CHAPTER 2

LITERATURE OVERVIEW

2.1 INTRODUCTION

Nanocomposite materials are multi-constituent combinations of nano-dimensional phases with distinct differences in structure, chemistry and properties. These materials typically contain an inorganic component in an organic host or vice versa, or consist of two or more inorganic/organic phases in some combinational form with the constraint that at least one of the phases or feature in the nanosize. In general, nanocomposite materials can demonstrate unique combinations of mechanical, electrical, optical, electrochemical, catalytic and structural properties compared to those of each individual component. The micron-size filled counterparts by taking advantage of the different structure, composition and properties of their constituents (Jiongxin Lu 2008).

This chapter briefly deals with an overview of literature about properties of nano dielectrics/nanocomposites, electric field analysis using FEM and effects of partial discharge in an insulating material coated conductors used in electrical machines.

2.2 POLYIMIDE ENAMEL

Moon (1931) describes the thermal breakdown occurs only for the higher temperatures and greater thickness, while other types of failure obtain in thin materials and at sufficiently low temperatures.
Aymonino et al (2006) explained the electrical characterizations performed on turn to turn insulation materials. The enamel wire was the same for all the samples under study, but different impregnation resins and the polymerization processes and mechanisms were envisaged. The evolution of both transient and conduction currents of enamel wires (with or without impregnating varnishes) versus temperature had been investigated. Some of the Epoxy varnishes under study present a very high conduction current level. On the contrary, varnish, which presents the lowest impurities content, has a conduction current close to the non-impregnated one.

Chao Zhang et al (2005) have explained that the dielectric measurement results show that the dielectric properties of the polyethylene and epoxy nanocomposites are different. In polyethylene nanocomposites, interfacial polarization can be easily seen and the nanocomposite with the highest loading of Alumina has the highest loss peak in low frequency region. In epoxy nanocomposites, the interfacial polarization induced by fillers cannot be observed. The reasons have been discussed in terms of improved dispersion and polarity differences between LLDPE and epoxy resin.

2.3 REVIEW ON NANO FILLER ADDED INSULATING MATERIAL

Fuse et al (2008) explains that the effects of nanofiller loading on the carrier transport and molecular motion in polyamide were discussed by analyzing their complex permittivity spectra.

Guoqin Zhang et al (2005) discussed about the characteristic of inorganic filler of new type magnetic wire and the effect on corona resistant. The corona resistant magnetic wire modified by nano TiO$_2$ filler suffers corona damage; the layer of nano TiO$_2$ precipitate can improve electric field distribution and increase capacity of heat conduction. The new pattern
composite magnetic wire is of longer life due to the nano TiO$_2$ protecting the insulation inside from destroying.

Takahiro Imai et al (2006) have discussed on the electrical insulation properties of a newly prepared composite material by nano- and micro-filler mixture. Nano- and micro-filler mixture composites were made by dispersing nano-scale layered silicate fillers and micro-scale silica fillers in epoxy resin. Nano- and micro-filler mixture is an effective approach to improve the electrical insulation properties, maintaining low thermal expansion. However, addition of nano-scale layered silicates tends to increase resin viscosity and cost. It is necessary to optimize the contents of the layered silicates to improve the electrical insulation properties.

Irwin et al (2004) investigated effect of nanofillers on the dielectric, mechanical and thermal properties of polyimides. It is concluded that nanofilled polyimide films have shown increased elongation and strength to failure ratio with increased scratch hardness.

Irwin et al (2003) explain the effects of nano-sized fillers on the thermal, mechanical and electrical properties of polymeric systems. Nanofilled polyimide films have shown increased elongation and strength to failure increased scratch hardness and increased thermal conductivity as compared to unfilled materials.

Kirkici et al (2005) discussed the recent developments in the area of nano-dielectric materials. The effect of nano-scale fillers on electrical, thermal and mechanical properties of polymeric materials was observed. Experimental results of surface flashover characteristics of epoxy resin and epoxy resin cast with powdered Al$_2$O$_3$ in partial vacuum was presented. Nanocomposite materials were found to have higher electrical breakdown strength.
Santanu Singha and Joy Thomas (2008) report an experimental work on the trends of dielectric permittivity and tan δ of epoxy anocomposites with single nanofillers of Al₂O₃ and TiO₂ at lower filler concentrations (0.1%, 0.5%, 1% and 5%) over a frequency range of 1 MHz – 1 GHz. This shows that there is a strong dependence of the filler concentration and nanofiller permittivity at all these frequencies. Tan δ values in nanocomposites with Al₂O₃ fillers are found to be lower at all filler concentrations when compared with the value for unfilled epoxy.

Chao Zhang and Stevens (2007) have reported the relationship between the dielectric properties and the structure of the polymer nanocomposites, especially the role of the interface in the dielectric phenomena, two polymers with different polarity have been used to form composites with nano Alumina, a polar inorganic compound. Consequently, two kinds of nanodielectrics with very different interfacial characteristics have been obtained. In epoxy nanodielectrics, broad band dielectric spectroscopy measurements show that no difference is found between the unfilled resin and the nanoAlumina filled composite under dry conditions. There is also very little low frequency dispersion observed. This suggests that there is no significant interfacial polarization occurring between the nano Alumina and epoxy matrix despite the permittivity differences. In contrast the polyethylene nanodielectrics do show low frequency dispersion.

Lihong cheng and Kyle jiang (2008) describe about the nanoparticles and composites examined under infrared spectroscopy and the surface modification of nanoparticles lead to a good hydrophobic property and adding low dielectric constant nanosilica particles, the dielectric constant of the composite will be increased, while the dielectric losses were lowered.
Yoshikazu Kondo and Keisuke Someya (2005) explain the Alumina/polymer nanocomposites characterized by XRD measurements, (SEM) scanning electron microscopy, and TGA analysis and the elongation (å) increase with increasing structural parameter (p). The elongation of Alumina/polymer composites is improving brittleness and mechanical property of polystyrene.

Imai et al (2005) have reported the preparation scheme for epoxy resin without silica particles and epoxy resin with nano-or micro silica particles. The results reported that the nano composite gained higher PD resistance and break down strength compared with epoxy resin without silica particles and micro composite. Further, the nano composite without a coupling agent is much inferior than with coupling agent nano composite.

Kurimoto et al (2008) have investigated the influence of dispersibility of nanoparticles on electrical properties. The fabrication of Alumina nano composites has been done with the help of ultrasonic wave and centrifugal force. Dispersibility of nanoparticles was evaluated by scanning electron microscopy (SEM) analysis. Dielectric properties such as permittivity and dielectric loss of the nanocomposite are estimated. Finally, the influence of the dispersibility of nanoparticles on the dielectric characteristics is examined.

Lizhu Liu et al (2009) explain the SEM morphology showed that the distribution of inorganic phase was uniform and the weight ratio of SiO₂/Al₂O₃ had a great influence on the morphology of inorganic phase. Compared with plain polyimide, mechanical properties and thermal stability of hybrid films were improved.

Mackersie et al (2000) have reported that the addition of either aluminum oxide or zinc oxide filler to the commercial epoxy resin can
produce a composite material with a non-linear resistivity characteristic when subjected to electric fields up to 11kV/mm. This non-linear behavior is critically dependent on the concentration of filler and the applied field strength. The decrease in resistivity was more marked for the resin filled with 15% ZnO than for the resin filled with 15% Al₂O₃. However the breakdown strength of the ZnO filled material was more variable than that of the Al₂O₃ filled material.

Chao Zhang et al (2005) have explained that the dielectric measurement results show that the dielectric properties of the polyethylene and epoxy nanocomposites are different. In polyethylene nanocomposites, interfacial polarization can be easily seen, and the nanocomposite with the highest loading of Alumina has the highest loss peak in low frequency region. In epoxy nanocomposites, the interfacial polarization induced by fillers cannot be observed. The reasons have been discussed in terms of improved dispersion and polarity differences between LLDPE and epoxy resin.

Ming-Yan-Zhang and Shu-jin zeng (2006) show the analysis of dielectric properties indicated that incorporating inorganic component into polyimide resin would have great effects on the dielectric properties of the PI/Alumina hybrid films.

Nguyen et al (2009) compare the dielectric and mechanical properties of standard nanoscale -filled and micro scale filled varnishes. The PD occurring between consecutive turns was avoided by using corona-resistant wires and standard enameled wires with a corona-resistant varnish. Varnishes are composed of a polymer matrix containing inorganic particles such as Al₂O₃, TiO₂, SiO₂ and ZnO to increase PD resistance by decreasing the PD induced erosion rate.
2.4 FINITE ELEMENT APPROACH OVER DIELECTRIC CHARACTERISTICS

Chakradhar Reddy Ch. and Ramu (2007) have computed thermal breakdown strength of nanocomposite cables. For insulation thickness >6 mm, the thermal breakdown strength increases with filler concentration up to about 5 phr. Among the four nanocomposites, the LDPE with 5 phr nano-MgO has the highest thermal breakdown strength.

Rebord et al (2008) have developed a CAD model for CNT nano composites cantilever plate and estimated Youngs Modulus using a analytical relation .The maximum deflection was predicted using trial and error FEA

Rohan Abraham et al (2004) have obtained the numerical values of the effective permittivity and tangent loss of dielectric mixtures by considering the volume ratio of the two constituents through the Finite Element Method. The results compared with well know effective modles such as the Maxwell-Garnett Formula and the Bruggeman Formula , as well as Empirical Models such as Power Law and Wakino’s formula. It is proved that the calculated values matched much closer to the values projected by the Bruggeman’s Formula.

2.5 SURFACE DEGRADATION EFFECTS

Di LorenZo del Casale et al (2007) have described the surface discharge phenomena using CIGRE method II for nano composites epoxy resins. A considerable improvement of time to breakdown under surface discharges was proved for nano compositive.

Fuse et al (2005) explains the complex permittivity, dielectric strength and electrical conductivity of polyimide were examined and the
complex permittivity suggest that molecular motion will be restricted in nanocomposites, it indicates a strong interaction between the resin and filter and also the conduction current decreases with the addition of nanofillers.

Fuse et al (2004) explains the polymer nanocomposites possess superior durability against partial discharges. The presence of mica, the resultant high crystallinity, strong ionic interaction at resin interfaces, and high durability against partial discharges of polyamide nanocomposites.

Gornica and Prociow (2008) found that electrical strength of polyesterimide nanocomposite with nanosilica exhibited more than 40% improvement upon what without fillers. Polyester and polyesterimide compounds for impregnating of electrical motors modified with nanoparticles of SiO$_2$, TiO$_2$ and ZnO when compared with standard compounds, show improved dielectrical properties and better water resistance, which may be attributed to scattering mechanism, caused by introduction of a second nanosized phase. Further stated that the nano silica obtained best results in compare with TiO$_2$ and ZnO fillers from the fact that nanosilica was characterized by a smallest size of nanoparticles among others.

Guastavino et al (2007) have suggested to deeply investigate the relationship between nano-structure and surface partial discharge resistance so that the related phenomena could be better understood and improved materials could be obtained. The manufacturing method does not significantly influence the final obtained nanostructure; in fact the preparation methods do not appreciably influence the basic intercalated structure. On the contrary the SPD resistance seems to be significantly sensitive to the manufacturing feature: in particular the nanoclay/epoxy premixing seems to be the way to get the best results.

Haq et al (2007) show an evaluation of the residual life of the wires, aged under high frequency ac waveforms, reveal that the wires with SiO$_2$ achieved a life that is twice the life of conventional wires. Finally, the paper discusses possible reasons for the reduction in surface erosion and improvements in breakdown strength of enameled wires filled with various types and concentrations of nanofillers.

2.6 PERFORMANCE OF NANOCOMPOSITE COATED WIRE FOR MOTOR APPLICATION

Hayakawa et al (2006) discuss PD inception characteristics as well as PD propagation characteristics after PD inception for magnet wire of inverter-fed motor under surge voltage application. Experimental results first revealed that PD inception voltage (PDIV) decreased with the increase in the length of enamel-coated wire i.e. size effect. Second, PD propagation characteristics were also investigated under the higher voltage application.

Imai et al (2008) discuss the various kinds of epoxy based nanocomposites were made and their properties evaluated to determine their applicability as insulating materials for heavy electric apparatuses. This paper describes the study demonstrates that nano-filler dispersion is effective in improving insulation properties of epoxy-based insulating materials. Moreover, the nano-filler/micro-filler combination systems not only verify that nanocomposite materials are practical insulating materials in terms of thermal expansion but also provides synergy effects on improvement of insulation properties.
Inuzuka et al (2006) measure the residual life of wires and surface roughness by scanning electron microscope. Alumina nanoparticles have excellent electrical, thermal, mechanical and physical properties for medium voltages. Increase in the loading weight of nanofiller cause an increase in partial discharge resistance but cause a reduction in mechanical strength.

Kikuchi et al (2008) have conducted an experiment for the investigation on effect of ambient humidity and temperature on the PD characteristics in the twisted pairs of nano composite enameled magnet wires which used for inverter fed random wound motors. Through the experiments the PDIV reduction with increase RH at low temperature and slight increase of PDIV with increased RH at high temperature is also observed. The PDIV in the conventional enameled wire significantly decreased at 95% RH, while the decrease rate of that in the nano composite one was relatively small. This was also observed in that experiment.

Kozako et al (2004) have discussed that the surface roughness caused by partial discharges was far smaller in specimens with nanofillers than those either without nanofillers, or those containing microfillers. The specimen with 2wt% nanofillers was found to have sufficiently improved resistance to PD. This superior PD resistance is caused by the presence of nanofillers, or mica, emergence of minute spherulites and high crystallinity, a nano-effect due to closely packed nanofillers, and strong chemical bonds at mica nanofillers/resin interfaces.

Naoki Hayakawa et al (2007) have expressed that PD inception characteristics and Pd propagation characteristics after PD inception for twisted pair and coil samples under repetitive surge voltage application. The results obtained that PDIV decreased with increase in the wire length, which was evaluated in terms of the stressed wire contact length also the evaluated
value of PDIV with respect to the regression lines for the size effect has been discussed.

Nguyen et al (2009) have discussed the dielectric and mechanical properties of standard and silica filled varnishes used in rotating machines electrical insulation. They have found out the nanoscale filled varnish shown better behavior than microscale ones. Dielectric and mechanical properties of standard and silica filled varnishes used in rotating machines electrical insulation have been investigated. Nanoscale filled varnish have shown better behavior than microscale ones. Both PDIV and lifetime have been increased and bonding strength has not deteriorated. On the contrary, the micro filled varnish has provided the worst results a lower PDIV, a very low increase in lifetime and a strongly reduced bonding strength.

Ozaki et al (2005) explain the insulation breakdown time of the nano hybridized enameled wire was improved and the effect of thickness on the insulation breakdown time was higher compared with standard wire and it results a good partial discharge resistance.

Saeed Ul Haq et al (2007) show an evaluation of the residual life of the wires, aged under high frequency ac waveforms, reveal that the wires with SiO$_2$ achieved a life that is twice the life of conventional wires. Finally, the paper discusses possible reasons for the reduction in surface erosion and improvements in breakdown strength of enameled wires filled with various types and concentrations of nanofillers (Fuse et al 2008).

Tanaka et al (2005) have given working hypothesis for interaction zones. Several parameters such as chain mobility, chain conformation, crystallinity, degree of the stochiometry have been discussed to formulate the multi-cored model. Partial discharge takes zigzag paths to select weak regions consisting of polyamide matrices resulting in strong PD resistance.
Uozumil et al (2007) describe the insulation properties of the nanocomposite enameled wires have been investigated in comparison with conventional ones and the V-t test shows that the lifetime of the nanocomposite enameled wire is much longer than that of the conventional one.

Zhang Mingyan et al (2004) describe a kind of nano-doped polyimide composite film was made by synthesizing polyimide/inorganic nano-particle matrix resin through sol-gel technique, the corona-resistant property was enhanced with the increasing of size of the inorganic particle.

Anurag Joshi and Sunil Kumar (1991) have carried out the moisture absorption test for F class insulation paper at three times at three different temperature based on IEC 243-1. It proved that the dielectric strength of the paper sample increases with the aging temperature. From this contraction results concluded that the behavior of the composite systems like clay filled insulation paper with regard to the thermal aging is quite different from the monolithic solid insulating material.

Diaham et al (2008) show that the electrical properties changes of polyimide films have been investigated during thermal ageing at 300 °C and Electrical improvement and increase of dielectric strength with nano filler has been observed.

Ekstrand et al (2005) have expressed that the thermal conductivity of filled epoxy cold be increased with 100% to 150% using thermally conductive fillers. It is proved that Alumina and SiO₂ composites attained the same conductivity in spite of different values of the ceramic powder. In contrary CNT composites lost the feature of thermal conductivity based on poor dispersion.
Ramirez et al (2008) explain the thermal degradation of nanofilled samples through Thermal Gravimetric Analysis (TGA). The nanofiller improve better heat and erosion resistance of Zirconia nanocomposites.

2.7 SUMMARY

The effect of nanofillers such as TiO$_2$, SiO$_2$, Al$_2$O$_3$ on the dielectric and thermal properties reported in the literature have been summarized in this chapter. In recent years semiconductor switches like MOSFET, GTO and IGBT are used particularly in inverter fed induction motors of ratings from few watts to megawatt ratings. Though semiconductor switches have better switching performances and they are affected by the heat produced due to harmonics. The local harmonic creates more heat in the switches, which could be partially transferred to the conductor. The average temperature rise could be tolerated by the existing enamel. Due to improper cooling, sometimes these enamel life might be affected without any further indication. Hence, nano filler added enamel have been considered in the present work for the improvement of dielectric and thermal properties of insulating materials used in electrical applications.

The synthesize technique, characterization process of nano fillers and detailed investigation on dielectric and thermal properties of nano fillers added polyimide enamel have been discussed in the subsequent chapters.