

Session Five: Modern XLPE Materials for Extruded Energy Cable Systems

Hakan Lennartsson

Senior Technical Service Manager, Borouge Hong Kong Pte. Ltd.

Abstract

The first medium voltage cables using extruded XLPE materials were manufactured and installed in the late 1960's. Over the years XLPE materials have become the preferred technology for manufacturing of MV cables. However the development has not been totally without problems. Cables installed in an early stage showed problems with premature field failures. The problems have been thoroughly studied and today there are different solutions to significantly improve reliability and service life expectations.

Another fast growing application is manufacturing of extruded cables for high voltage and extra high voltage. High voltage cable designs has to handle significantly higher electrical stress levels compared to medium voltage designs and this has to be addressed by selection of materials and optimization in material handling and cable manufacturing process

The paper discusses background, basic material characteristics, and enhanced materials for medium voltage application as well as important considerations for high voltage materials.

Polyethylene

Polyethylene is long chain hydrocarbon molecules manufactured by the polymerization of ethylene gas. The main chemical elements making up polyethylene is carbon and hydrogen. The elements are combined by covalent chemical bond and the polymer structure has low polarity which gives inherent good electrical characteristics as low electrical losses.

Polyethylene is manufactured from petrochemicals as oil/nafta or gas and recently there have also been studies to use biomass as raw material. Polyethylene is a very versatile polymer with a lot of different end applications. Polyethylene is commonly classified based on density and melt flow rate which gives some of the basic characteristics. In wire and cable applications a commonly used reference for polyethylene classification is ASTM D1248. In this specification type refers to the density range and category refers to melt flow range. There are different polymerization processes for manufacturing of polyethylene and these different processes give somewhat different characteristics to the polymer.

The high pressure process will manufacture low density polyethylene, LDPE and copolymers as ethylene-ethyl-acrylate, EEA, ethylene-butyl-acrylate, EBA and ethylene- vinyl- acetate, EVA, respectively. The LDPE is the preferred material for XLPE insulation and copolymers as EBA and EEA are used as base resins for bonded conductive screens. EVA may be used as base resin for bonded as well as strippable

insulation screens, however when used as insulation screen EVA based compounds has a temperature limitation in the curing process.

Low pressure processes uses catalyst and these processes are suitable for manufacturing of linear materials as linear low density polyethylene, LLDPE, medium density polyethylene, MDPE and high density polyethylene, HDPE. The robustness of particularly MDPE and HDPE makes these types of materials suitable as jacketing materials of cables.

Crosslinking

The crosslinking is a chemical reaction where polymer chains are linked together forming a three dimensional network. The link formed between the polyethylene molecules is a covalent chemical bond and it is practically an irreversible reaction i.e. the polymer can not be molten and formed to a different shape. Polymers containing a three dimensional network is sometimes referred to as thermo-sets, while polymers that can be molten and reshaped are referred to as thermoplastic materials.

Crosslinking of low density polyethylene can be performed by different technologies as

- Peroxide crosslinking
- Silane crosslinking
- Irradiation crosslinking

Peroxide crosslinking is by far most the common practice for medium voltage (MV) and the only technology applied in high voltage (HV) and extra high voltages (EHV) cable manufacturing. Silane crosslinking is the dominating technology for manufacturing of low voltage XLPE cable.

Irradiation crosslinking are mainly used in special applications where the thickness of the polymer layer is relatively thin.

Hot set test is the normal test methods used to determine that XLPE insulation is sufficiently cross linked. A specimen is prepared from the insulation and the cross sectional area is determined. The specimen is placed in a heat oven operating at 200 °C with a load of 0.20 MPa. Elongation is determined after 15 minutes, then the load is removed and the sample left to recover for 5 minutes. The requirements are maximum 175% elongation with load and a maximum 15% permanent elongation.

Energy Cables

Electrical cables for medium voltage and high voltage application typically have three polymeric layers making up the cable core.

- Conductor shield
- Insulation
- Insulation shield

Medium Voltage cables can have strippable or bonded insulation shield while high voltage always has bonded insulation shield. Another difference between MV and HV cable is the electrical stress that the materials will be subjected to.

Electrical Stress

Detailed considerations about cable design parameters or mathematical calculations on cable designs is far beyond the scope of this presentation and this information as well as equations for calculations can be found in published books or in conference papers. What we need to understand is that the demand on used materials increase with increasing cable rating. Looking at commercially available cable designs gives an indication on typical stress in different cable designs.

	Conductor stress (kV/mm)	Core stress at (kV/mm)
Medium Voltage	2 - 4	1 – 2
High Voltage	4 - 8	1.5 – 4
Extra High Voltage	8 - 12	3.5 – 6.5

If we try to translate the typical electrical stress into requirements on material characteristics:

- It is of greatest importance that the semi conductive shields has a smooth interface with the insulation i.e. smoothness is very important for the conductor shield
- The XLPE insulation must have minimum contaminants which can enhance electrical stress build up in the insulation; i.e. cleanliness of the insulation need to be carefully controlled

The material in different cable designs will experience different demand of performance as electrical stress increases with increasing cable rating. However it needs to be recognized that cable rating only give an indication of the requirements. Other parameters that have significant influence are conductor size and insulation thickness. It is recommended to consider stress in each specific design of HV and EHV cables to gain the best understanding of requirement on materials and cable manufacturing process.

Defects in Polymeric Cables

Manufacturing of XLPE insulation material as well as semi conductive screen compounds as well as cable manufacturing is industrial processes and it is not possible to have a 100 % control or manufacture “zero defects” products. The important factor is to exclude the most dangerous size/types of defects and control and minimize acceptable defects. The potential defects in the polymeric part of the cable core refer to any structure that has different characteristics compared to the polyethylene matrix.

XLPE Manufacturing

Wire and cable application is only using a small part of the world wide production of polyethylene. Wire and Cable is estimated to use approximately 2-3 % of the total polyethylene capacity.

Manufacturing of XLPE insulation for particularly high voltage and extra high voltage require specially designed and dedicated manufacturing set up.

- Reactor – tubular reactor to minimize risk of metal
- Additives and adding process Qualified suppliers with defined specifications and statistical incoming control - cleanliness inline check
- Production line and packing- special design with all material mapped for rapid identification if wearing. Completely closed system filtered air and special packing monitored by cleanliness check.

Cleanliness inspection is performed by an automated inspection unit. A tape is produced from the insulation material and it is inspected by laser and CCD camera. The inspection is made on transparent tape and all structures is identified and classified. The observed structures can be further analyzed to determine origin.

	MV	HV	EHV
Cable rating (kV)	6-36	36-220	>220
Typical electrical stress (kV/mm)	2	6	10
Contaminants to be excluded (microns)	200-500	100-200	70-100
Contaminants to be controlled (microns)	100-200	70-100	50-70

Semi conductive compounds for conductor and insulation shield are designed to have certain conductivity and carbon black is compounded into a base resin to give conductive properties. Carbon black from two different manufacturing processes is used in W&C applications:

- Acetylene carbon black – gives the best technical performance and is a very chemically clean carbon black with gives excellent surface smoothness
- Selected furnace carbon black – quality depends on source and grade

At manufacturing of semi conductive compounds the focus is monitor surface smoothness.

Cable Manufacturing Process

At the cable manufacturing process every manufacturing step may include risks of defects to the cable.

- Material handling risk of introduction of foreign contaminants from the system or from the air. or build up and oxidation with time with increased risk of ambers and oxidized particles
- Extrusion process - risk of scorch and ambers and
- Curing and cooling process – risk of voids, insufficient cross linking
- Finalizing – mechanical damages
- Testing and shipment- mechanical damages

It is the recommendation that cable manufacturers get to know their manufacturing process and collect all necessary data from the basis of engineering purpose, and not only rely on data from final quality control.

Installation

It is of the greatest importance that the cables are installed according to best practice and to avoid any damages to the cable system. Mechanical damage to cable jacket due to abrasion, cuts or cracking occurs and often cables are checked for any damages to jacket after installation. There have been move from PVC jacketing to polyethylene jacket, particularly MDPE and HDPE. The latest generation of linear materials has excellent heat deformation properties very good mechanical properties as hardness and abrasion resistance and good crack resistance. Polyethylene has also a significant better resistance to moisture diffusion compared to PVC.

Specifications

There are a number of international specifications as well as national specifications and end user specifications. IEC specifications are commonly used as the guiding specifications for HV and EHV cable.

- IEC60840
- IEC62067

These specifications covers routine test, sample test as well as type test of the cable system. With the increasing number of HV and EHV cable systems installed the interest in ageing characteristics has increased. This test is referred as pre-qualification test and it is a one year test at $1.7 U_0$ with 180 heat cycles up to 90-95 °C followed by lightning impulse test. The test includes testing of a complete cable system with joint and terminations. Particularly joints and terminations have had some problems with failures in HV and EHV systems and it is important to verify compatibility and establish good craftsmanship in installations.

Track Record

XLPE cables have over the years built up an extensive track record and become the totally dominating material for medium voltage cables world wide. There has been some set backs particularly with “water treeing” of the early generation of cables in USA and Germany. The origin of the problems is now well understood and the problems were solved by cooperation between material suppliers, cable manufacturers and utilities. There are testing protocols that address testing under wet conditions. New type of materials with improved performance have been developed and proven during more than 20 years field service.

The manufacturing of HV cables starting during 1980's was a challenge for material manufacturers, manufacturing equipment suppliers and cable manufacturers. Again it was a joint effort between all involved parties and the result is that most HV cables installed today is extruded XLPE cables.

XLPE cables have also entered the EHV area and cable rated up to 525 kV has been manufactured and successfully installed. EHV cables are a growing area and new projects are coming particularly in larger cities.

HVDC cables manufactured with XLPE are a growing area and the first projects have been installed for a decade.

Future Outlook

The worldwide demand for energy is growing and the demand for electricity in particular is growing at a fast rate. International Energy Authority has made predictions of very significant need for investments both in electricity generation and in transmission and distribution networks for they scenario until 2030.

The demand for electricity is driven by technology development, change in life style as well industrialization in developing countries. Very many people are today depending on a secure and reliable supply of electricity both when they are working as well as they are spending time at home.

Unfortunately there has been as couple of black outs around the world, which has created a lot of concern as well as huge economical losses. There has also been reported a number of occasions where severe weather conditions as typhoons, hurricanes, heavy storm, rain and mudslide or snow has caused loss of power supply. Many countries have not implemented legislation forcing service providers to apply best reliable technical solutions and this has driven underground cables in favor of overhead systems.

Material Developments

The development work with XLPE compounds are focused on:

- Improved productivity based on new base resin

A continuous curing (CV) line may have different limiting factors:

- Material temperature in extruder and risk of scorch
- Curing section – heat transfer to crosslink insulation outside to inside

- Cooling section – need to be sufficient to cool the cable to avoid voids and partial discharge due to curing by-products

- Reduced degassing to improve safety and reduce lead time

All cables manufactured by peroxide curing will contain by-products from the decomposition of peroxide and curing reaction. The most common by products are Methane, Acetophenone and Cumylalcohol. The by-products may have influence on the cable performance as well as installation. The issues with by-products are:

- Increased dielectric loss
- Gas pressure build up
 - Distortion of metallic foil sheath
 - Displacement of pre-fabricated as joints and terminations
 - Safety due to explosion risk with methane
- Influence PD measurements filling voids or hollow structure

Medium voltage XLPE cable is normally sufficient degassed by storage of the cable core in the manufacturing plant before it finalized by adding jacket.

The thicker wall thickness of transmission cables and the common use of metallic sheath as moisture barrier/screen in high voltage cable request for a special treatment prior to further processing of the cable core. The degassing treatment is performed at elevated temperature typically in heated chambers at 50-70 °C for 2 to 4 weeks depending on cable size.

- New solutions for HVDC cables

Conclusion

Extruded XLPE cables are a very important part of transmission and distribution network all around the world. XLPE materials were developed about 40 years ago and have proven performance from low voltage cables up to extra high voltage cables rated up to 525 kV.

However, history has showed that there may be unforeseen difficulties and that basic understanding of the technology as well as ambient operation condition is very essential.

The highest standards need to be implemented in material manufacturing, cable manufacturing, and installation and in operation/maintenance to assure reliability as well as cost efficiency. Specifications are in place but these documents can not cover for all occasions, thus it is important to actively monitor performance and take necessary action both in existing operation and for new challenges.