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Implementation and Statistical Analysis of Filled and Unfilled SRN Using SVM Tools

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Abstract--*In power sector, with increase in voltage level in transmission, there is a need for new insulating material with better electrical and mechanical performance at affordable cost. But the major problem posed in using high voltages is different from those encountered at low voltages. Some major problems in high voltage are transients, interruptions, sag, swell, voltage fluctuation, corona, frequency variation. One major problem under wet conditions, insulators are vulnerable to corona discharges. If the corona is allowed to occur continuously it will collapse the system. This paper mainly concentrated on analysis of aging phenomenon of unfilled and filled silicone rubber Nano composites materials. An AC voltage of 8kv is applied continuously for the required duration of about 30 hours of aging. Corona discharge will be generated by needle plate electrode enclosed in a large chamber. Support Vector Machine (SVM) is used to analyze the performance of the samples. This paper is concentrated on review the performance of the nanocomposites material which is much better than the unfilled silicone rubber materials.*

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I. Introduction

Over past few years, silicone rubber nanocomposites have attracted a great deal of attention due to several advantages. The advantages include light weight, easier transportation as well as good resistance. They also provide much better performance under all environmental condition during the initial period as compared to ceramic insulators. Corona generates simultaneously a mixture of species and radiations [1]. The water drop corona can result in permanent loss of hydrophobicity on the silicone rubber insulator. Damage occurs due to corona of the polymer surface depends upon both the duration and intensity of the discharge. Addition of a few weight percent of Nano filler has a consideration impact on electrical, mechanical, physical, thermal and chemical properties of the polymer. Good improvement in the resistance of Nanocomposites against electrical discharges as compared to unfilled silicone rubber.

II. Silicone Rubber Nanocomposites(SRN)

A) Introduction of SRN

Some silicone rubbers can be bulky are thick in appearance, which can be a disadvantage if hoping to create a discrete look. Silicone rubber also has a high viscosity, resisting the force that allows liquid to flow. This is the disadvantage of using silicone rubber in insulation [2]. This rubber must be vacuumed and degassed to stop bubbles from becoming trapped in the rubber. Except for liquid silicone rubber, all types of silicone rubber are susceptible to these disadvantages [3]. The Nanocomposites are added to the silicone rubber to improve surface hydrophobicity, electrical conductivity, thermal conductivity, relative permittivity.

B) Preparation of SRN

Vulcanized silicone rubber, polydimethyl siloxane and platinum catalyst [4] are mainly used for the production of sample. Vulcanized silicone rubber is a good insulating material which is used for coating on ceramic insulators used in high voltage power transmission lines [5], [6] and [7]. So it is mostly used for outdoor insulators. Precipitated Nano filler of size ~20nm has been used for making the nanocomposites.

C) Fabrication of SRN

Processing of rubber include mastication and various operations like mixing, calendaring, extrusion. This all process is being essential to bring crude rubber into a state suitable for shaping the final product. The silicone rubber breaks down the polymer chains and lowers their molecular mass so that viscosity is low enough for further processing. The silicone rubber may be masticated on a roll mill or in an industrial mixer.

Vulcanized silicone rubber & polydimethyl siloxane are taken and kept under evacuated conditions for 24 hours to remove air & moister from them. Fillers are kept under high temperature of 150-170°C for at least one day to remove moisture & filler. Required quantity of filler is weighted using a precision digital balance with a reliability of 0.1mg. Vulcanized silicone rubber and the fillers are mixed and run at a moderate speed using mechanical mixer. Then the material is evacuated and sonicated. Sonification is carried out for 75 minutes in water bath at frequency of 24 KHz with intermitted stirring. After sonification process, material is again evacuated and required amount of polydimethyl siloxane is added and mixed with a stirrer and the ratio of the components is 3:1 which is used for getting samples with low tackiness, hardness and good curing. The component is again preheated in 60°C to prevent the tendency of the fillers to settle at the bottom of the sample. Samples have been cured in two stages i.e. primary & secondary curing. Curing can differed by temperature. Finally the samples sc1-1, sc1-2, sc2-1, sc2-2 are made with diameter 70mm and thickness of 3mm and the samples s1, s2, s3, s4, s5 are made with different thickness and have the same diameter of 70mm.

III. NANO Fillers

Pure silicone rubber shows little tracking and erosion resistance which reduces service life. In order to extend service life, some properties of silicone rubber need to be improved [8]. The fillers are added to the silicone rubber to improve surface hydrophobicity, electrical conductivity, thermal conductivity, relative permittivity and also to reduce costs [9]. Six different Nano fillers are selected for sample preparation and they are Alumina, Barium Titanate and Titanium Dioxide, Magnesium Oxide, Zinc Oxide and CCTO (Calcium Copper Titanium Oxide).

A) Alumina ($\mathbf{Al_2\,O_3}$)

Alumina added with silicone rubber to improve thermal conductivity and avoid tracking & erosion. Alumina is classified as semi-reinforcing filler, improves the physical properties of silicone compositions through molecular bonding with the silicone polymer [10]. The thermal conductivity of the composite material is dependent on the thermal conductivity, particle size and bonding of the filler particles to the silicone matrix.

B) Barium titanate ($\mathbf{BaTiO_3}$)

Barium Titanate added with silicone rubber to improve relative permittivity and thermal stability which led to higher decomposition temperature. It contains a high dielectric constant and high electrical breakdown strength. It has been extensively employed as ceramic filler.

C) Titanium dioxide ($\mathbf{TiO_2}$)

Titanium Dioxide is a wide band-gap (3.2eV) semiconductor which exhibits high photo catalytic efficiency. With its combined features, low cost and stable properties, added with silicone rubber to improve relative permittivity, thermal stability and photo catalytic. It has been also extensively utilized in environmental applications. Increasing the amount of TiO_2 also led to a decrease in the cross linking density of the silicone matrix.

D) Magnesium Oxide (mgo)

Magnesium Oxide added with silicone rubber to improve thermal conductivity and to reduce tracking & erosion. Magnesium Oxide is added to the silicone rubber as an anti-tracking agent and flame retardant. It made strong bonding of the filler particles to the silicone matrix.

E) Zinc Oxide (zno)

Zinc Oxide is an important semiconductor material with a band gap of 3.3eV at room temperature. Zinc Oxide fillers increase the relative permittivity and also the thermal conductivity of the composite. The mechanical and thermal properties of silicone rubber incorporated with zinc oxide. ZnO filled silicone rubber exhibited better thermal performance compared to $Al_2\,O_3$ filled silicone rubber. ZnO is also better reinforcement filler for improving the mechanical properties of the silicone rubber compound.

F) CCTO ($\mathbf{CaCu_3Ti_4O_{12}}$)

Great improvement of the mechanical, rheological and flame retarding properties of Nano calcium has been increased. It is a wide-band gap insulator of 0.35eV with rhombohedra unit cell and dielectric constant 8.19.CCTO added with silicone rubber to improve flame retarding and hydrophobicity.

IV. Corona Aging Test & Analysis

A) Experimental setup

Fig 1 shows the experimental setup of corona aging test. The needle-plane electrode is enclosed in a large chamber for the generation of corona discharge. The high voltage brass electrode of diameter 58mm and thickness 11.5mm is fitted with needle-plane electrode which is made up of steel. The minimum gap between the tip of the lowest needle and the sample top surface is kept at 3mm using a mechanism attached to ground electrode.

Figure 1. Experimental setup.

B) Coupling capacitors

High voltage coupling capacitors are used mainly for partial discharge measurements in high voltage testing. The measurements of partial discharge are based on measurement of high frequency voltage drop across measuring impedance in the ground lead of the test object or of the coupling capacitor [11]. Any partial discharges appearing in or on a test object under high frequency charge. Transfer between the high voltage potential and ground give rise to high frequency current. This current produces drop across the measuring impedance which is connected to the partial discharge meter for evaluation, measuring and display.

C) Partial discharge

Partial discharge usually begins with voids, cracks or inclusion within a solid dielectric at dielectric interfaces. PD occurs within an electrical insulation without any significant manifestation outside and leads to unwanted failure.

D) Recognition of PD

Partial discharge signals differ from the disturbances and noise in several aspects. The discharge time is very short and it has a band–passing characteristics. The disturbances can be classified into three types: periodic noise has a relatively fixed phase distribution; the pulsed noise focuses in certain phase. The magnitude of PD is relatively constant if the scale changes. The white noises in the complex wavelet domain have a diminishing magnitude rapidly with increasing scaling levels. The white noise and PD has different magnitude spectrum characteristic

V. Measurement Of Pd Signal

Fig 2 represent the single wave partial discharge signal and fig 4 represent the multi wave partial discharge signal for S3 sample. Then, 3D pattern is drawn in mat lab using the parameters: phase angle (ϕ), charge (q) and number of discharges (n) which obtained from partial discharge signal. Fig 3 represent the corresponding 3D (ϕ-q-n) pattern of single wave partial discharge signal & Fig 5 represent the corresponding 3D (ϕ-q-n) pattern of multi wave partial discharge signal for S3 sample. Each 3D and PD pattern has its own characteristics and degradation mechanism.

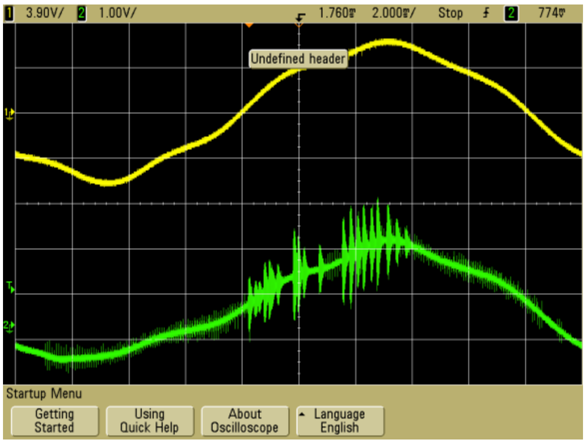

Figure 2. Single curves PD for sample (S3)

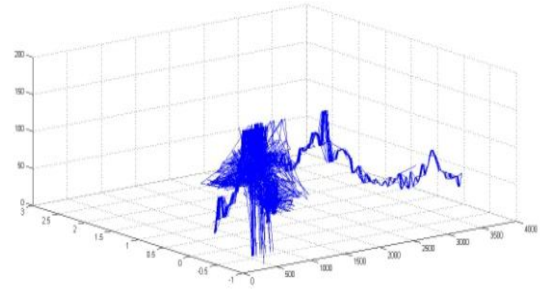

Figure 3. single curves 3D for sample (S3)

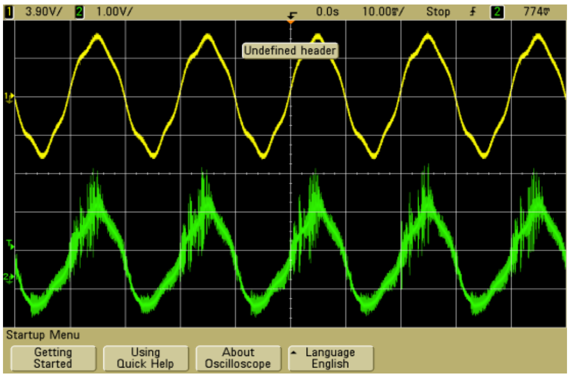

Figure 4. Multi curve PD for sample (S3)

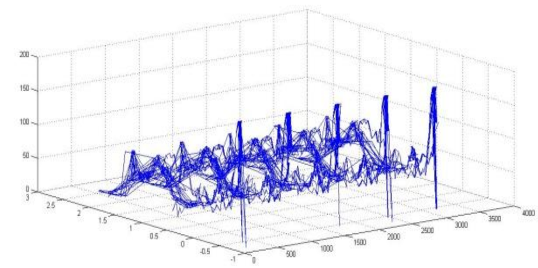

Figure 5. Multi curve 3D for sample (S3)

A) Skewness

Skewness is a measure of symmetry or more precisely, the lack of symmetry. The skewness value can be positive or negative or even undefined. The skewness for a normal distribution is zero and any symmetric data should have skewness near zero.

In positive skewness "tail" of the distribution is more stretched on the side above the mean. Negative skewness indicate data that are skewed left (left tail is long relative to right tail) and positive skewness indicate data that are skewed right (right tail is long relative to short tail). If the data are multi-model, then this may affect the sign of the skewness.

B) Kurtosis

Kurtosis is a measure of whether the data are peaked or flat relative to a normal distribution. Kurtosis is a descriptor of the shape of a probability distribution.

Data set with high kurtosis tend to have a distinct peak and have heavy tails. Data set with low kurtosis tend to have a flat top near the mean than a sharp peak. Standard normal distribution has a kurtosis of zero.

C) Cross correlation (cc)

Correlation can be defined as the degree of relationship between two variables. It needs pairs of points to be available for every set of values of each of the variable.

Correlation coefficient will always lie between -1 to +1. The variables are closer to each other. If correlation coefficient is close to +1, then there will be strong positive correlation. When correlation coefficient attains +1, it shows a perfect positive fit. If correlation coefficient is close to -1, then there will be strong linear correlation. When correlation coefficient attains -1, it shows a perfect negative fit.

D) Standard deviation

Standard Deviation is a measurement of the dispersion of a set of data from its mean. The more spread apart the data, the higher the deviation.

Standard deviation is calculated as the square root of variance. The standard deviation close to zero indicates that the data points tend to be close to the mean. The standard deviation is a numerical value used to indicate how widely individuals in a group vary.

VI. Statistical Analysis For Nine Different Samples

Statistical Analysis such as Skewness, Kurtosis and Cross correlation is calculated for different samples at the time interval of 5hours. The obtained skewness, kurtosis and cross correlation of nine different samples are represented in TABLE 1, 2, 3, 4, 5, 6, 7, 8 and 9 which is used for the calculation of SVM (RBF), SVM (polynomial), SVM (linear) and Artificial Neural Network (ANN).

Table 1: Statistical Analysis for sample (SC1-1)

Hours	**Skewness**	**Kurtosis**	**CC**
5	0.0874	1.693	0.7578
10	0.043	2.4438	0.6079
15	0.0314	2.257	0.6571
20	0.3542	2.901	0.6681
25	0.6829	3.1271	0.6472
30	0.0735	0.8026	0.8026

Table 2: Statistical Analysis for sample (SC1-2)

Hours	**Skewness**	**Kurtosis**	**CC**
5	0.0799	1.5429	0.8168
10	0.1201	1.802	0.7125
15	0.0612	2.001	0.6795
20	0.028	2.1518	0.64
25	-0.104	2.246	0.6002
30	-0.249	2.2663	0.5651

Table 3: Statistical Analysis for sample (SC2-1)

Hours	**Skewness**	**kurtosis**	**CC**
5	0.047	1.516	0.5357
10	0.0498	1.521	0.617
15	0.2334	1.543	0.6228
20	0.4112	1.623	0.7164
25	0.0172	1.697	0.7324
30	0.0573	1.788	0.7412

Table 4 : Statistical Analysis for sample (SC2-2)

Hours	Skewness	kurtosis	CC
5	0.0251	1.074	0.821
10	0.0671	1.5005	0.765
15	0.0835	2.042	0.642
20	-0.1521	2.456	0.5571
25	-0.385	2.301	0.692
30	-0.1465	1.6856	0.8185

Table 5: Statistical Analysis for sample (S1)

Hours	Skewness	kurtosis	CC
5	0.026	1.598	0.8372
10	0.047	1.6001	0.8124
15	0.081	1.758	0.7235
20	0.124	2.054	0.6423
15	0.079	2.243	0.5942
30	-0.0871	2.0856	0.5687

Table 6: Statistical Analysis for sample (S2)

Hours	Skewness	kurtosis	CC
5	0.0671	1.7423	0.8124
10	0.1432	2.5712	0.7761
15	0.0687	2.271	0.6271
20	0.0274	2.972	0.5432
25	-0.124	3.4213	0.6571
30	-0.2051	0.8412	0.8251

Table 7: Statistical Analysis for sample (S3)

Hours	Skewness	kurtosis	CC
5	0.0542	1.492	0.818
10	0.1105	1.6416	0.745
15	0.0421	1.741	0.632
20	0.0141	2.034	0.546
25	-0.1023	2.145	0.683
30	-0.2014	2.0731	0.807

Table 8: Statistical Analysis for sample (S4)

Hours	Skewness	kurtosis	CC
5	0.023	1.063	0.818
10	0.042	14983	0.745
15	0.079	2.014	0.651
20	0.114	2.397	0.5632
25	0.063	2.201	0.683
30	-0.076	1.591	0.793

Table 9: Statistical Analysis for sample (S5)

Hours	Skewness	kurtosis	CC
5	0.5967	1.6789	0.8754
10	0.4896	2.4357	0.7496
15	0.2476	2.786	0.6784
20	0.4783	3.126	0.5266
25	0.5672	3.4357	0.6357
30	0.3989	3.6788	0.8901

VII. Support Vector Machine And Artificial Neural Network

A) Support vector machine (SVM)

The method of Support Vector Classification can be extended to solve regression problems. This method is called Support Vector Regression. The model produced by support vector classification depends only on a subset value of the training data because the cost function for building the model does not care about training point that lie beyond the margin. SVM used in this proposed method is one against all. Cross validation with 50% hold out is used for testing and training. Data is used to train the classifier and it is not looked during testing phase. The kernel used is liner, polynomial and RBF kernel.

B) Types of SVM kernel
There are three types of SVM kernel and they are Radial Basis Function, Polynomial and Linear

C) Radial basis function (RBF)
Support vector machines and other models employing the kernel trick do not scale well to large numbers of training samples or large number of features in the input space, several approximations to the RBF has been devised output.

D) Linear kernel function (linear*)*
The linear kernel is the simplest kernel function. It is given by the inner product <X, Y> plus optional constant C kernel algorithms using a linear kernel is often equivalent to their non-kernel counterparts.

E) Polynomial kernel function (poly)
The polynomial kernel is a non-stationary kernel. By using adjustable parameters are the slope alpha, the constant term c and the polynomial degree d are used to obtain polynomial kernel.

F) Artificial neural network (ANN)
By using MATLAB action we are able to get the mathematical values or features of PD pattern. All these features are arranged in a matrix form named as input matrix and test matrix. The data will be trained and it is compared with the allocated target values. Thereafter a set of test signals (test matrix) is applied for the evaluation of the trained network which will again give the confusion matrix of final output (tested data).

G) Result analysis
Skewness, kurtosis & Cross Correlation are obtained from MATLAB using the PD data. By using these parameters, the comparative results are obtained for nine different samples. The analysis result is performed using MATLAB tools SVM and ANN as shown in TABLE 10.

Table 10: Result Analysis

Sample	SVM (RBF)	SVM (POLY)	SVM (LINEAR)	ANN
sc1-1	99.96	88.99	87.5	96.57
sc1-2	99.96	86.45	75	96.5
sc2-1	99.96	87.01	84.4	96.8
sc2-2	97	88.99	83.95	95.6
s1	99.99	88	81.5	97.12
s2	99.99	86.93	83.9	97.38
s3	99.9	87.75	81.6	97.65
s4	96.66	85.5	68.07	94.05
s5	96.95	82.34	65.91	92.52

VIII. Conclusion

From the comparison result, SVM (RBF) result is better than SVM (POLY) and SVM (LINEAR). The SVM (RBF) result is higher than 95% for all the samples and it is better than ANN result. If the values of Skewness, Kurtosis and Cross correlation are known for a sample, then the number of hours of ageing of the particular sample can be identified by using ANN. The samples sc1-1, sc1-2, sc2-1, sc2-2, s1, s2, s3 (1 to 3% Nano filler) are showing better performance than s4 & s5 (0% Nano filler). The reason for the better performance is addition of 1 to 3% of Nano filler.

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