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ENHANCING PERFORMANCE OF HIGH VOLTAGE METALLIZED FILM CAPACITORS BY USING NEW INDUSTRIAL NANO-COMPOSITES

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This paper explains the enhancement on the performance of conventional High voltage metalized film capacitor doped with the Nanoparticles; the studied model has been discussed how the characteristics of High voltage metalized film capacitor has been enhanced depending on the concentration of the doped Nanoparticles and also their electric and dielectric properties. Also, this research investigates 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 enhanced the dielectric constant, dielectric strength, self-healing properties, temperature stability and volumetric efficiency that allowing achieving the highest capacitance per unit volume for 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. Finally, the present contribution has computed equivalent series inductance (ESI), equivalent series resistance (ESR), volumetric energy density, peak discharge current …etc. for multi section, high voltage windings, including limitations caused by various new nanocomposite materials.

KEYWORDS: *ESI, ESR, volumetric energy density, Nano-composite, Nanoparticles, Capacitors*

1. INTRODUCTION

Over the recent years particulate composites have received much attention particularly with the introduction of nanoparticles. Nanoparticles offer improved mechanical, electrical, and thermal properties of composites at relatively low concentrations. One of the important properties of composites in general is their dielectric properties which have been studied extensively. More recently however, research tends to suggest that the dielectric properties of the interphase are also inhomogeneous, varying with respect to the radial distance from the centre of the spherical inclusion [1-3]. Such an inhomogeneous transition is due to the bonding mechanisms occurring in the space between the inclusion and matrix. A controlled design of the spatial varying property also enables one to control the overall property of composites [2]. Results for the dielectric constant have been published for two-phase composites in which perfect

bonding is assumed to exist between the inclusion and the matrix. The results are from Maxwell-Garnett theory [1] with the same result derived later by using the composite spheres assemblage model [4]. This same result can also be used for the electrical and thermal conductivity, magnetic permeability and diffusivity, provided that the spherical inclusions and matrix are isotropic. There has been a first principles approach developed to find the effective dielectric response of composites with a dilute suspension of graded spherical particles. Vo and Shi measured the dielectric properties of composites as a function of inclusion concentration using a proposed theoretical model based on effective medium theory [4 - 6]. 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 (ESI). THE inductance, ESR, and implications thereof for pulsed power applications of single section metalized film capacitor windings were discussed in a recent publication [7]. 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. 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 introducedand fully characterized. Nanocomposite film improves charge density and performance of the capacitor. Recently published a study of the relationship of winding inductance (ESI) 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[8]. 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 ESI. Thus the relationships among film metallization resistivity, film dielectric constant, winding design, ESR, and ESI are explained. 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[9]. The nature of end connections is a complex subject beyond the scope of the present discussion [10, 11].

Optimizing the dispersion of nanosized ceramic particles has been occurred for achieving higher dielectric constant, thereby higher capacitance density in nanocomposites. It has been observed that high solids loading leads to entrapment of porosity in the microstructure which lowers the effective dielectric constant of the films. Also, it is cleared that, the interplay between the rheological properties of the nanoparticles and polymer matrix have effective factors on the dielectric properties of

the film capacitors. And so, the use of multiple sections within a metalized film capacitor facilitates high voltage and reduced equivalent series resistance within a compact winding. As a result of high voltage and low inductance, large peak currents are, in principle, possible. The limitation to the peak current and power density is the ability of the end connection to withstand the peak current. The energy density of multi-section windings is also limited by the margins which are required between sections, the total width of which is limited solely by the rated voltage and margin operating field. Nanocomposites of organically modified nanoparticles in an epoxy matrix have been synthesized and evaluated as dielectrics for the fabrication of integral thin film capacitor arrays. Organic modification of the polymer inorganic interface has been used as a design tool to control the cross link density of the polymeric matrix and the interfacial interactions [13-18].

In this work, a new dielectric nanocomposites which consist of a polymer and various types of nanoparticles have been developed for application in thin film metalized capacitors. The nanocomposite polymer is custom formulated for high dielectric constant and strength with minimum dielectric losses. The nanocomposite can be wound and processed using conventional wound film capacitor manufacturing equipment. Also, the present contribution focuses on the effect of adding nanofillers to high voltage capacitor to enhance ESR and ESI, i.e., how to minimize the contribution to ESR and ESI 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 as shown in Fig. (1.a), this reduces the required width of the winding by a factor of two and reduces inductance slightly [13]. Another option is to have one, very wide winding with the return on a coaxial conductor Figure 2. (b). For a single winding as shown in Fig. (2), the total film width is:

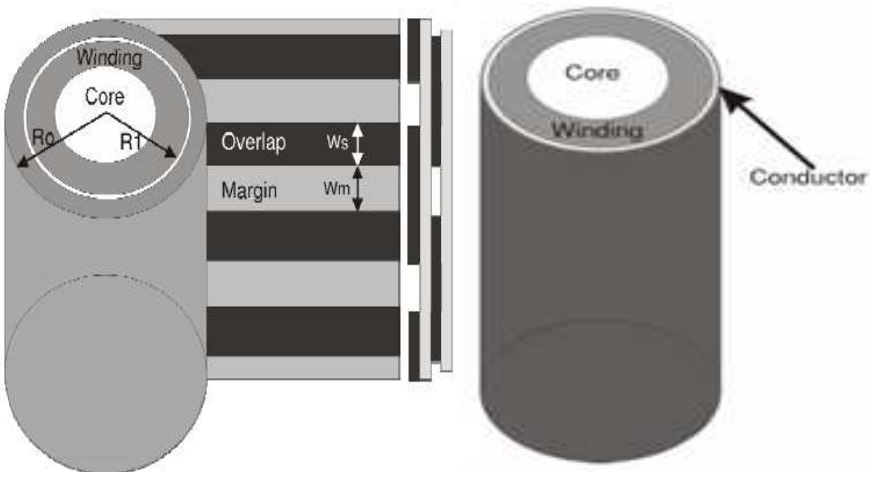
$$W = N\,(Ws + Wm) \tag{1}$$

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.

It can be defined 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.

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

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



(a) Multisession coaxial winding (b) Single winding capacitor

Fig.1 Construction of high voltage metalized film capacitor

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 Fig. (1) in the coaxial case this can be expressed as:

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

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

Where *R1* is the outer radius of the inner winding and *Dg* is the thickness of the insulation between the coaxial windings in Fig. (1.a) or between the winding and conductor in Fig. (1.b), *Ri* is the inner radius of the windings. In equation 3, *Ls* can be expressed as

$$Ls=Ss/Ws \quad (6)$$

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

$$Ss = \frac{Co.Df}{2.\varepsilon.\varepsilon o} \quad (7)$$

where *Co* is the capacitance for each section

$$Co=N.C \quad (8)$$

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],

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

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

$$ESRm = \frac{N.\rho m.Wm}{Ls} \quad (10)$$

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

$$ESRm = ESRm + ESRo \quad (11)$$

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.

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

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)

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

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

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

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, it has been assumed that "as shown in ref [13]" 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.

$$Tp = \frac{\mathrm{Ln}(\frac{p1}{p2})}{p2 - p1} \quad \{\ p1,2 = \frac{-R}{2ESI} \pm \sqrt{\frac{R^2}{4\,ESI^2} - \frac{1}{ESI.C}}\ \} \quad (15)$$

The peak current:

$$Ip = \frac{-Uo}{ESI(P2 - P1)}\left(e^{p1.Tp} - e^{p2.Tp}\right) \quad (16)$$

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 multi-section, 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 will be as follows, where R_{load} is the load resistance, here 9 times the ESR.

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

3. SUGGESTED INDUSTRIAL MATERIALS

3.1 Nanoparticles

- Clay mineral used in the polymer industry is kaolinite. Kaolinite is the main constituent of filler clays, significant quantities of other minerals can often be present. The particle shape is the most important characteristic of kaolinite for polymer applications. The platy nature means that clay fillers have a greater effect on properties such as viscosity, stiffness and strength, using clay as nano filler (10-100nm) gives high levels of flame retardancy to the produced composite, and it's selected in this study. Cost less of Clay catalyst to be the best filler among nano-fillers industrial materials.
- MgO: is the chemical compound silicon dioxide, also known as silica nano-silica with typical particle size of 10~50nm is widely used as fillers to improve the mechanical and thermal properties of polymers. Magnesium Oxide (MgO) film has high secondary electron emission (SEE) yield, and is found applications in flat panel display and other devices. However, the value of SEE yield strongly depends on the surface conditions and crystalline quality of MgO film. It is found applications in flat panel display and other devices; it can be used in nanowires and nanocapacitors applications.
- $BaTiO_3$: it can be used in low and high voltage capacitors applications. The following table contents some properties of Barium Titanate. $BaTiO_3$ production of spherical $BaTiO_3$ powders at 700 and 900°C by the spray pyrolysis of ethanol/water solutions of BaCl2 and $TiCl_4$ that were suspended using two-fluid and ultrasonic atomizers.

3.2 Industrial polymers

- Polypropylene: It is one of the most common and versatile thermoplastics in the plastics industry. Polypropylenes are perhaps the only thermoplastic surpassing all others in combined electrical properties, heat resistance, toughness, chemical resistance, dimensional stability, and surface gloss at a lower cost than most others. Filling polypropylene with a certain nanoparticles (Clay, MgO, and $BaTiO_3$) greatly increases electrical properties, tensile strength, impact strength, flexural modulus, and deflection temperature under load with a corresponding reduction in elongation according to type and percentages of nanofillers. Also, it is one of the most important polymers where it is used as insulation of modern HV capacitors. Table (1) shows overview of nanoparticles and industrial materials which are currently presented in this research.

Table1. Characteristics of Industrial Insulation Materials

Polymers	**Dielectric Constant**
Polypropylene	2.3
Nanoparticles	**Dielectric Constant**
Clay	2.8
$BaTiO_3$	3.8
MgO	9.7
Nanocomposites	**Dielectric Constant**
Polypropylene + 5wt% Clay	2.34
Polypropylene + 10wt% Clay	2.38
Polypropylene + 15wt% Clay	2.42
Polypropylene + 5wt% $BaTiO_3$	2.41
Polypropylene + 10wt% $BaTiO_3$	2.53
Polypropylene + 15wt% $BaTiO_3$	2.62
Polypropylene + 5wt% MgO	2.71
Polypropylene + 10wt% MgO	3.02
Polypropylene + 15wt% MgO	3.35

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_o=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 differences across the end connections, thickness of the insulator

layer cannot be less than ~3 mm. And so, with respect to the multi section structure of high voltage capacitor, all the parameters can be expressed as functions of section overlap width for studying the effects of various nanoparticles on high voltage metalized film capacitor.

4.1 Effect of clay nanoparticles on high voltage capacitors characteristics

Figures ((2.a) - (2.h)) illustrate the Equivalent Series Resistance (ESR), Equivalent Series Inductance (ESI), current rise time, the peak current, fraction of useful volume (excluding core), fraction of useful volume (including core), energy density (excluding core), and energy density (including core) respectively of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials PP with Clay nanoparticles. Figure (2.a) shows the effect of clay nanoparticles on the Equivalent Series Resistance (ESR). It is cleared that increasing percentage of clay nanoparticles in the polypropylene matrix increases the equivalent series resistance. Figure (2.b) shows the effect of clay nanoparticles on the Equivalent Series Inductance (ESI). It is cleared that increasing percentage of clay nanoparticles in the polypropylene matrix decreases the equivalent series inductance value in the high voltage metalized film capacitor clearly.

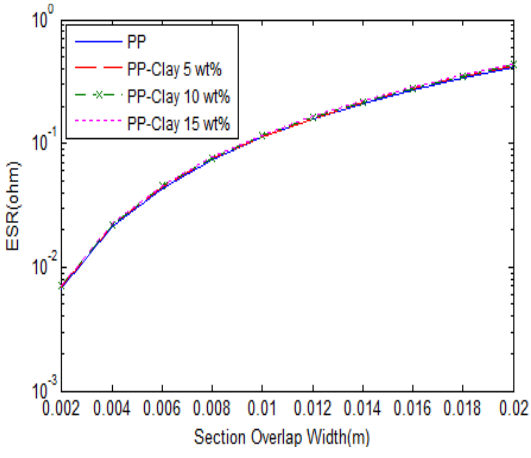


Fig. (2.a): ESR for metalized film capacitor

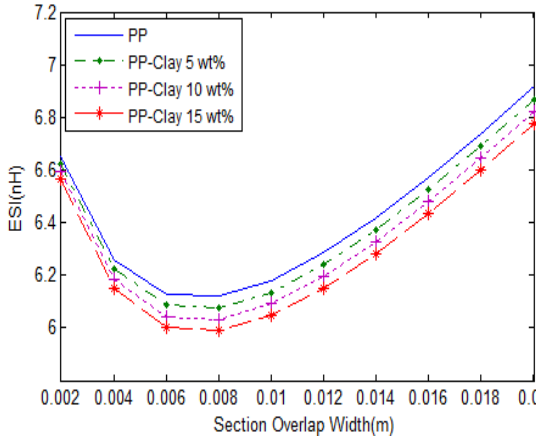


Fig. (2.b): ESI for metalized film capacitor

Figure (2.c) shows the effect of clay nanoparticles on the current rise time in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has no effect in the current rise time for the high voltage metalized film capacitor. The same behavior of peak current has been shown in Figure (2.d) and has cleared the effect of clay nanoparticles on the current rise time in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has no effect in the peak current for the high voltage metalized film capacitor.

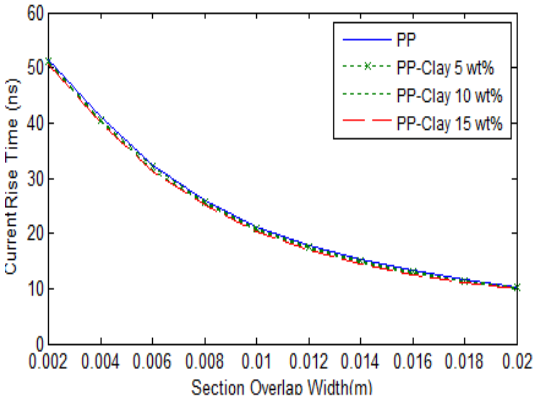


Fig. (2.c): Current rise time for metalized film capacitor

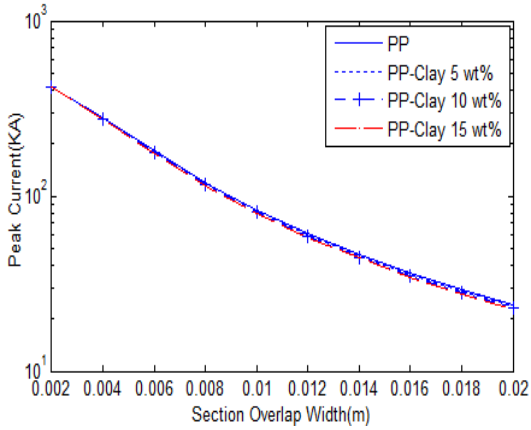


Fig.(2.d): Peak current time for metalized film capacitor

Figure (2.e) shows the effect of clay nanoparticles on the fraction of useful volume (excluding core) in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has low effect for decreasing the fraction of useful volume (excluding core) in the high voltage metalized film capacitor. Figure (2.f) shows the effect of clay nanoparticles on the fraction of useful volume (including core) in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has a clear effect for decreasing the fraction of useful volume (including core) in the high voltage metalized film capacitor.

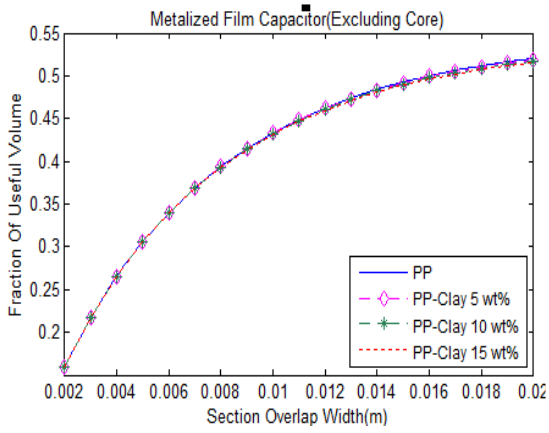


Fig. (2.e) Metalized film capacitor (Excluding Core)

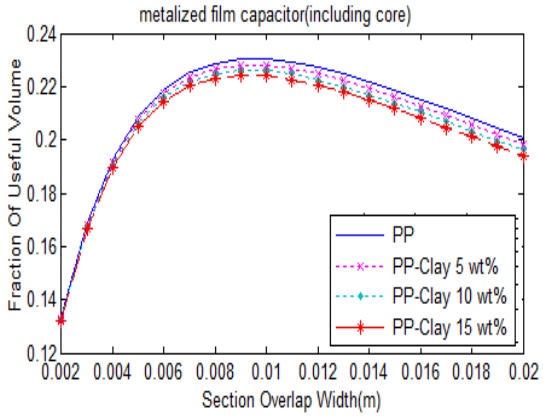


Fig. (2.f): Metalized film capacitor (Including Core)

Figure (2.g) shows the effect of clay nanoparticles on energy density (excluding core) in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has a clear effect for increasing energy density (excluding core) in the high voltage metalized film capacitor. Figure (2.h) shows the effect of clay nanoparticles on energy density (including core)

in the metallized film capacitors. It is shown that increasing percentage of clay nanoparticles in the polypropylene matrix has a clear effect for decreasing energy density (including core) in the high voltage metalized film capacitor.

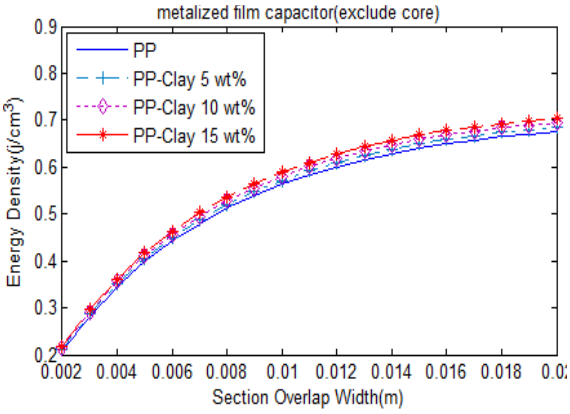


Fig. (2.g): Metalized film capacitor (Excluding Core)

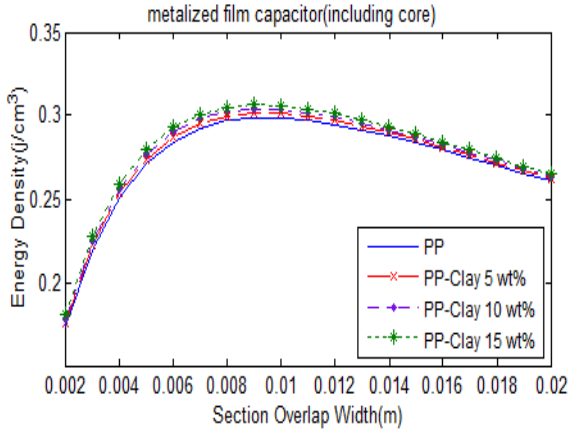


Fig. (2.h): Metalized film capacitor (Including Core)

Fig. 2 Effects of clay nanoparticles concentration on characteristics of metalized high voltage capacitors

4.2 Effect of $BaTiO_3$ nanoparticles on high voltage capacitors characteristics

Figures ((3.a) - (3.h)) illustrate the Equivalent Series Resistance (ESR), Equivalent Series Inductance (ESI), current rise time, the peak current, fraction of useful volume (excluding core), fraction of useful volume (including core), energy density (excluding core), and energy density (including core) respectively of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials PP with $BaTiO_3$ nanoparticles. Figure (3.a) shows the effect of clay nanoparticles on the Equivalent Series Resistance (ESR). It is cleared that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix increases the equivalent series. Figure (3.b) shows the effect of $BaTiO_3$ nanoparticles on the Equivalent Series Inductance (ESI). It is cleared that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix decreases the equivalent series inductance value in the high voltage metalized film capacitor clearly.

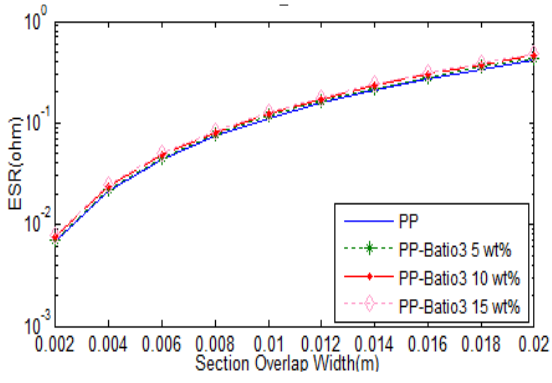


Fig. (3.a): ESR for metalized film capacitor

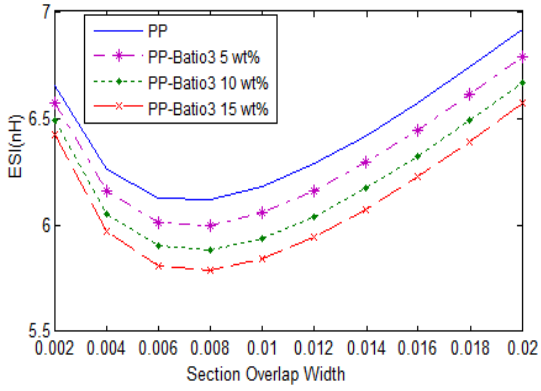


Fig. (3.b): ESI for metalized film capacitor

Figure (3.c) shows the effect of $BaTiO_3$ nanoparticles on the current rise time in the metallized film capacitors. It is shown that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix has low effect for decreasing the current rise time in the high voltage metalized film capacitor. The same behavior of peak current has been shown in Figure (3.d) and has been cleared the effect of $BaTiO_3$ nanoparticles on the current rise time in the metallized film capacitors. It is shown that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix has low effect for decreasing the peak current in the high voltage metalized film capacitor.

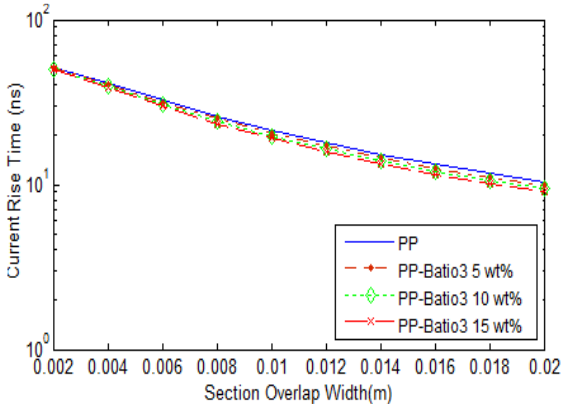


Fig. (3.c): Current rise time for metalized film capacitor

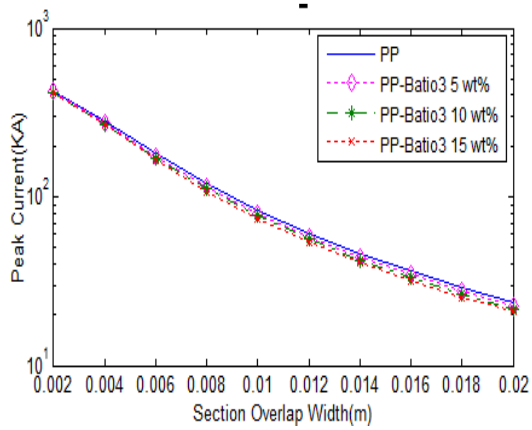


Fig.(3.d): Peak current time for metalized film capacitor

Figure (3.e) shows the effect of $BaTiO_3$ nanoparticles on the fraction of useful volume (excluding core) in the metallized film capacitors. It is shown that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix has low effect for decreasing the fraction of useful volume (excluding core) in the high voltage metalized film capacitor. Figure (3.f) shows the effect of $BaTiO_3$ nanoparticles on the fraction of useful volume (including core) in the metallized film capacitors. It is shown that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix has a clear effect for decreasing the fraction of useful volume (including core) in the high voltage metalized film capacitor. Figure (3.g) shows the effect of BaTiO3 nanoparticles on energy density (excluding core) in the metallized film capacitors. It is shown that increasing percentage of BaTiO3 nanoparticles in the polypropylene matrix has a clear effect for increasing energy density (excluding core) in the high voltage metalized film capacitor. Figure (3.h) shows the effect of $BaTiO_3$ nanoparticles on energy density (including core) in the metallized film capacitors. It is shown that increasing percentage of $BaTiO_3$ nanoparticles in the polypropylene matrix has a clear effect for decreasing energy density (including core) in the high voltage metalized film capacitor.

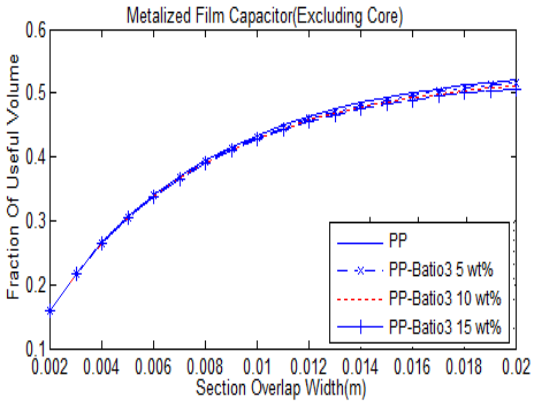


Fig. (3.e) Metalized film capacitor (Excluding Core)

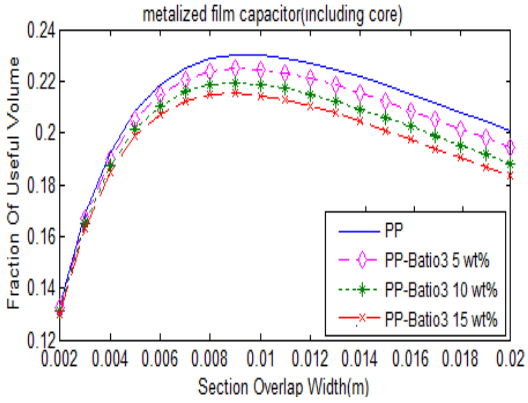


Fig. (3.f): Metalized film capacitor (Including Core)

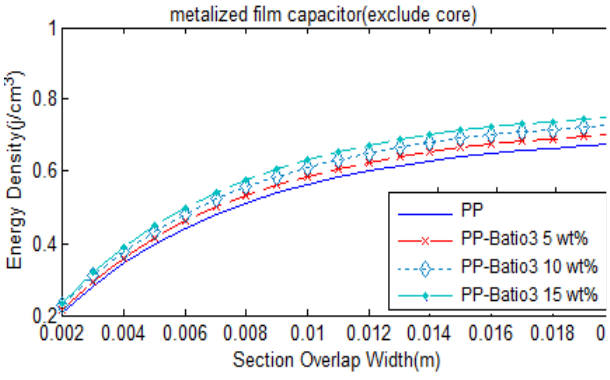


Fig. (3.g): Metalized film capacitor (Excluding Core)

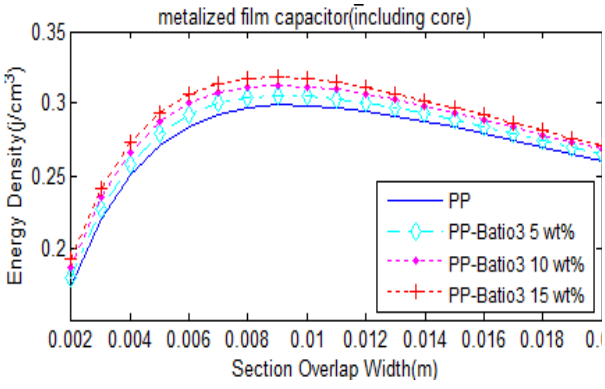


Fig. (3.h): Metalized film capacitor (Including Core)

Fig. 3 Effects of BaTiO3 nanoparticles concentration on characteristics of metalized high voltage capacitors

4.3 Effect of MgO nanoparticles on high voltage capacitors characteristics

Figures ((4.a) - (4.h)) illustrate the Equivalent Series Resistance (ESR), Equivalent Series Inductance (ESI), current rise time, the peak current, fraction of useful volume (excluding core), fraction of useful volume (including core), energy density (excluding core), and energy density (including core) respectively of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials PP with MgO nanoparticles. Figure (4.a) shows the effect of clay nanoparticles on the Equivalent Series Resistance (ESR). It is cleared that increasing percentage of MgO nanoparticles in the polypropylene matrix increases the equivalent series resistance clearly. Figure (4.b) shows the effect of MgO nanoparticles on the Equivalent Series Inductance (ESI). It is cleared that increasing percentage of MgO nanoparticles in the polypropylene matrix decreases the equivalent series inductance value in the high voltage metalized film capacitor very clearly. Figure (4.c) shows the effect of MgO nanoparticles on the current rise time in the metallized film capacitors. It is shown that

increasing percentage of MgO nanoparticles in the polypropylene matrix has high effect for decreasing the current rise time in the high voltage metalized film capacitor. The same behavior of peak current has been shown in Figure (4.d) and has cleared the effect of MgO nanoparticles on the current rise time in the metallized film capacitors. It is shown that increasing percentage of MgO nanoparticles in the polypropylene matrix has high effect for decreasing the peak current in the high voltage metalized film capacitor.

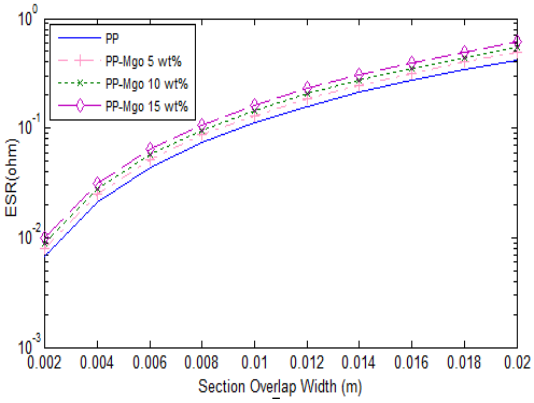


Fig. (4.a): ESR for metalized film capacitor

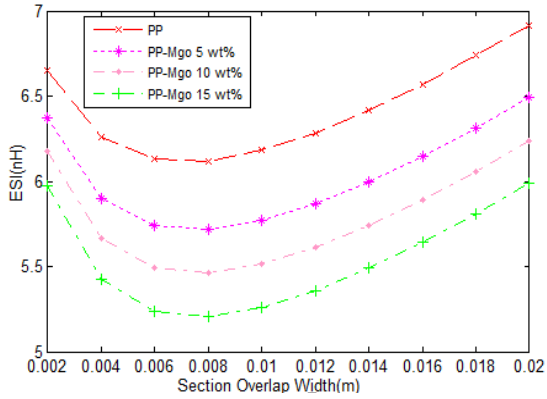


Fig. (4.b): ESI for metalized film capacitor

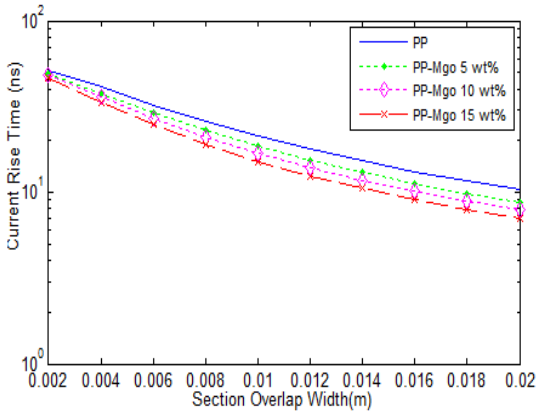


Fig. (4.c): Current rise time for metalized film capacitor

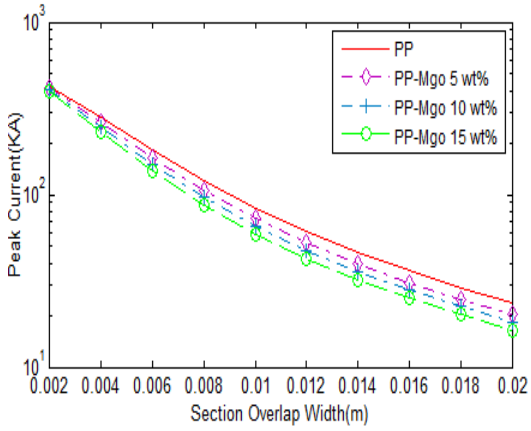


Fig.(4.d): Peak current time for metalized film

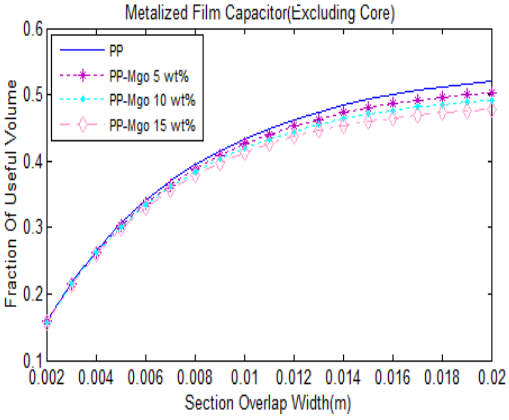


Fig. (4.e) Metalized film capacitor (Excluding Core)

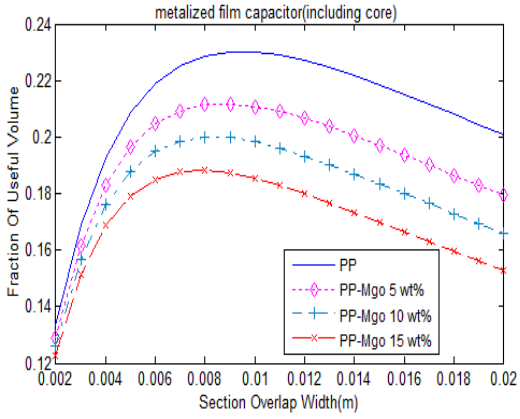


Fig. (4.f): Metalized film capacitor (Including Core)

Figure (4.e) shows the effect of MgO nanoparticles on the fraction of useful volume (excluding core) in the metallized film capacitors. It is shown that increasing percentage of MgO nanoparticles in the polypropylene matrix has high effect for decreasing the fraction of useful volume (excluding core) in the high voltage metalized film capacitor. Figure (4.f) shows the effect of MgO nanoparticles on the fraction of useful volume (including core) in the metallized film capacitors. It is shown that increasing percentage of MgO nanoparticles in the polypropylene matrix has a clear effect for decreasing the fraction of useful volume (including core) in the high voltage metalized film capacitor.

Noting that, Figure (4.g) shows the effect of MgO nanoparticles on energy density (excluding core) in the metallized film capacitors. It is shown that increasing percentage of MgO nanoparticles in the polypropylene matrix has a clear effect for increasing energy density (excluding core) in the high voltage metalized film capacitor. Fig. (4.h) shows the effect of MgO nanoparticles on energy density (including core) in the metallized film capacitors. It is shown that increasing percentage of MgO nanoparticles in the polypropylene matrix has a clear effect for decreasing energy density (including core) in the high voltage metalized film capacitor.

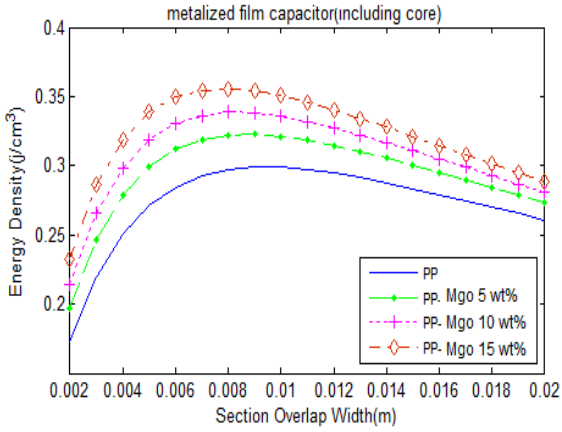


Fig. (4.g): Metalized film capacitor (Excluding Core)

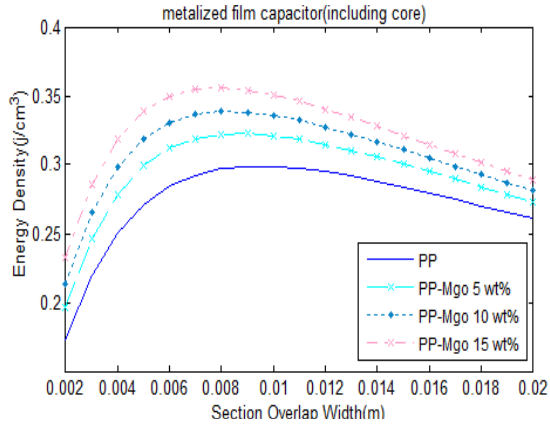


Fig. (4.h): Metalized film capacitor (Including Core)

Fig. 4 Effects of MgO nanoparticles concentration on characteristics of metalized high voltage capacitors

4.4 Effect of nanoparticles on ESR of high voltage metalized film

Figure (5) illustrates the Equivalent Series Resistance (ESR) of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). It is noticed that the Equivalent Series Resistance of the metallized film capacitors increases with increasing section overlap width for all used nanocomposite materials. Also, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the better one for enhancing the equivalent series resistance value within the investigated range.

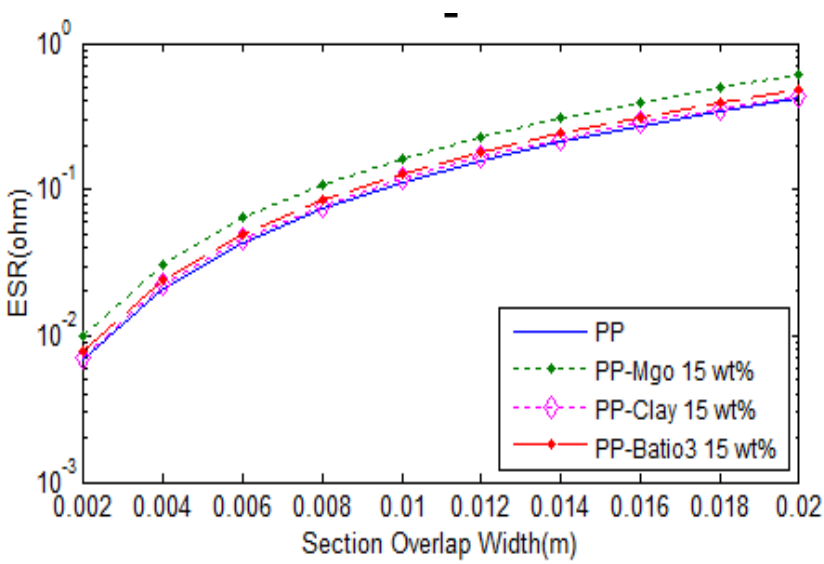


Fig. 5 ESR for high voltage metalized film capacitors with various new nano-composites

4.5 Effect of Nanoparticles on ESI of high voltage metalized film capacitors

Figure (6) illustrates the Equivalent Series Inductance (ESI) for the coaxial winding structure of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). It is noticed that the nanocomposite film materials which are composed of 15wt%MgO is the better one for decreasing the equivalent series inductance value in the high voltage metalized film capacitor within the investigated range.

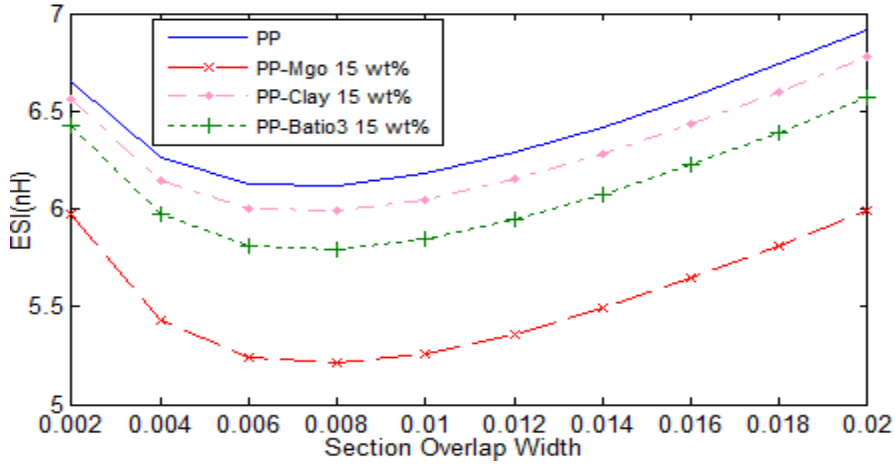


Fig. 6 ESI for high voltage metalized film capacitors with various new nano-composites

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

With respect to ESI and ESR which computed for three nanocomposites in Figures (5, and 6). Figure (7.a) shows the current rise time in the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). It is noticed that the current rise time in the metallized film capacitors decreases with increasing section overlap width for all used nanocomposte materials. Also, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the better one for decreasing the current rise time.

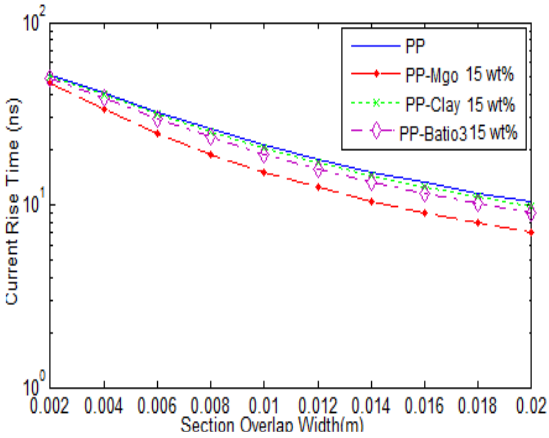


Fig. (7.a): Current rise time for metalized film capacitor

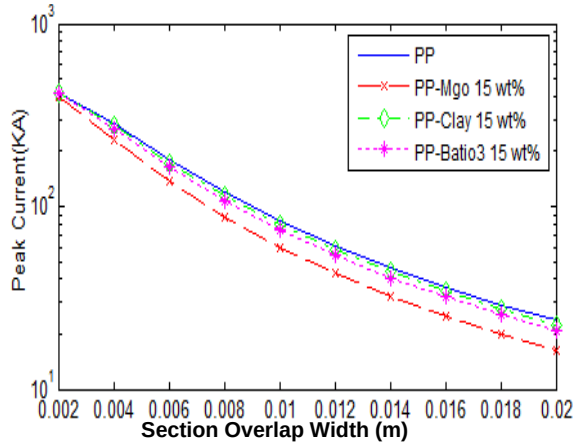


Fig.(7.b): Peak current time metalized film capacitor

Fig. 7 Current rise time and Peak current for high voltage metalized film capacitors with various new nano-composites

The same behavior of peak current has been shown in Figure (7.b) which is showing the peak current in the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). Fig. (7.b) also depicts that the peak current in the metallized film capacitors decreases with increasing section overlap width for all used nanocomposite materials. And so, the nanocomposite film material which composed of 15wt%MgO is the better one for decreasing the peak current value.

4.7. Effect of Nanoparticles on Fraction of Useful Volume in high voltage metalized film capacitors

Figure (8.a) depicts that the fraction of useful volume (excluding core) of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO).

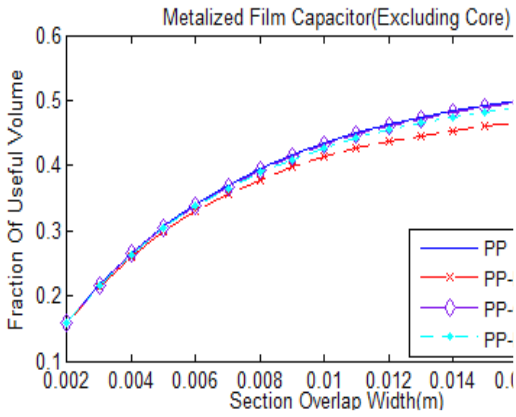


Fig. (8.a) Metalized film capacitor (Excluding Core)

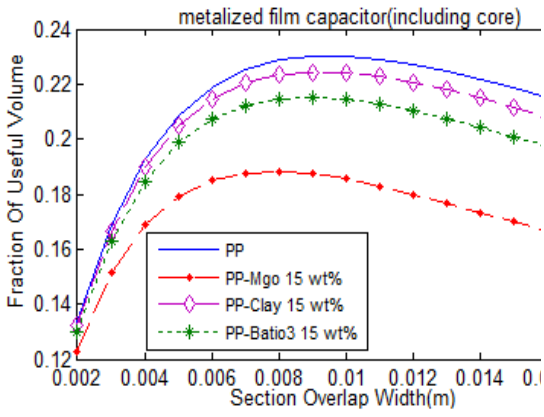


Fig. (8.b): Metalized film

Fig. 8 Fraction of useful volume in high voltage metalized film capacitors with various new nano-composites

Also, it is obvious that the fraction of useful volume (excluding core) of the metallized film capacitors increases with increasing section overlap width for all used nanocomposite materials. And so, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the best one for decreasing the fraction of useful volume (excluding core). Figure (8.b) has depicted that the fraction of useful volume (including core) of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). And so, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the better one for decreasing the fraction of useful volume (including core).

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

Figure (9.a) depicts that energy density (excluding core) of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). Also, it is obvious that energy density (excluding core) of the metallized film capacitors increases with increasing section overlap width for all used nanocomposite materials. And so, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the best one for increasing energy density (excluding core). Figure (9.b) has depicted that energy density (including core) of the metallized film capacitors as a function of section overlap width by using different nanocomposite film materials (PP with 15wt%Clay, PP with 15wt%BaTiO3, PP with 15wt%MgO). And so, it is noticed that nanocomposite film materials which composed of 15wt%MgO is the better one for increasing energy density (including core).

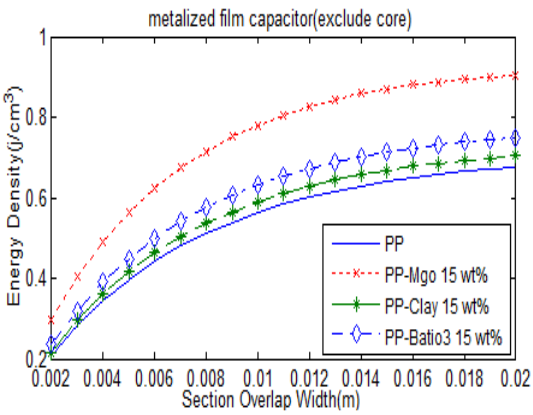


Fig. (9.a): Metalized film capacitor (Excluding Core)

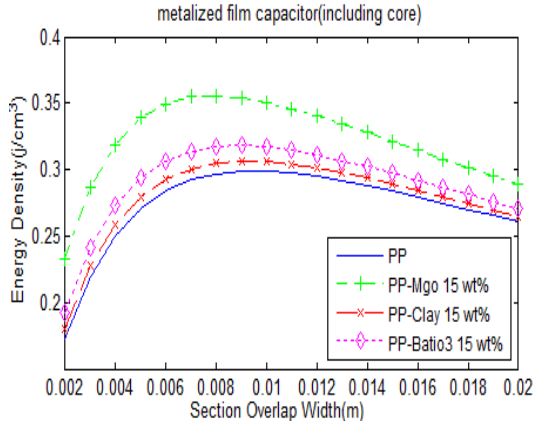


Fig. (9.b): Metalized film capacitor (Including Core)

Fig. 9 Energy density for the multi-section capacitor as a function of section overlap width and without effect of the core volume

5. CONCLUSIONS

- 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 $BaTiO_3$) increase ESR, ESI 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 better values of ESR, ESI and energy density and peak current and rise time within the investigated range.

ACKNOWLEDGMENT

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تحسين أداء مكثفات الجهد العالى باستخدام مركبات النانو الصناعية

هذا البحث يشرح التحسين على أداء مكثف الجهد العالي مع استخدام حبيبات متناهية الصغر (بحجم النانومتر)، وقد ناقش النموذج الذى تم دراسة كيفية تحسين تعزيز مكثفات الجهد العالي الفيلمية اعتمادا على تركيز الحبيبات المتناهية فى الصغر ، وكذلك على خواصها الكهربائية وسماحيتها. كما أن هذا البحث أستطاع أن يحقق فى اختيار مواد صناعية نانومترية لتعزيز الأداء الكهربى للمكثفات الكهربائية بانواعها التي تلبي مجموعة كبيرة ومتنوعة من تطبيقات التيار المتردد، والتطبيقات الإلكترونية ، وكذلك اكساب المكثفات الفيلمية افضل الخصائص طبقا للتطبيقات المحددة لها عن طريق اختيارالانواع المناسبة المواد من الحبيبات المتناهية فى الصغر. فإضافة الحبيبات المتناهية فى الصغر النانومترية الى المواد التقليدية للمكثفات الفيلمية تعزز قيمة عزلة الثابتة، وقوة عازلة، اتزانة الحرارى والكفاءة الحجمية لة وكذلك تحقيق أعلى سعة سماحية في حجم وحدة هذا النوع من المكثفات الفيلمية. وقد تم التحقيق في النتائج النظرية والمقارنة بين المواد التقليدية والمواد الجديدة المستحدثة بهيكل المواد الصناعية لمركبات الحبيبات المتناهية في الصغر. فقد تم حساب الممانع المكافئة والمقاومة المكافئة وكثافة الطاقة الحجمية وتيار تفريغ الشحن .....الخ لمختلف المواد المبتكرة النانومترية لتحسين خواص مكثفات الجهد العالى الفيلمية.

Authors' information

Ahmed Thabet was born in Aswan, Egypt in 1974. He received the BSc (HIE) Electrical Engineering degree in 1997, and MSc (HIE) Electrical Engineering degree in 2002 both from High Institute of Energy, Aswan, Egypt. PhD degree had been received in Electrical Engineering in 2006 from El-Minia University, Minia, Egypt. He joined with Electrical Power Engineering Group of Faculty of Energy Engineering in South Valley University as a Demonstrator at July 1999, until; he held Associate Professor Position at October 2011 up to date. His research interests lie in the areas of analysis and developing electrical engineering models and applications, investigating novel nano-technology materials via addition nano-scale particles and additives for usage in industrial branch, electromagnetic materials, electroluminescence and the relationship with electrical and thermal ageing of industrial polymers. A lot of mobility's has investigated for supporting his research experience in UK, Finland, Italy, and USA …etc. On 2009, he had been a Principle Investigator of a funded project from Science and Technology development Fund "STDF" for developing industrial materials of ac and dc applications by nano-technology techniques. He has been established first Nano-Technology Research Centre in the Upper Egypt (http://www.aswan.svu.edu.eg/nano/index.htm). He has more than 55 publications which have been published and under published in IEEE journals and conferences and held in Nano-Technology Research Centre website (http://www.ghson.net/FOLDERS_INDEX/nano/dr_athabet.htm).