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Rubber Insulated Power Cables

Rubber insulation for cables date back to the Gutta Purcha used on Samuel Morse's telegraph lines. Synthetic ethylene propylene rubber (EPR) became available in the mid 1960s with the invention of Ziegler Natta polymerization catalysts. Insulation compounds based on these synthetic EPRs became available in the 1970s[1]. These insulation types are approaching 40 years of reliable service. Rubber insulation is chosen for its proven service life, flexibility and performance in high temperature operation[2]. Most rubber insulations produced today are based on ethylene propylene (EP) or ethylene propylene diene (EPDM) polymers. EPDM insulations are used on cables rated up to 138 kV.

Insulation Materials

Some have attempted to classify EPDM polymers by the percentage of ethylene present in an EPDM base resin. One theory is that the higher the ethylene content, the higher the crystallinity (semi-crystalline) and therefore, the greater the susceptibility to treeing and early failure. All EPDM cable insulations, however, are inherently resistant to treeing. It is believed that EPDM's high resistance to degradation and reduced hydrophobicity prevents water from condensing and causing the oxidation associated with water trees. It is also theorized that the ionic species introduced by the clay filler makes the water too conductive to form trees[3].

ASTM D3900 states that differences in ethylene sequence distribution causes differences in the crystallinity at the same ethylene content. In other words, how the base resin is made determines crystallinity, not how much ethylene it contains. ASTM further states that the ethylene content should not be used as the sole measurement to determine the suitability of a particular rubber for an intended purpose. Higher ethylene-content type insulation has been used in the utility industry for greater than 30 years with excellent results.

Low crystallinity (amorphous) EPs have the ability to allow for the incorporation of large quantities of oils and fillers while maintaining high levels of physical and electrical properties. The high loading not only lowers the compound's overall cost, but can also make them easier to handle and process into cables. Semi-crystalline EPs can be pellitized, thus allowing for compounding on modern continuous compounding machines and, transport in completely enclosed handling systems. Small amounts of polyethylene are frequently added to the formula to aid in pellitizing (clay filled polyethylene is also tree retardant). The diene content of EPDM affects the rate and state of cure, therefore high diene means more cure sites.

Clay fillers, as mentioned above, are essential to the electrical performance as well as to providing high deformation resistance at elevated temperatures. The clay is treated with vinyl silane to render it hydrophobic and to couple it with the polymer. Advances in the processing and quality of clay fillers have produced modern insulations with lower dielectric loss.

Lead oxide, which gives the characteristically pink color, together with zinc oxide and other antioxidants are added to the insulation to thermally and electrically stabilize the compound. Lead is believed to neutralize the polymerization catalyst residue. Zinc oxide, on the other hand improves the electrical breakdown strength. Some manufactures add iron oxide, which gives the insulation a redder color. Most medium- or high- voltage insulations are cured with organic peroxide.

EPDM insulations typically have a dielectric constant of 2.6 to 2.8 and desirably a dissipation factor of under 0.5% at 90°C. EPDM insulations have an average 2000 psi tensile strength and a 250% elongation, which are more than sufficient to produce a tough, flexible cable with a small bending radius. Most EPDM insulation compounds have greater than an 80% retained tensile and elongation after ageing 7 days at 136°C, making them suitable for operation at 105°C

Conductors

Conductors are typically stranded, compressed or compact, aluminum or copper. They are typically reverse concentric lay. Conductors with smaller gauge strands are more flexible. In the United States, the American Wire Gauge (AWG) references conductors up to 4/0, and thousand circular mils (kcmil) for larger sized conductors. Copper is about 1.7 times more conductive than aluminum, so smaller diameters will result with copper although the conductor will be heaver. Conductors are sized to adequately carry the required current at the rated temperature of operation (temperature is influenced by the heat transfer properties of the materials and conditions in which they are installed.). The cable manufacturer can assist in sizing.

Conductor Shield

A conductor shield is required over stranded conductors above 2kV. The conductor shield provides for a smooth, radial electric field within the insulation[4]. The conductivity must be greater than the dielectric constant times the frequency, for power frequency operation. The dielectric constant of a semicon is in the order of 1000, so even if the phase angle of the shield approached 90º, the field in the shield would be negligible compared to that in the insulation. Therefore the conductor shield can perform its function at low fairly low conductivity levels[5]. Industry specifications require a resistivity of below 1000 ohm-meters. The conductor shield is produced with a copolymer of ethylene or EPR filled with carbon black to make the material semi-conducting. Some manufacturers use a nonconductive material with a dielectric constant of about 10. All are compatible with, and firmly bond to, the insulation. Modern ethylene copolymers allow for compounding of exceptionally smooth materials on continuous compounding machines and transport in completely enclosed handling systems in pellet form.

Insulation Shield

The insulation shield, like the conductor shield, is required in medium- and high- voltage cables rated 2kV and above. The insulation shield provides for a smooth, radial electric field within the insulation. Industry specifications require a resistivity of below 500 ohm-meters to adequately carry current to the metallic shield. Most commercial materials are below 100 ohm-meters. One very important aspect of the insulation shield is its degree of "strip-ability". The insulation shield must be easily removable in order to be terminated and spliced. In most cables, the insulation shield is co-extruded with the insulation and cross-linked to its surface. Most insulation shields are based on ethylene vinyl acetate (EVA) copolymers that have a high enough polarity that even though cross-linked to the insulation, do not mix with and bond permanently to it. Note: EVA can generate acetic acid, noticeable by a strong vinegar odor, if overheated during cure. Acid scavengers are added to neutralize small amounts of acid if generated. Computer programs are used to predict and control the surface temperature of the cable during manufacture.

Metallic Shields

The metallic shield is applied over the insulation shield and serves several purposes: it provides a path for the flow of charging current and a path for the flow of fault current. If the metallic shield is of sufficient size and conductivity, it can provide a path for the return current and thereby act as a system neutral. There are a number of designs of metallic shields including round wire, flat strap, copper tape helically applied with an overlap or longitudinally applied corrugated copper tape. The embedded corrugated wire metallic shield type has a high short-circuit capacity when compared to an overlapped copper tape and is used to easily and quickly strip the jacket away from the insulation.

Jackets

Jackets are available in a number of different compounds for specific requirements. Jacket types include polyvinyl chloride (PVC), polyethylene (LLDPE, MDPE, HDPE), Polypropylene (PP), Neoprene, Hypalon®, and thermoplastic chlorinated polyethylene (CPE). For certain applications, a lead sheath and interlocking or corrugated armors are available for multiconductor cables. Jackets may offer properties, such as sunlight, flame, chemical and abuse resistance. Jacket selection depends on where and how a cable will be used and the exposure conditions, both during installation and while in service.

New Developments

Over the past decade, improvements in reactor and catalyst technology have enabled polymer producers to control alkene building blocks and provide ethylene-alkene copolymer (EAM) polymers)[6]. These new polymers are proving to have superior electrical properties to traditional materials. Ziegler Natta polymerization catalysts leave substantial residues of iron, vanadium and chlorine. Concentrations of these are believed to cause bow tie trees[3]. Modern catalysts are super efficient and leave almost immeasurably low residues. Lower dielectric loss results from these lower residues.

Ethylene propylene rubbers are now also being produced with these catalysts. Pelletized EAM processes efficiently, cross-links effectively, and allows clean-room handling to reduce occurrence of contaminants in the cable. Standards committees have already taken the first steps toward including EAM in their electrical cable standards. Cable insulation compounds without lead are under development based on EAM polymers. EAMs should also allow the development of even more thermally stable, higher operation temperature compounds.

References

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Mark has over 10 years experience in wire and cable and holds over 12 patents on medium and high voltage cable materials. He currently oversees the sales and marketing of General Cable's EP power cable compounds to other cable companies worldwide.