Asian Journal of Convergence in Technology **Volume IV Issue I**
ISSN NO.:2350-1146 I.F-5.71

Polymer Studies for Insulated Power Cable

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***Abstract*— In reviewing the history of the development of power cables have gained popularity among quality of power in terms of transmission. A new class of plastic materials has been developed; the outstanding characteristics of Polymers have pre-determinable electrical conductivities and possess perfection in physical, electrical as well for mechanical properties. The supply of power with higher reliability is the main aspect of power system and trouble-free performance of power cable is extremely important in utility side. Power outage causes by failure of cable insulation to overcome all the issues the new polymer materials came in use for the improvement in power cables. Aim to search new material which can improve the environmental compliance of wire and cable in all regions of the world. The variety of uses associated with the manufacturing and installation of insulated power cable consisting a number of materials of high conductivity metals polymers base, that are extruded around the centre conductor which are having different effects in terms of performance. Present days power cables are amazingly developed with improved dielectric properties and progress has been made by adopting method of preparation.**

Keywords*— *Power cables, Polymers, Insulation materials, Electrical properties, Ferrites, Power quality.

I. INTRODUCTION

The performance of cable for any industrial or commercial environment has been the centre Nervous system of operating area. The physical demands are low smoke low flame and fire retardant. At the point of evolution and material development the variety of material available can be manufactured and processed easily. The number of new materials exists for desire to improve our impact or safety and security for working environment.

The standards are required to sound good or it is all about Engineering balance. There are two requirements for balancing first is complementary effect and another one is cable design. Balance world correlates its reflection in terms of power cable that is environmental, cable performance requirement, fire safety concerns vice versa.

The technical gap exists from the starting to the end of life. Transmission performance, physical performance, fire requirement and environmental hazards is a long chain running from the origin to present day. The electrical and physical characteristic of insulation material are important in design of cable under normal service condition so that high temperature can be reached during overloading.

The pace at which each and every nation is moving toward power quality is very high out of many factors faults in power system cannot be predetermined there are many few of them which can be predetermined [1] . In term of manufacturing of insulation cable the polymers plays a huge role polymers for power shows a strong link with each others.

Polymers are the giant molecules they are as important chemicals in our bodies (proteins, poly-nucleic acid). In plants (starch and cellulose) and in our daily lives (fibers, plastic, elastomers). Polymers are classified as Thermoplastic, Thermoset and Elastomers. QUESTRA a crystalline polymer a new material option for electrical insulation system. According to IEEE 117 and IEC 61857 this is new thermoplastic and now recognized under UL446 it is so called as syndiotactive polystyrene as it is arranged in a symmetrical pattern or either of the polymer backbone [2]. The electrical performance of polymers when used as insulation in cables plays a vital role. The crosslink polymers has become popular material because of excellent electrical properties and dielectric properties. In power system voltage range is divided into several categories the different polymeric insulation materials used in low or high voltage power cables. Under various stress condition the growth of water trees in polymers occur as the moisture exists in the system resulting failure of conductivity in the cable. The different types are cable are using are cross linked polyethylene XLPE, PE, PVC cables [3]. The polymers are of three material type material-1 consisting LDPE material 2- poly(ethylene-co-dien) material 3- single site material. Metals are crystalline polymers are insulator and ceramic are brittle the engineering material are to be used. The polymers are electrically insulating materials some of polymers are made electrically conductive for making plastic material conducting fillers materials such as graphite, metal powder are used. The Izod test is the most common test for plastic and charoy test is used to measure the toughness of polymer material.

II. METAL USED IN CABLE MATERIALS

Modern three wire PVC insulated cable known as Nomex comes into role the electric cables having different classifications.

- VIR, vulcanized insulated rubber cable
- CTS, cab tyre sheathed
- TRS, tough rubber sheathed

- PVC
- Lead sheathed cable
- Flexible cable and cord
- Whether proof cables.

Fillers and blinders are used for three reasons to fill the gaps in cable for a more attractive appearance to maintain a sequence of components and to add the strength to a cable [4]. The paper are used as a filler extensively in power cables as they are available in flame moisture resistant version. Cotton, Rayon keylar commonly used in fiber optics cable to improve the impact and strain resistance.

III. THE CHALLENGING PHASE OF INSULATION CABLES

The challenging phase of evolution of high voltage cables is the reduction of cable dimensions of polymeric material when dielectric polymer is utilized in air as of potential source in term of breakdown and electric field converts air into ozone and other activated gases which then in turn to attack the polymer. As moisture decrease the strength of polymer behavior and characterization when used in power cables. Thermal conductivity plays an important role and can be defined as the capacity of material to conduct heat [5]. The thermal expansion and contraction during cycling of a cable the conductive layer over the conductor varies with the temperature. The major problem is associated with the crystalline material used in cable insulation. The main challenging task is to find the best material for manufacturing of cable in terms of cost and performance wise.

The cable need to be chosen for the suitable application and depend upon the parameters of cables the parameter for selection of type of cable are voltage, current carrying capacity, short circuit value, ambient temperature and voltage drop. In spite of these all the insulation material must restrict to a particular voltage limiting value the increasing and decreasing dielectric constant the effect of voltage when conducting the halogen free.

Current trends in the plastic industry are to prepare electrically conductive plastic, blending and alloying, polymer matrix composites, Recycling and sustainability, Biodegradable plastic and high temperature plastic [6]. GMT Glass mat thermoplastic composite it is the most common class of thermoplastic composite this matrix polymer included PP, PVC, PC, PA, PPS (polyphenylene sulphide), Polyesters PBT, PET. The light weighted reinforced thermoplastic composite are development of GMT materials with very high stiffness, impact resistance, high flexural modulus, these materials are produced with glass and PP due to greater potential a HV to EHV cable insulations opting this polymer because of their physical performance, dielectric strength, dissipation factor and volume resistivity. The XLPE have excellent properties and has effect of enhancing room temperature properties and this cable can work for voltage 240kv to 500kv.

IV. RELATED DEVELOPMENT OF POWER CABLES

The first insulation systems were composite materials which were based on natural fibers of cellulose, cotton, quartz, wool, asbestos, sand, silk and are naturally highly viscous substance derived from trees, plants, insects and petroleum deposits that is typically convertible into polymers. In the early years of electrical industry, the focus was on renewable materials and experimentation to find power quality systems which met minimum design criteria. The fillers in the polymer matrix were applied as individual shore for wires and in combined forms. During the First World War the polymer in the form of mica were splitting then mixed with bitumen reinforce on both sides by a fine grade of cellulose paper so-called Kraft paper was formed by muscovite mica splitting bonded with natural shellac. Mica having characterizes of high resistance for creepage of current for organic insulator it exhibit the best results for partial discharge handling mica, therefore plays an important focusing role66 for the material used in analyzing high-voltage electrical machines spectrum[7]. Initially, mica was used as insulating material and after advancement for the manufacture of composite materials for Natural and Synthetic resins too.

The first synthetic material was developed in 1875 was cellulose nitrate. In 1812 the first power cable was used in Russia. In 1890 Ferranti developed the concentric construction for power cables Between the 1920s and 1940s, other synthetic products were introduced in the electrical engineering industry, including alkyd resins, aniline-formaldehyde, polyvinyl chloride (PVC), acrylic, polystyrene (PS) and nylon, glass fibers , in the applications of electrical insulation. During the 1940s and the 1950s, the availability of integral types of synthetic polymers and resins increased in an impressive way. In 1903 the first PVC was used in Germany, First DC power transmission cable in 1957 in Sweden.

The intervening 100years the prominent product developed for power cable were fluid impregnated paper –paper insulted cable which were perfected by Pirelli company in 1971.and XLPE developed by general electrical company in 1963 after the world war II there were rapid progress in polymers and polymer insulated cable system.

V. LIST OF COMMON INSULATING MATERIALS

There is a variety of cables available that can be sorted into four categories according to the type of insulation, that is paper-oil, oil filled, polypropylene paper laminated and extruded polymer. The insulation layer typically consists of XLPE and is the most crucial layer in a cable as it prevents current leakage to the surroundings. They are listed in three different types' solid, liquid, and Gases.

- In Solids – Clays, Plastic, Glass, Paper/cardboard, Mica, Teflon, Rubber Wax and oil.
- In Liquids- Insulating oil and Transformer oil.
- In Gases- Gas insulated switchgear, gas insulted transformers[8].

Historic Bell wires, low voltage with two under wrap of cotton and treated with wax were used.

- TYPE -C Lamp chord in 1880-1970 with rubber insulator.
- TYPE –R rubber covered house wire in this Asphaultham outer coat to protect the rubber.
- Triplex telephone chord, rubber insulated , cotton braid painted.
- SJTWA-PVC hard service chord
- POSJ 32 Early flat chord, plasticized PVC
- Modern vinyl speaker chord- PVC rated upto 300volts.
- Early PVC ROMEX cable from 1950
- Type-SE cable from the 1950 with neoprene insulation.
- Modern: 3 size of Romex, PVC coating
- Modern: Black jacket service cable deigned for outdoor services.

VI. CABLE INSULATION PROPERTIES

The various polymers have different properties a new wire insulation of polymers offers better performance and significantly less environment hazard due to its electrical and mechanical properties. The concern with most of the cable wires and insulating materials is dielectric constant heat absorbent, smoke, toxic gases and acids when they are burnt.

TABLE I. CABLE INSULATION PROPERTIES

Parameters	***PVC***	***PE***	***PP***
Density g/cm³	1.3-1.55 at heat resistant 105ºc	0.94-0.98 at heat resistant 105ºc	0.91
Breakdown voltage kv/mm (200c)	25	85	75
Dielectric constant 50Hz (200c)	4.5-6.5	2.3	2.3-2.4
Melting point (+ 0c)	>140	>130	>160
Flame resistance	Self Extinguishing	Flammable	Flammable
Thermal conductivity W.K-1.m-1	0.17	0.4	0.19
Water Absorption %	0.4	0.1	0.1

A. High temperature materials

PVDE - Polyvinylidene Fluoride Dyflor
ETFE - Ethylene-tetrafluoroethylene
FEP - Fluorine ethylene propylene
PTFE - Polytetrafluoroethylene.

Progress has been made during last few years in the research area for increasing the thermal conductivity breakdown electric field of the insulating material. To enhance all the physical and electrical properties one must choose fillers for polymer having properties similar to the polymer matrix . As the thermal conductivity of the filler should be greater than 100 times to the thermal conductivity of the polymer matrix the main goal is to develop a material with high thermal conductivity, low dielectric constant, high breakdown strength, high electrical resistivity and low in cost. From the chemical aspects, fillers can be classified such as inorganic, organic, natural, synthetic polymer substances consisting of oxides, hydroxides, carbon, silk, wool, kevlar and carbon black [9]. For the approaching all above parameters need to introduce some fillers for polymers few of them are Al2O3 Aluminum oxide, silica nitride and boron nitride. The thermal conductivity increases when ratio of intrinsic conductivity to the Thermal conductivity of polymer matrix increases. The above oxides particles have different properties and are available in several forms in both the crystalline and fumed formed. They exhibit low dielectric constant, corrosion resistant, and have excellent electrical properties.

The thermal conductivity of the composite cannot be fully determined by size, distribution, by orientation of the particles. In High voltage applications the electric field distortion are caused by the difference in dielectric constant and electrical conductivity. The examples of high electric conductivity fillers are carbon, fibers, carbon black, graphite, carbon nanotubes. Carbon nanotubes improve the electrical and thermal resistivity and Al2O3 is usually selected for high thermal conductivity while TiO2 nano particles have photo catalytic properties. Calcium carbonate (CaCO3) is typically used for low costs and for large number of deposition. ZnO having non linear electrical characteristics for electric stress control the ZnO is employed in composites.

The resulting electrical properties depends upon the aspects and nature of particular filler and the polymer matrix being used. Additions of polymer are prepared by combining Hygroscopic agents for examples carbon, carbon black, cabon fibers. The material developments include some compounds these are PVC compounds, Fluropolymer compound and Halogen free compounds.

B. Ferrites Materials

Now a day's conducting polymers have different properties in different are a number of studies found that conductivity depends upon the several factors such as the type of filler the concentration and on the strength of the polymer [10]. Ferrites performs a vital role in behavior for making a polymer electrical conductive. The structure consists of cubic close packing of oxygen atom (32) in which 8 are tetrahedral (A) and half of octahedral (B). The substitution of ferrites results different parameters for better results. The substitution can be synthesized by sol gel method, X-ray Diffraction, FTIR spectrum. By substituting different ferrites such as Cd, Cr and Ni, the properties changes as the electrons starts moving from

one place to other by these substitution the properties saturated behavior magnetization electrical properties got affected.

The importance of ferrites materials has been known to mankind for many centuries the electric and magnetic properties have started in the year of 1930. The material of ferrites includes or possesses high electrical and high resistivity dielectric losses permeability magnetization which is almost valid in most of the field. By knowing properties of each ferrite the best polymer matrix material can be prepared by various technical methods. When ferrites are mixed with certain polymers, they provide easily extrudable compounds most suitable for wire and cable fabrication. These features wire and cable insulation after mixing of ferrites materials can be fabricated for attenuating interference signals of both lower and higher frequencies for the transmission lines polymeric shielding layer in the fabrication of high frequency attenuating wire and cable. Electromagnetic compatibility is the ability of an equipment or system to function satisfactory in its electromagnetic environment without introducing intolerable electromagnetic disturbances to anything in that environment. The conducting polymeric shielding layer matrix of the wire and cable is filled with ferrite particles that attenuate EMI. Shielding is therefore a good measure to reduce electromagnetic noise outside of the equipment by keeping the noise inside. Shielding can be applied to enclosures and cables.

C. Electric properties of ferrites

In ferrites cations are surrounded by close pack oxygen anion and can be treated as isolated from each other. As the electrical properties are mainly affected by cation distribution and amount of Fe2+ present the resistivity varies from the range of 10-3 to 1011Ω at room temperature. The resistivity of ferrites is very sensitive to temperature the ferrites require some activation energy for transferring the electron as ferrite charge is not free to move through crystal lattice. The fine powder of ferrite are to be present of particular diameter and thickness and by heating and cooling at particular temperature the bulk material is obtained and the resulted samples are useful to measure DC resistivity by pasting silver pellets on both the sides of the material.

The dielectric constant is mostly found to decrease rapidly with the increase in frequency. The insulation stealth material in a cable is generally made up of PE and PVC matrix with some additives [11]. The effect of fillers not only reduces the cost of compound but also plays a part of improving mechanical and dielectric properties of the cables.

In present studies it is evident that some absorption is still present with components of power factor and capacitance due to absorption, component being a function of amount of the moisture present. In some power cable construction the insulation material is exposed to water and in combining with the electrical stresses will cause tree like structure to grow this tree reducing the life of the cable starts increasing the dielectric losses and breakdown strength. The tree grows predominantly in the amorphous region of polymers the water tree grows in both the thermoplastic and thermosetting system.

VII. PROPERTIES OF INSULATING MATERIALS

The insulating materials have become a focus in many types of electrical equipments in best example the electrical motor can be taken the winding of copper and steel core making up the magnetic circuit both contributes to power output of the motor in this insulation keeps these two components apart.

As the insulating material has high electrical resistance. The three major properties of insulating materials are the specific resistance, Dielectric constant and the Electrical Dissipation Factor. To withstand the electrical stress without breaking up is the most important characteristic of an insulating material.

Another significant aspect that these are categorized is the maximum temperature to perform satisfactory. The main grading or class of insulation as defined IEC60085:1984.

It is not at all necessary that all the insulation are located at the point of maximum temperature the insulation with lower thermal values are too classified with different operating temperature.

VIII. MATERIALS AND METHODS

A number of approaches are currently being considered to improve insulation materials. By the addition of nanoparticles the DC insulation properties improves as it reduces the electrical conductivity. To enhance the dielectric properties of polymer insulators the nano composites of polyethylene and metal oxide nanoparticles are used as they tends to reduce the DC conductivity While handling the metal oxide nanoparticles the hydroxide layer tends to cover the surface which results the absorption of water at ambient condition this presence of water in insulation raises the risk of water treeing among the power cables. Nano composite can be prepared by extruded process or by sol gel method the electrical characteristics includes both the DC conductivity and AC conductivity measurements.

The DC conductivity can be measured by placing a thick film between the electrodes. The desired current as well as voltage can be measured by electrometer.

Water treeing methods can be performed at room temperature using wire plane method. In this method a Aluminum tape is connected to a tungsten wire which then attached to sample prepared the AC voltage is applied further at the electrode of tungsten wire and formation of tree can be observed in Situ- Raman spectroscopy.

A large amount of studies have been published in last two decades. The different type of particles different functioning varying shape and size in order for improving the conductivity another attributes there are much issues yet to be resolved.

IX. ENVIRONMENTAL CONSIDERATIONS

Cables overhead or underground in power system are used for both energy and data transmission and deigned from many years. Today cables are recovered because high value of metals which are having high and different properties in performance wise. The cables are collected for the purpose of recovery the metal and chopped into small pieces by some method in this case the metals and the insulation are separated and can took for further use[12]. The Polyolefins (Pe, PP, XLPE) having high energy content when they are burned can be used as fuel that creates carbon dioxide and water.

Finding a better scheme for recycling cable insulation is an important issue for the cable industry. Hitachi has developed a new recycling technology that makes cable-to-cable recycling (use of waste cable materials in the production of new cables) possible. The technology can transform Si-XLPE (silane cross-linked polyethylene) into thermoplastic PE (polyethylene) which can be recycled as insulation in new cable. This technology uses Sc-MeOH (supercritical methanol) at a temperature of 330 and pressure of 10 MPa.

PVC when burned HCL is formed. Like XLPE the waste cable of XLPE formed PE as a fuel. One abundant source or scrap of Thermoset XLPE is wire and cables, separating the cables into perfect material are only the first step as thermo set materials are not melt processable but can be mixed with thermoplastic to enhance the material properties.

Plastics present significant disposal issues. Its harmful additives leak into the groundwater in landfills and produce toxic gases when burned. PVC can be recycled but it is not always technically feasible and rarely cost effective. Other common wire insulations present similar, if less severe, problems. On the other hand, mPPE is thermoplastic and more easily recycled as it does not contain the aforementioned hazardous materials.

As seen from many study the polymers seen as work product from metal being recovered. The recovery collection of cables are into pace by economical consideration many technical solution has been done for recycling and recovering especially from energy cables.

CONCLUSION

The insulating materials used in Power Cables application are challenging. Although the different emerging trends are adopting for electrical benefits earlier also and many outcomes remains unanswered and many are explored. The contribution of electrical, mechanical, material science, chemistry and physics is bundling a strongest evolution to the society. From this collaboration the performance for better understanding of Polymers, insulation materials Power pool can be analyzed easily.

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