IMPROVEMENT CHARACTERISTICS OF HIGH VOLTAGE CAPACITORS USING NEW NANOCOMPOSITE MATERIALS

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Abstract: The objective of the present contribution is to compute ESL, ESR, volumetric energy density, peak discharge current, etc. for multi section, high voltage windings, including limitations caused by various new nanocomposite materials. This paper explains the enhancement on the conventional High voltage metalized film capacitor doped with the Nanoparticles; our advanced model has been discussed how the characteristics of High voltage metalized film capacitor enhanced depending on the concentration of the doped Nanoparticles and also their electric and dielectric properties. Also, This paper has been investigated novel Nano-metric industrial materials for enhancing the electrical performance of multi section metalized film capacitors which satisfy a large variety of ac applications, electronic applications, and optimizing the characteristics of metalized film capacitors for specific applications by selecting suitable nanocomposite materials. Adding nanofillers to the conventional materials of multi section metalized film capacitors has been enhanced the dielectric constant, dielectric strength, self-healing properties, temperature stability and volumetric efficiency that allowing to achieve the highest capacitance per unit volume this type of capacitors. Theoretical results have been investigated for comparing with conventional structure materials and new nanocomposite industrial materials of multi section metalized film capacitor.

Keywords: ESL, ESR, volumetric energy density, Nano-composite, Nanoparticles

1 INTRODUCTION

A large high voltage film capacitor typically consists of numerous “windings” connected in series and parallel, as necessary to achieve the desired voltage and capacitance rating. The discharge properties of such a capacitor are determined by the equivalent series resistance (ESR) and equivalent series inductance (ESL). THE inductance, ESR, and implications thereof for pulsed power applications of single section metalized film capacitor windings were discussed in a recent publication [1]. High voltage metalized film capacitor windings usually employ multiple sections in series based on the use of floating electrodes, which introduces a substantial number of issues beyond those considered in The obvious advantage of a multiple section winding is the support of high voltages in a compact structure. The disadvantages are several, including: Firstly when clearing occurs in one section, the voltage of that section is transferred to other sections. For a small number of sections, this can cause clearing in another section. In the Worst case, continuous clearing may destroy the capacitor. And secondly the potential between sections which occurs along the surface of the film, between wound layers. The breakdown strength of the film is laminar system, the breakdown strength along the layer surface is weak and depends on the interfacial pressure, which means the pressure between layers after “curing” of the winding, i.e., thermal relaxation of mechanical stresses therein. In general, the interfacial pressure increases with decreasing radius within the winding.

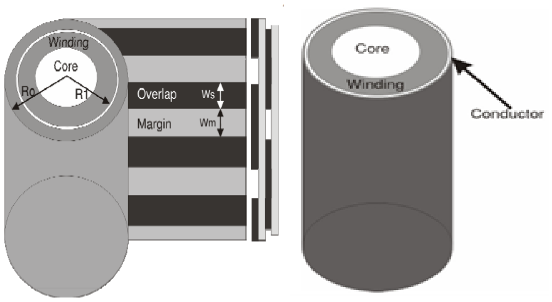
This study metalized capacitor with nanocomposite films were newly introduced and fully characterized. Nanocomposite film improves charge density and performance of the capacitor. Recently published a study of the relationship of winding inductance (ESL) and equivalent series resistance (ESR) to winding design based on bringing current from one end of the winding back to the other, either along the outside radius or through the center of the winding[2]. The former generally resulted in lower inductance than the latter. As would be expected, ESR was reduced by using narrower film to produce a more “pancake” like winding, which also tended to reduce the ESL. Thus the relationships among film metallization resistivity, film dielectric constant, winding design, ESR, and ESL are understood. Current rise times has been suggested less than a few hundred ns are unlikely based on metalized film windings, although very high peak current can be realized if the end connections can sustain them[3]. The nature of end connections is a complex subject beyond the scope of the present discussion [4-6].The present contribution focuses on the effect of adding nano-fillers to high voltage capacitor to enhance ESR and ESL, i.e., how to minimize the contribution to ESR and ESL which results from connecting multiple windings in series and parallel as necessary to meet a given voltage and capacitance rating.

2 ANALYTICAL MODEL

In order to minimize inductance, the connections must be at one end of the winding so that the magnetic field outside the winding can be minimized. One option for achieving this is to employ two coaxial windings separated by a coaxial insulator so that the current goes down one winding, transfers to the other winding, and comes back to the same end of the capacitor Figure 1. (a). this reduces the required width of the winding by a factor of two and reduces inductance slightly. Another option is to have one, very wide winding with the return on a coaxial conductor Figure 2. (b). for a single winding (Figure 2), the total film width is:

$$W= N\,(Ws + Wm) \tag{1}$$

Where N is the number of sections, Ws is the electrode overlap width for each section, and Wm is the margin width between sections as illustrated in Figure 1 for a 4-section winding. In the case of two coaxial windings the width of each winding is half of W.



(a) Multisession coaxial winding (b) Single winding capacitor
Figure 1. Construction of high voltage metalized film capacitor

We define the “volumetric efficiency” or “fraction of useful volume”, Vf, as the ratio of the volume of the overlap section part of the winding which stores energy to the total volume V.

$$Vf = \frac{N.Ws.Se}{V} \tag{2}$$

$$Se = 2Ls.Df \tag{3}$$

Where Se is the end connection area, Ls is the film length and Df is the thickness of dielectric material in one turn of the winding. Ro is the outer radius of the outer winding (Figure 1). In the coaxial case this can be expressed as:

$$Ro = \sqrt{(\frac{Se}{\Pi} + (R1 + Dg)^2} \tag{4}$$

$$R1 = \sqrt{(\frac{Se}{\Pi} + R1^2} \tag{5}$$

Where R1 is the outer radius of the inner winding and Dg is the thickness of the insulation between the coaxial windings in Figure 1 or between the winding and conductor in Figure 2, Ri is the inner radius of the windings. In equation 3, Ls can be expressed as

$$Ls=Ss/Ws \tag{6}$$

Ss is the overlap area for each section which is given by:

$$Ss = \frac{Cs.Df}{2.\varepsilon.\varepsilon o} \tag{7}$$

where C_o is the capacitance for each section

$$Co=N.C \tag{8}$$

C is the total capacitance of the multi-section capacitor winding and N is the number of sections. As section electrode overlap increases, the winding length decreases which increases the ESR. The contribution to the ESR caused by the overlap regions is given by [1],

$$ESRo = \frac{4N.\varepsilon.\rho o.\varepsilon o.Ws.}{3.Df.Co} \tag{9}$$

And the resistance caused by the resistivity of the margin regions between winding sections is:

$$ESRm = \frac{N.\rho m.Wm.}{Ls} \tag{10}$$

Where the unit of ρm and ρo is Ω or Ω/sq. The total ESR is the sum of these two contributions.

$$ESRm = ESRm + ESRo \tag{11}$$

Assuming the current through a capacitor is I, the inductance can be obtained from integrating the energy in the magnetic field as shown in equation (12). In this work, Ampere’s law was applied to approximate the magnetic field from the current and to derive the magnetic energy density.

$$L = \frac{1}{I^2.\mu o}\int B^2\, dV = \frac{2Wm}{I^2} \tag{12}$$

Based on equation (12), the inductance for the winding with similarly, for the coaxial winding structure discussed above, the inductance is given by the outer return structure can be obtained with reasonable accuracy from equation (13)

$$L2 = \int_{Ri}^{R1} \frac{\mu\pi W(R^2 - Ri^2)^2}{8.R.Ls^2.Df^2} dR + \int_{Ri}^{R1} \frac{\mu\pi W}{2\pi R} dR \tag{13}$$

Similarly, for the coaxial winding structure discussed above, the inductance is given by

$$L = \int_{Ri}^{R1} \frac{\mu\pi W(R^2 - Ri^2)^2}{8.R.Ls^2.Df^2} dR + \int_{R1}^{R1+Dg} \frac{\mu\pi W}{2\pi R} dR + \int_{R1+Dg}^{Ro} \frac{\mu\pi W(Ro^2 - R^2)^2}{8.R.Ls^2.Df^2} dR \tag{14}$$

In any application, the load resistance should be substantially greater than the capacitor winding ESR in order to transfer most of the energy stored in the capacitor winding to the load. In much of the analysis below, we assume that the load resistance is 9 times greater than the ESR so that total resistance in the circuit is 10 times the ESR. Since the load impedance may be fixed, the load impedance may dictate a maximum capacitor ESR. We can derive the time to peak current, Tp, and the peak current, Ip.

$$Tp = \frac{Ln(\frac{p1}{p2})}{p2-p1} \tag{15}$$

$$\{\ p1,2 = \frac{-R}{2ESL} \pm \sqrt{\frac{R^2}{4\,ESL^2} - \frac{1}{ESL.C}}\ \}$$

The peak current:

$$Ip = \frac{-Uo}{ESL(P2-P1)}(e^{p1.Tp} - e^{p2.Tp}) \tag{16}$$

The useful volume of the capacitor is defined as the volume of the overlap sections which store energy, given by:

$$V_{use} = 2 \cdot N \cdot L_s \cdot D_f \cdot W_s \quad (17)$$

The overall volume of the capacitor:

$$V1 = \pi . Ro^2 \frac{N}{2}(Ws + Wm) \quad (18)$$

If the core volume is excluded, the overall volume is:

$$V2 = \pi(Ro^2 - Ri^2).\frac{N}{2}.(Ws + Wm) \quad (19)$$

The mulitsection, coaxial winding structure has two components of volume which increase in proportion to the section overlap, i.e., the volumes of (i) the core and (ii) the coaxial insulator between the two coaxial windings. The power density at peak current where Rload is the load resistance, here 9 times the ESR.

$$Pd = Ip^2 . R_{load} / V2 \quad (20)$$

3 SELECTED MATERIALS

polypropylene is one of the most important polymers where it is used as insulation of modern HV capacitors. Fumed Silica, Mgo and Clay the main advantages of this fillers are Costless and Have a great effect on properties such as viscosity, stiffness and strength and dielectric properties. Although the interest here is primarily the dielectrically properties of this new class of material, it is likely that many of the applications will also take advantage of attendant changes in other attributes, particularly thermal conductivity, coefficient of the thermal expansion and thermal endurance. Table [1] provide overview of industrial materials which currently presented in this paper.

Table 1: Industrial insulation materials characteristic

Polymer	Dielectric constant	Nonmaterial's	Dielectric Constant
Polypropylene	2.3	MgO	9.7
		Fumed Silica	4.5
		Clay	2.3

4 RESULTS AND DISCUSSION

A 100 kV capacitor winding could be based on 4 layers of 7μm capacitor film, two metalized and two un-metalized. For a single winding capacitor, the winding width is the width of the margins plus the total width of the overlap of the sections. In the coaxial configuration, the total winding width will be half this value. We assume a metallization resistivity in the overlap regions of ρ_0=100 Ω/sq and ρ_m=10 Ω/sq in the margin regions. High resistivity in the overlap regions improves clearing efficiency and low resistivity in the margin regions reduces the ESR.

The winding diameter can depend on several factors including film thickness and length of film edge. To support the 100 kV potential difference across the end connections, thickness of the insulator layer cannot be less than ~3 mm.

4.1 Effect of Nanoparticles on ESR of high voltage metalized film capacitors

Based on the multi section structure of high voltage capacitor, all the parameters can be expressed as functions of section overlap width. Figure 3 shows the ESR as a function of section overlap width using different film materials, The ESR increases with increasing section overlap width and Mgo Nanoparticles enhance the value of ESR

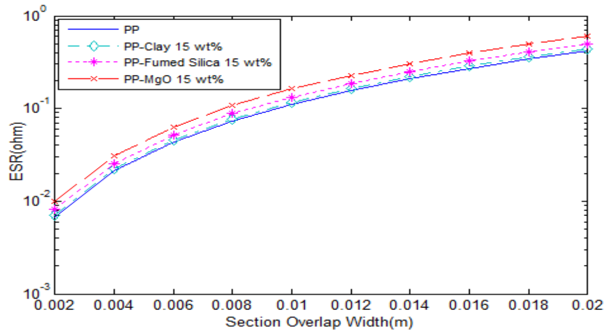


Figure 2. ESR as a function of section overlap width.

4.2 Effect of Nanoparticles on ESL of high voltage metalized film capacitors

Figure 3 shows the ESL for the coaxial winding structure as a function of section overlap width. As shown in the figure MgO Nanoparticles reduce and enhance the value of ESL of high voltage metalized film capacitor.

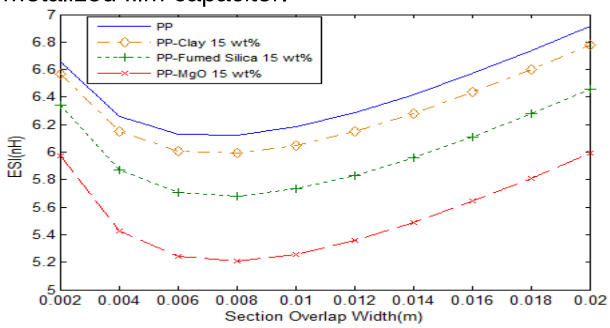


Figure 3. ESL as a function of section overlap width

4.3 Effect of Nanoparticles on discharge characteristics of high voltage metalized film capacitors

Figures 4 and 5 show the based on the ESL and ESR computed for a three nanocomposites. As shown in figure 4, MgO Nanoparticles enhance the time to peak current and so Figure 5 shows that the MgO Nanoparticles reduce the peak current.

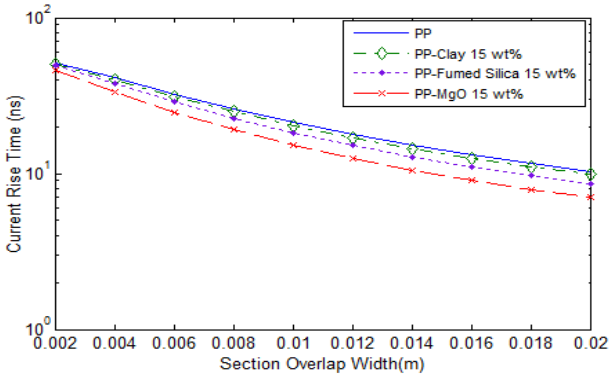


Figure 4. Current rise time as a function of section overlap width.

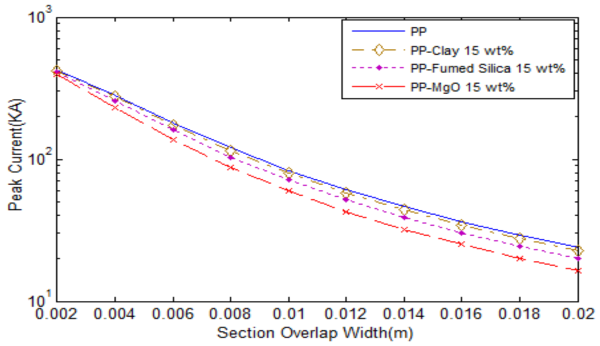


Figure 5. Peak current for the multi section capacitor as a function section overlap width.

4.4 Effect of Nanoparticles on Energy density of high voltage metalized film capacitors

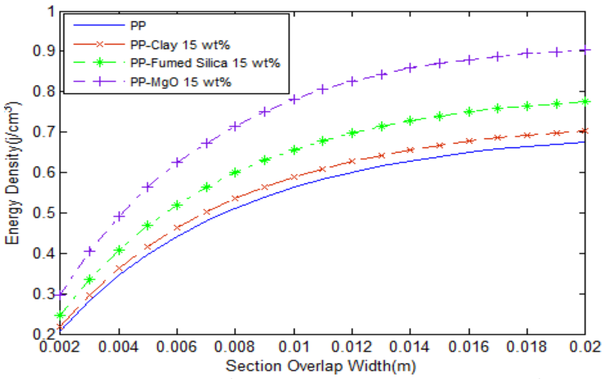


Figure 6. Energy density for the multi section capacitor as a function of section overlap width, without the effect of the core volume.

Figures 6 and 7 show the energy density as a function of section overlap width in case of a three nanocomposites and as shown in these figures, MgO nanoparticles enhance energy density of high voltage metalized film capacitors

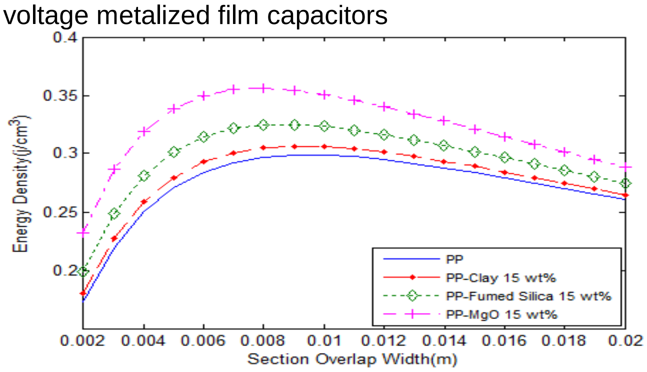


Figure 7. Energy density for the multisession capacitor as a function of section overlap width, with the effect of the core.

5 CONCLUSION

For a multi section, high voltage, low inductance capacitor, peak current and peak power density are likely to be dominated by end connection current density. Such windings have the potential for current densities and power densities far in excess of what present end connection technology can withstand. Adding nanofillers (Clay, Mgo and Fumed Silica) increase ESR, ESL and Energy density and reduce peak current and rise time which give high voltage capacitors with good limitation of end connection current. Effect of Mgo spherical Nanoparticles is higher than fumed silica and clay on characteristic of high voltage capacitor Adding Mgo Nanoparticles to polypropylene give best values of ESR, ESL and energy density and peak current and rise time.

6 ACKNOWLEDGMENT

The present work was supported by the Science and Technology Development Fund (STDF), Egypt, Grant No: Project ID 505.

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