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RESEARCH ARTICLE

DESIGN AND ANALYSIS OF HIGH VOLTAGE CAPACITOR BY METALIZED POLYPROPYLENE FILM

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ABSTRACT

At present condition both type of capacitor high and low voltage capacitors are made up of using All Polypropylene Film (APP) and Low tension capacitors made up of using Metalized Polypropylene Film (MPP).APP film capacitor having less dielectric losses and high voltage stress. It also have long life hence generally used in high voltage and low voltage capacitor. But the cost of low voltage capacitor is increased due to use of All Polypropylene film. So due the high, the use of this type of capacitor is less. Most important disadvantage of this type of capacitor non-self-healing property means if fault occur in capacitor large amount of capacitance value decreases or may be damage of capacitor takes place. On the other hand, MPP Film capacitor having self-healing property. This is heart of MPP type of capacitor. For increasing the current economy of the power system and to manufacture efficient and economical capacitors, in this thesis we worked on the loss angle or called dissipation factor, the cost of capacitor and voltage stress. By using Metalized film the size and weight of the capacitor also reduces. Due to metalized film the time required for production of capacitor will reduces. Similarly the material required for capacitor for same rating as of APP is reduces, so weight and size will be decreases. Hence the cost of capacitor decreases.

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INTRODUCTION

The Polypropylene used as Dielectric and Aluminum foil used as conducting metal for high tension capacitor. Polypropylene is plastic material applicable in field like packaging and labeling, lab equipments, polymer back notes. Automotive components, loudspeaker etc. All Polypropylene film capacitor made up of dielectric film .These type of capacitor having less dielectric loss, low ESR and self induction, long life, reliable and stable over time. Generally these film is very thin by using drawing process can achieve required thickness. This capacitor is free from polarization problem so it is applicable for AC signal. Now for reducing cost, weight and size, capacitors are manufactured by Metalized Polypropylene film. In this thesis we focused on size of capacitor, weight of capacitor, loss angle and voltage stress of capacitor. In this, as a dielectric we are using Metalized Polypropylene film & silicone material for cooling. As compared to APP film capacitor production time required. MPP film capacitor and voltage withstanding capacity is more.

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App film capacitor

APP Film is nothing but thermo softening plastic material that can be stretched both the direction. This film having low loss angle (tanδ 0.0003) and permittivity equal to 2.25. They can be operated variety of frequency range of 50Hz to 1MHz. This type of capacitor is manufactured by using two layers of Polypropylene with one layer of Paper, three layers of Polypropylene with one layer of Paper or four layers of Polypropylene with one layer of Paper. Two types of winding is possible one is Buried type and second is extended type the buried type contain the aluminum foils within the range of dielectric and extended foil contain the foil beyond the edge of the dielectric media. Voltage stress capacity of capacitor can be increases if layers of Polypropylene film will increases. Polypropylene is a plastic material which can be easily mould above particular temperature applicable in various field like package system, labeling stationary, lab purpose, textiles, and loudspeakers. It is also applicable in manufacturing of piping system as well as in medical field. It has good clarity.

Drawback of app film capacitor: Vacuum impregnation is most of important process during manufacturing of capacitor.

For this 0.1 torr vacuum is needed to fill oil in proportion. In this pure and high quality oil is needed. Due to this process impurities can be destroy and air packet will be removed. Another drawback is these type of material don"t have self healing properties, so if fault occur in this type of capacitor, large value of capacitance decreases or winding may get damage. The time required for manufacturing of this type of capacitor is also lengthy.

MPP film capacitor

This type of capacitor contain low loss insulating material made up of good quality polypropylene film. A polypropylene film is coated with metal such as zinc or aluminum or (addition of both) on one side. The thickness of the metallization is 0.2μm. Now this metal coating act as electrode and film act as dielectric, called metallised polypropylene. The number of layers required is depend upon design criteria In some application unmetallised layers are also added. The film are wound in roll by using mandrill. Some design use cylindrical container while other flatter the rolls and use rectangular containers. On the winding ends the zinc spray is spread which facilitating high current load and ensure low connection between windings and terminals.

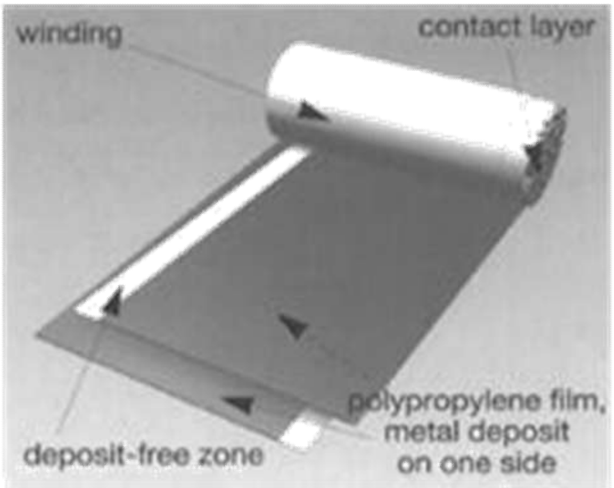

Fig. 1. Metallized Polypropylene Film

The MPP paper-film having various advantages like negligible dielectric heating, high dielectric strength, low losses, excellent self-healing property, capable to carry high current as well as high pulse carrying capacity etc. The size is also smaller due to high dielectric stress. This is greatest advantages of metalized film capacitor. it is the capability of material which clear the fault like impurities in windings or pores by introducing high voltage beyond its rated voltage. Due to metallization, the arc can be extinguished without any damage. Suppose there is defect in the winding layer, only small part winding will be affected. And capacitor bank will be continuing in service. These type capacitor uses in high electrical stress, so in smaller volume they can store larger energy. The thickness of vacuum deposited metal coating in the range of 20 to 50nm. The dielectric breakdown may be occurs at weak points if its strength is exceeded, due to this temperature will be increases to high value. Because of this transformation of dielectric to compressed plasma is takes place. The evaporation of metal coating is takes place due to plasma interaction. The plasma expanded rapidly and it will be cooled within small fraction of time and quench the discharge without any voltage loss and capacitor regains its operational state. Tan delta is less because of less temperature hence heating losses are also less so high efficiency. Due to low losses in metalized film current carrying capability of capacitor is higher.

Cooling Agent

In this type of capacitor silicon material is for cooling purpose for winding. Silicones having following characteristics

- Less chemical reactive
- Less toxic
- Thermal capability lies in the range of 100 to 250 °C.
- Highly Resistance to UV light , oxygen, ozone. Due to this property generally used in construction field like fire protection, coating purpose, glazing seals. It is also be used in external gaskets in automotive field.
- Less conductive
- Gas permeability is higher at ambient temperature (25 °C), the permeability of silicone rubber for such gases as oxygen is approximately 400 time that of butyl rubber, also applicable in medical field in which increased aeration is desired.

These are used in many products. Electrical field used as insulation, in electronics used for coatings also used for household some apparatus which is used for cooking also used in automobile field like airplane, gaskets, in machins for keyboard pad purpose, medically used like teeth treatment, in textile and paper industry.

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This is greatest advantages of metalized film capacitor. it is the capability of material which clear the fault like impurities in windings or pores by introducing high voltage beyond its rated voltage. Due to metallization, the arc can be extinguished without any damage. Suppose there is defect in the winding layer, only small part winding will be affected. And capacitor bank will be continuing in service. These type capacitor uses in high electrical stress, so in smaller volume they can store larger energy. The thickness of vacuum deposited metal coating in the range of 20 to 50nm. The dielectric breakdown may be occurs at weak points if its strength is exceeded, due to this temperature will be increases to high value. Because of this transformation of dielectric to compressed plasma is takes place. The evaporation of metal coating is takes place due to plasma interaction. The plasma expanded rapidly and it will be cooled within small fraction of time and quench the discharge without any voltage loss and capacitor regains its operational state. Tan delta is less because of less temperature hence heating losses are also less so high efficiency. Due to low losses in metalized film current carrying capability of capacitor is higher.

Formulaes

1. Capacitance Value = Reactive KVA*10^9 / 2πfV^2 in μfd

2. Capacitance Value =
ε_0* Relative permittivity (ε_r)*Area* layers required /thickness * Space factor ...... for APP

3. Capacitance Value =
ε_0* Relative permitivity(ε_r)*Area *No. of Sides* Space factor /thickness ... ……for MPP

4. Length (L) = Area (A) / Width (W) in „m"

5. Length = (π* Interdiameter * turns required(N)) + (2π* thickness* Space factor * N^2)

6. Voltage

$$\text{Stress} = \frac{\text{Rated Voltage V}/\mu}{\text{Thickness * Total Series Group}}$$

7. Polypropylene Paper weight per element
= thickness * Length * W * density

8. Aluminum Foil weight of per element
= thickness * Length * W * density

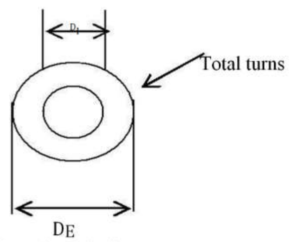
9. MPP Film weight per element
= thickness * Total area * density * no. of sides

Design details of APP film as well as MPP film capacitor

Designing details of High Voltage capacitor by using APP Film

Capacitor Specification

size	: 200 KVAr, 7.3 Kv, 50Hz, 1 Ph.
Polypropylene Thickness	: 10 μm
Aluminum foil Thickness	: 0.2 μm
Total layers	: 1
Total sides	:2
Space factor	: 1.05
Space factor of winding	:0.95
Actual Width	: 125 mm
Effective width (W)	: 120 mm
Interdiameter	: 010 mm
Relative permittivity of MPP(ε_r)	: 2.2
Permittivity of Free space (ε_0)	: 8.854* 10^{-12}μfd/m^2/m



Capacitor winding

From figure,
N=Turns required
D_I=Inter Diameter in „m"
D_E=External Diameter in „m"

Calculations

1. As per equation 1st , calculate capacitance value
Capacitance value = Reactive KVA*10^9/2πfV^2

Capacitance value = 200 * 10^9/ 2 π * 50* $(7300)^2$ = 11.94 μfd.

According to design requirement total number of series section is equal to 3 and in each section total element will be 8.Now we know that if 3 capacitors are arranged in series then equivalent capacitance equal to

$$\frac{1}{C_{eq}} = \frac{1}{C_1} + \frac{1}{C_2} + \frac{1}{C_3}$$

Total Capacitance value / series section
3 * 11.94

= 35.82 μfd.

Each element Capacitance =

$$\frac{\text{Total Capacitance value of each series section}}{\text{Total elements per section}}$$

= 35.82 / 8
= 4.48 μfd.

2. As per equation 3rd , calculate total capacitor area

C = ε_0* Relative Permittivity(ε_r) *Area*total layers / thickness * Space factor

4.48 = 8.854 * 2.9 * A * 3 / 2* 35.4 *1.15 A = 4.73 m^2

3. As per equation 4th , calculate element length Length = Area (A) / Width (W) in m

= 4.73 / 0.27
= 17.52 m

4. As per equation 5th , find turns required for element

L = (π* interdimeter * turns required N) + (2π * thickness * Space factor * N^2)

17.52 = (π * 0.065 * N) + (2π * (35.4 + 5) * 10^{-6}

1.15 N^2) N = 78 turns

5. As per equation 6th, calculate voltage stress

$$\text{Voltage stress} = \frac{\text{Voltage Rating}}{\text{Polypropylene film thickness} \quad \text{total series group}}$$

$$= \frac{7.3 * 103}{35.4 * 3}$$

=68.74 V/μ

6. As per equation 7th, calculate Polypropylene Film weight Polypropylene Film weight per element

= thickness * Length * Width * density
= 2 * 35.4 * 10^{-3} * π * 0.0736 * 78* 300 * 0.905
= 346.68 gm.

Total amount of PPF weight is

= 346.68 * 24
= 8.32 Kg

7.As per equation 8th, calculate Aluminum Foil weight

Aluminum Foil weight per element

= thickness * Length * Width * density
= 2 * 5*10 ^{3} 0.0736 *78 * 290 * 2.7
= 141.21 gm.

Total aluminum weight is

= 141.21 * 24
= 3.39 Kg

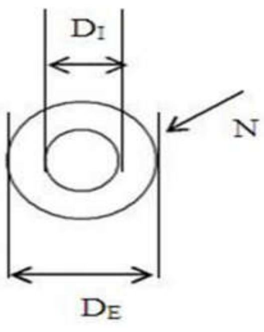
Total amount of weight of APP film capacitor is equal to

= Polypropylene Weight + Aluminum foil Weight
= 8.32 + 3.39
= 11.71 Kg.

The final ready Capacitor includes all raw materials like Polypropylene film material, Aluminum foil material, container for assemble, insulation paper for separation, bushing and oil etc. So final weight of ready to use capacitor is near about 27Kg.

Designing of High Voltage capacitor by using MPP Film Type

size	: 200 KVAr, 7.3 Kv, 50Hz, 1 Ph.
Polypropylene Thickness	: 10 μm
Aluminum foil Thickness	: 0.2 μm
Total layers	: 1
Total sides	:2
Space factor	: 1.05
Space factor of winding	:0.95
Actual Width	: 125 mm
Effective width (W)	: 120 mm
Interdiameter	: 010 mm
Relative permittivity of MPP(ε_r)	: 2.2
Permittivity of Free space (ε_0)	: 8.854* 10^{-12}μfd/m^2/m



Capacitor winding

From figure

N = Turns required
D_I = Inter diameter in „m"
D_E = External diameter in „m"

Solution

1. As per equation 1st , calculate capacitance value Capacitance value = Reactive

KVA * $10^9/2\pi fV^2$

Capacitance value = 200 * 10^9/ 2 π * 50* $(7300)^2$ = 11.94 μfd.

According to design requirement total number of series section is equal to 12 and in each section total element will be 10.Now we know that if 3 capacitors are arranged in series then equivalent capacitance equal to

∴Total Capacitance value / series section

= 12 * 11.94
= 143.28 μfd.

$$Capacitance\ of\ eac\ \ element = \frac{Total\ capacitance\ value\ of\ each\ series\ section}{\text{Total elements per section}}$$

2. As per equation 3rd, calculate total capacitor area

C = ε_0 *relative permittivity (ε_r)*Area* Space factor * total sides / thickness

14.32 = 8.854 * 2.2 * Area * 2*0.95 / 10
A = 3.87 m^2

As per equation 4th, calculate element length Length = Area (A) / Width (W) in „m"

= 3.87 / 0.12
= 32.25 m

As per equation 5th calculate total turns required

3. By using Length

= (π *interdiameter * turns required N) + (2π * thickness * N^2)

32.25 = (π * .01 * N) + (2π * 10 * 10-6 * N2)
N = 509 turns

4. As per equation 6th, calculate voltage stress

$$\text{Voltage Stress} = \frac{\text{Voltage rating}}{\text{Thickness of MPP film * no. of series group}}$$

$$= \frac{7.3 * 10^3}{10 * 12}$$

= 60.83 V/μ

Comparative Results

Particular	Result of MPP Capacitor	Result of APP Capacitor	Differencebetween APP &MPP	% Saving of MPP over APP
Voltage Stress (V/μ)	60.83	68.74	9.26	18.5%
Loss Angle (Tan δ) (Watt / kVAR)	0.00014	0.001	0.00086	14%
Weight of capacitor (Kgs.)	29Kg	36Kg	7Kg	19.5%
Final Cost	8300/-	11500/-	3200/-	27.8%

5. As per equation 9^{th} , calculate MPP Film weight
Total Weight of MPP Film per element

= Total area * thickness * density * no. of sides
= 3.87 * 125/120 * 10* 0.905 * 2
= 72.97 gm.

Final weight of capacitor is = 72.97 * 120 = 8.76 Kg

Comparison of Performance of APP and MPP type capacitor

We compare performance result of the both type capacitor and that is tabulated in table no. 6 as follows,

Conclusion

At the end of upper mathematical calculation and final result we came to know that metallization on Polypropylene film leads to positive effects on the performance of the High voltage capacitor. When metalized Polypropylene film is applied as insulating material in designing of high voltage capacitor, the voltage stress will be lowered 45%. Dissipation factor or tan delta losses lowered to 14%. The raw material required to manufacture this capacitor is less so the most important factor the weight and cost of capacitor is also decreases. The cost of capacitor decreases to 27.8%. This type of capacitor having high capacitance value (in terms of μF) in small volume. It also has good voltage capability& good mechanical strength.

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