CARMINE communications

Client: Cable Corporation Of India	Issue: April, 12
Magazine: Energetica India	Page No: 46 to 48
Edition/City	Media Evaluation:

The Cable Connection

MR. HITEN KHATAU, CHAIRMAN & MANAGING DIRECTOR, CABLE CORPORATION OF INDIA LTD

Mr.Hiten Khatau shares with Energetica India's readers the type of cables available in India's power sector and their properties.

The increasing urbanization and industrial development has led to ever increasing demand of electric power. This has been met by increasing generating capacity of existing plants and setting up of new plants for power generations. Generally the generating plants are located far away from the users due to various reasons and transmitted to the users for consumption.

Electric power has thus to be transmitted and this generally done by either overhead lines or underground cable systems. Both the systems have their merits and de-merits and the choice is made after a proper techno-economic feasibility study.

The transmission system brings the power not only to the receiving station, sometimes also to the load centre and user.

Generally in India the transmission voltages are 400 kV, 220 kV, 132 kV and 66 kV for AC transmission.

In urban area especially in the metros the trend is towards underground cables for power transmissions due to various reasons like environment, safety, aesthetics, right of way, reliability, etc.

Cables used for system voltage 66 kV and above are designated as EHV cables in India. Earlier these cables were with paper insulation, oil filled or oil pressure type and generally termed as of. However, of late, these have been replaced by solid

Dielectric cables especially by cross-linked polyethylene (XLPE) cables at least in the voltage range of 66 kV to 220 kV and attempts are being made to replace it in 400 kV range.

This paper discusses the philosophy for design, construction and testing such extra-high voltage XLPE cable systems as well as technical progress and trends in the future.

Materials for Solid Dielectric Cable Insulation

The paper insulated power cables over the years have been replaced by PVC in the low voltage range (i.e. 1.1 kV) and by XLPE in the range of 11 kV to 33 kV. The time tested and reliable OF cables with paper insulation are gradually being replaced by solid dielectric insulated cables in the EHV range and this is mainly because of the advantages of solid dielectric cables over paper cables. Table 1 shows a comparison of these two dielectrics.

In the EHV range the preferred solid dielectrics are XLPE and EPDM. Table 2 shows the comparison of typical properties of the dielectrics used in power cables.

From the comparison it is clear that PVC is not suitable as a dielectric above 11 kV and generally limited upto 1.1 kV for industrial application. However, though paper insulation is time tested and well established is not considered as already discussed in Table 1.

Thus for EHV usage only EPDM and XLPE are considered. The use of EPDM is

TABLE 1: COMPARION OF OIL FILLED PAPER AND SOLID DIELECTRIC (XLPE) CABLES

Characteristic Cables	Oil Filled Paper XLPE Cables	Solid Dielectricity
Dielectricity Properties	Highly Complex because of necessity of maintaining oil pressure, Heavy Cables. Jointing and terminating need very high skills.	Easy to handle due to light weight. No problem of oil migration, etc. Jointing and Terminating is relatively easier.
Maintainance during Operation	Consistant vigil required for maintaining oil pressure.	Practically maintainance free
Manufacturing Facilities	Not available in India	Available

TABLE 2: TYPICAL PROPERTIES OF DILECTRICS USED IN POWER CABLES

Properties	PVC	XLPE	EPDM	PAPER
Breakdown Strength kV/mm	30	40-50	30	40
Dielectric Constant	5,8	2,3	3,0	3,5
Tan k	0.08-0.1	0,001	0,003	0,003
Conductor Operation Temp xC	70	90	90	65
Conductor Short circuit temp xC	160	250	250	160-200
Specific Gravity	1.3-1.5	0,91	1,35	0,8
Flame Resistance	Good	Poor	Poor	Poor
Flexibility	Poor	Poor	Good	Poor *
Resistance to Water Permeability	Good	Very Good	Fair	Very Poor

* Due to metal sheating

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very limited due to its exorbitant cost and are used in few countries. Generally nowadays XLPE is used for all HV and EHV usages.

Unlike for XLPE cables upto 33 kV, there exists at present no comprehensive international/National Specification for cables 66kV and above, giving complete details of construction. This is mainly because no standardization of dimensions of cable, especially thickness of insulation and special constructional features such as longitudinal and radial water barrier etc. can be done due to widely varying practices requirements; manufacturing practices and environmental conditions.

Nevertheless there exists some national specifications for constructional details upto 220 kV, however for higher voltages recommendations exist for testing and evaluation. Thus the procedure for fixing the insulation thickness and constructional details assumes paramount importance and are discussed subsequently.

Design of Extruded Insulation

The most critical aspect in the design of an EHV cable is the thickness of insulation for a specified rated voltage. For cables upto and including 33 kV grade, the thickness of insulation is standardized, based on years of experience. These cables normally operate at low electric stress, and their basic impulse levels are also relatively low and operating stress does not exceed 4 kV/mm. However, if the same operating stress is considered for EHV cables, the calculated insulation thicknesses become too large and unwieldy. In view of this, higher operating stresses in the range of 6 to 10 kV/mm are considered for cables upto 220 kV and 14 kV/mm (max) for 400 kV.

This is based on improvement in insulation materials, cleanliness, manufacturing hygiene etc. A comparison of thickness using above electric stresses are indicated in Table 3. However actual thicknesses have to be arrived as discussed subsequently.

The general approach to arrive at thickness of insulation for EHV XLPE cables is to base the same on a) Impulse Breakdown Stress, and b) AC Breakdown Stress. The higher of the values arrived at by the above criteria is adopted for design.

TABLE 3: TYPICAL PROPERTIES OF DIELECTRICS USED IN POWER CABLES

kV Rating of cable	Calculation Insulation Thickness (mm) based on		Smallest conductor (Sq. mm.)	Actual Stress (kV/mm)
	Maximum Stress 4 kV/mm	Maximum Stress 6-10 kV/mm		
38/66	21	11	95	5,8
64/110	49	16	150	7,2
76/132	65	18	185	7,7
127/220	138	27	400	8,7
230/400	566	31	630	13,4
		Maximum Stress 14 kV/mm		

THE MOST CRITICAL ASPECT IN THE DESIGN OF AN EHV CABLE IS THE THICKNESS OF INSULATION FOR A SPECIFIED RATED VOLTAGE

Constructional Details of EHV Cables

When operating at high electrical stresses, the XLPE insulation becomes prone to deterioration and gradual failure due to the phenomenon called "Treeing" if moisture or contamination is present in the insulation. Contaminants lead to Electrical tree growth under electric stress and is prevented by eliminating/reducing contaminants in insulation by improved manufacturing techniques and hygiene. In presence of moisture and high electric stress Water tree growth takes place and can lead to failure of the cable. Since EHV cables operate at high stresses of 6 kV/mm to 14 kV/mm, the XLPE insulation in these cables are to be prevented from water treeing by prevention of moisture entry into the insulation.

For prevention of radial water entry, the popular methods are as follows:

1. Metal laminate tape
2. Corrugated Aluminum Sheath
3. Lead Alloy Sheath

TABLE 4: TABLE OF COMPARISON OF VARIOUS TYPES OF RADIAL WATER BARRIERS

Type	Advantage	Disadvantage
Extruded Lead	Water Proof Good Mechanical Protection Good Chemical Resistance Low Eddy Current Good Oil Resistance	Very Heavy Not Resistant to Viberation & Shock Low Earth Fault Capacity Large Thickness Expensive
Extruded Aluminium Sheath	Water Proof Good Mechanical Protection Good Earth Fault Capacity Very Flexible Light Weight Cheaper than Extruded Lead Design	Corrugation leads to large Cable Higher Eddy Current Loss
Stainless steel sheath	Water Proof Good Mechanical Protection Very Low Eddy Current Loss	Low Earth Fault Capacity Very Expensive
Luminated Tape with Copper with Shield	Water proof Light Weight Thin hence Compact Cable Very Good Earth Fault Capacity Low Eddy Current Loss	Expensive Non Seamless Little Mechanical Protection

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TABLE 5: MAXIMUM PERMISSIBLE OPERATING TEMPERATURE

Cable Component Rating	Continuous (over load) Rating	Short Time Rating	Short Circuit
Copper Condensor	90	105	250
Aluminium Condensor	90	105	250
Sheath / Screen / Armour	-	-	200

4. Welded Stainless Steel sheath

The choice of one or the other depends upon factors such as installation conditions, size and voltage rating of cables, economics, etc. Laminated metal tape and corrugated Aluminum sheath are two popular methods being followed in majority of the countries. The last two call for additional metal reinforcement in the form of wire armour/screen, which is not required for Aluminum Sheath. A comparison of various types of radial water barrier is indicated in Table-4.

For protection against longitudinal water penetration, water blocking tapes are used within the cable. These tapes, when they come into contact with water, swell 6 to 10 times their normal size and completely block water penetration. Resistance to longitudinal water penetration is mainly to prevent moisture ingress in the event of accidental damage to radial water protection, since the possibility of water penetration from the cable end is extremely unlikely because of careful design of end terminations and straight through joints. As such, where the radial water penetration is provided by means of a Corrugated Aluminum sheath, protection against longitudinal water ingress is not required because of the tough nature of the corrugated Aluminum sheath.

Testing of EHV Cables

At present testing of EHV is covered by IEC: 840 for voltages upto 150 kV for type tests and routine tests. For cables above 150 kV for type, routine and special tests, the current IEC: 840 can be Extended and a draft IEC: 840 is available. However, the AC Voltage testing required modification from the present Requirement of 2.5 Uo. The design of the AC test is based on two different considerations, eg. Maximum test voltage and the other minimum test voltage.

The tests after installation for cables upto 150 kV are specified in IEC: 840 and above 150 kV are also indicated in draft IEC: 840.

The details of development tests for EHV cables, which are not officially specified in IEC and is at the discretion of the manufacturer and vary widely. In order to gain some indication of the long term reliability of the proposed cable system, it is preferable to carry out Development Test and Pre-qualification tests. These tests are generally performed before a cable is commercially offered and comprises:

- Material & process evaluation for voids, contaminants, projections, etc.

FURTHER DEVELOPMENTAL WORK IS NECESSARY INDIGENOUSLY FOR EVALUATION AND VALIDATION OF DESIGN, SELECTION OF MATERIAL, MANUFACTURING PROCESS AND TESTING PARAMETERS OF EHV CABLES OF 400 KV BEFORE COMMERCIALIZATION

- Evaluation of Weibull parameters
- Determination of long term life factor
- Tests on model cables
- Tests to indicate long term performance and reliability of the complete cable system

These tests need be carried out once unless there is a substantial change in the cable system with respect to material, processing, design and design levels.

Selection and Installation of EHV Cables

The following are the critical parameters that influence the choice of right design of an EHV cable:

1. Rated Voltage
2. Continuous current rating
3. Short circuit rating of conductor
4. Short circuit rating of metallic sheath/screen/armour
5. Short time (overload) rating
6. Environmental considerations
7. Type of barrier for longitudinal and radial moisture protection
8. Method of bonding of metallic sheath/screen/armour

Once the above parameters are clearly defined the basic constructional features of the cable can be finalized.

The earlier sections have dealt with the design, construction and testing of an EHV cable, however the continuous current rating are calculated using IEC-287. This takes into account all the relevant features including installation and environmental conditions. The standard conditions of installation assumed in India are as below:

1. Maximum continuous operating conductor temp. 90xC.
2. Standard ground temp. : 30xC
3. Ambient air temp. : 40xC
4. Thermal resistivity of soil : 150xC
5. Depth of laying : 150 cm
6. Trefoil formation

Employing a similar principle, the short-time (overload) rating can be determined. The maximum permissible temperature of conductor and other metallic components of the cable for continuous rating, short time rating and short circuit rating are given in Table 5.

The short circuit ratings of a conductor or a metallic sheath /screen/armour are determined on the assumption that all the heat generated in the respective metallic components is totally absorbed by the respective metallic components themselves.

Conclusions

In India, design, construction and manufacture and testing of EHV cables upto 220 kV have been mastered by the local manufacturers.

However further developmental work is necessary indigenously for evaluation and validation of design, selection of material, manufacturing process and testing parameters of EHV cables of 400 kV before commercialization.

References:
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