84	3.70	1.10	0.03
7% SH	113.91	90.37	69.55	51.46	36.09	23.43	13.50	6.29	1.80	0.03
8% SH	253.50	200.85	154.32	113.91	79.62	51.46	29.42	13.50	3.70	0.03
9% SH	1002.89	793.50	608.60	448.19	312.28	200.85	113.91	51.46	13.50	0.03

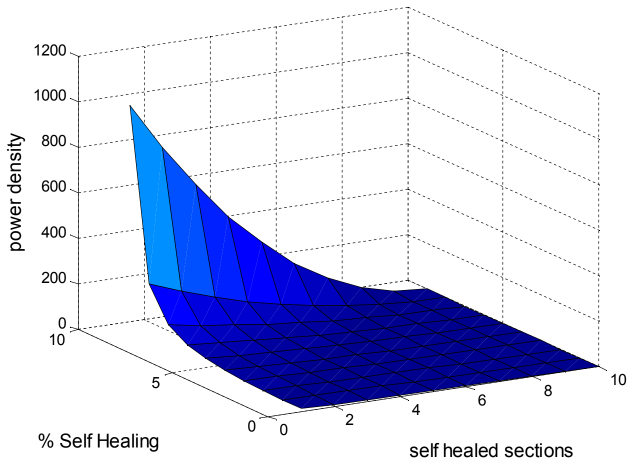

Figure 7. 3D graph of power density (µw /cm^2) in the remaining healthy area of self healed section as a function of magnitude and location(section) of SH

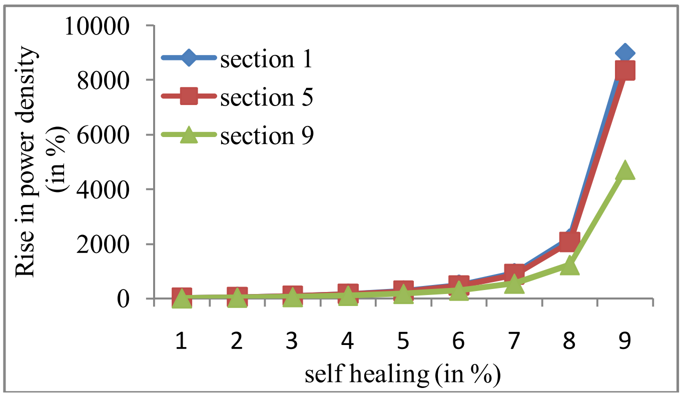

Figure 8. % Rise in Power density

4.2 COMBINED POWER DENSITY PROFILE UNDER SELF HEALED CONDTION ON BOTH THE ELECTRODES

Combined power density profile can be studied by plotting power density on both upper and lower plates simultaneously.

Figure 9 shows power density in the remaining healthy area of self healed section on upper and lower electrodes when self healing occurs in various sections at different magnitudes. From the plot it is evident that power density is less while self healing occurs at the middle of film's cross width. As location of self healing moves from centre towards contact edge across the width (for lower and upper electrodes contact edges lie at the opposite ends), power density increases rapidly. As location of self healing moves from centre towards clear margin across the width (for lower and upper electrodes clear margin lie at the opposite ends), power density decreases rapidly. (Refer Fig.1).

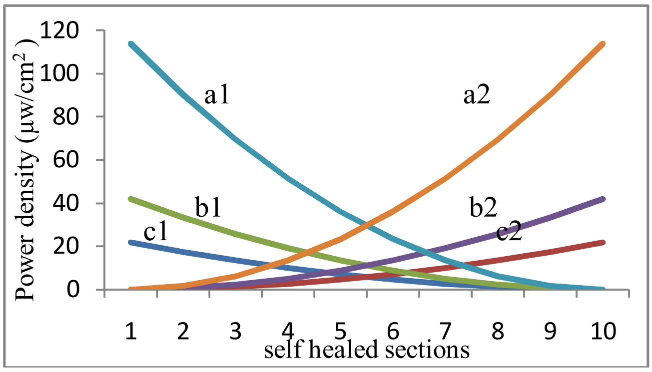

Figure 9. Power Density in µw/cm^2 at remaining healthy area of self healed section when SH occurs at different sections a1. Upper electrode – 7% SH; a2.. Lower electrode – 7% SH b1. Upper electrode – 5% SH b2. Lower electrode – 5% SH c1. Upper electrode – 3% SH; c2. Lower electrode – 3% SH

5 CONCLUSION

In this study, with 10 stage element modeling, cross width strips of MPPF capacitor is analyzed incorporating the effect of self healing. Power profiles are computed using PSPICE. From the analysis the following are inferred.

a. As the magnitude of loss of capacitance increases due to self healing process, current density and power density increase in the path adjacent to the eroded area.

b. Location of SH plays a dominant role in the power profiles. When self healing ccurs at the middle of cross width, performance is less affected where as self healing near the edges causes increased current density and higher power dissipation on either of the electrodes.

c. Through modeling it is theoretically proved, beyond 5% of self healing, power density of remaining healthy area adjacent to self healed area increases rapidly.

d. For 5% of SH, percentage increase in Power density at the adjacent path of eroded area is 279% where as it is 8975% for 9% self healing when SH occurs nearer to contact edge.

e. Reason for worsening of the performance of MPPF capacitor beyond 5% SH is because of rapid increase in power density and current density of the electrodes.

f. Effect of SH at different magnitudes and various locations are reported quantitatively.

g. Analysis made with 10 strips and results obtained hold good for any length of capacitor film.

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