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Circuit Integrity Assessment of Fire-Resistant Cables

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Abstract

In the electrical industry, fire accidents may happen due to overheating of electrical equipment, short circuit faults and any external source of fire. Polymeric Electrical Cables are prone to spread fire along the cable run as the insulation and sheathing materials are of flammable nature. Hence various flame retardants and low-smoke polymers are being used so that the flame spread and toxic gas release can be controlled. There are some special application cables called Fire Resistant cables which need to maintain the circuit integrity of the cable even during fire conditions. The construction of these fire-resistant cables requires fire-resistant insulation to achieve the fire-resistance property. They are such as Glass-Mica tape, Silicone Rubber, mineral insulation, metal insulation and fire retardant coating. There is various International and National standard assessing methods to assess these special cables. In this paper, the fire-resistant insulating materials and their performance during the assessment in achieving the required fire-resistant property are discussed.

Keywords: Fire Resistant cables, Fire Retardant coating, Glass-mica insulation, Silicone insulation

1. Introduction

Control Cables of up to 1.1 kV rating are used in metro coaches, fire alarm systems, hospitals and Oil and Gas industries for controlling essential circuits which are required to be in operation even during the fire. Hence these control cables should possess fire resistance properties and have to maintain the circuit integrity for a specified duration at rated voltage. In order to achieve this, special insulating materials are used. In the firefighting environment, these fire-resistant cables experience various other stresses such as falling water droplets from the fire protection system spraying water to extinguish fire and mechanical impact due to other disintegrated structural materials falling on the electrical circuit along with voltage stress. Hence the fire-resistant material should be capable of withstanding these additional stresses and maintaining the circuit integrity of the cable. There are standard test methods by which all these stresses are simulated to check the performance of the fire-resistant cables.

2. Circuit Integrity Tests

The fire-resistant cables are normally control cables i.e., the voltage rating of the cable is up to and including 1.1 kV Cables. Circuit Integrity tests such as Resistance to Fire Alone, Resistance to Fire with water, Resistance to Fire with Mechanical Shock and Resistance to Fire, Mechanical shock and water spray is carried out by various standards such as IEC 60331-11 and 21, BS 6387 and BS EN 60505[1-4].

2.1 Fire-Resistant Insulation Materials

Various types of additional fire-resistant insulating materials are incorporated in the construction of power cables in order to achieve the fire resistance property in power cables. The proven insulating material which is being used for years is Glass Mica Tape insulation. There are other insulating materials such as ceramified silicon insulation, mineral insulation and metal insulation which are also used in the construction of fire-resistant cables.

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The conductors are wrapped with these kinds of fire-resistant insulation and are protected from short circuits when exposed to fire.

Mica is a natural insulation material. Mica Glass insulation is formed as mica tape of 2 to 3 layers laminated over a glass fibre layer. Mica powder is coated on the glass fibre layer to improve the fire resistance characteristic to about 900°C and for more than 2 hours.

Silicone rubber insulation is mineral in nature and it is being used as fire-resistant insulation in fire-resistant cables. When silicone insulation is under fire, a film of fused silica is deposited onto the conductor which acts as a fire-resistant insulation. Additives are also added to enhance the strength of this fused silica around the conductor[5].

Nowadays a new fire retardant material of fire retardant paint is being adopted to achieve circuit integrity in power cables.

Fire retardant coatings are used to achieve the fire resistance property in power cables by way of a Passive method of Fire Protection. When these coatings are applied on power cables, the coating prevents the cables from getting burnt due to external fire and thereby prevents the fire spread and emitting low smoke, so that it provides additional escape time.

Basically, Fire retardant coatings are chemicals applied to any combustible materials in order to prevent the growth of the fire. Fire retardant cable coating is a water-based coating that can be easily applied to the existing installed electrical cables.

Fire Resistant paints are of Intumescent Coating, and it has the tendency of expanding under heat which forms a foamed charred layer over the cable. This expanded layer of the char continues to act as fire-resistant insulation and does not allow the flame to penetrate the cable. These fire resistance paints are stable with UV rays radiation also. Hence the power cable sheathing is protected from the damage of UV rays as well and the life of the cable can be extended.

2.2 Resistance to Fire Alone

In this category, the cable shall maintain the circuit integrity throughout the prescribed test duration under the fire application alone with a specified flame temperature. Fire Resistance cables are being assessed as per IEC 60331-11 and 21 and BS 6387 standards for this particular category[1–3]. The required flame temperature and the duration of the test as per these two particular standards are given in Table 1. The burners used for both standards are also different. The propane and air mixture is used to achieve the flame temperature. During the test, a current of 0.25 A for continuity checking is passed through all the conductors of the cable and this current is achieved by connecting a suitable load or lamps to each of the conductors. The test voltage between conductors should be the rated voltage of the cable. A short circuit prior to the test time and rupture of the fuse indicates a failure.

Table 1. Details of fire-alone tests

Sl.No	Standard	Flame temperature	Duration of the test
1	IEC 60331-11-1999 and IEC 60331-21-1999	750°C + 50° C	90 minutes
2	BS 6387-2013 Category C	950 °C ± 40° C	180 minutes

The table shows the cables tested for this category and the methodology or material used to achieve the fire-resistant property.

From Table 2, it is evident that failures are observed with all types of fire-resistant temperature-insulating materials. In all cases, the quality of the fire-resistant material plays an important role in achieving the fire-resistant property. In the case of fire retardant coating, the thickness of the coating plays an important role in achieving the fire-resistant property. When the charred layer of the coating falls down due to gravity, cable failure is observed. Figure 1 shows the resistance to fire alone test carried out on a fire retardant coating coated on a three-and-a-half core 1100 V cable as per IEC 60331-11 and 21. From Figure 1 it is evident that the coating expands and forms a charred layer and protects the cable.

Table 2. Results of fire alone test on various fire-resistant cables

Particulars of Cable	Standard	Fire Resistance Material	Result
10 Pair Control Cable of 500 V rating	IEC 60331-11 and 21	Fire Retardant Cable Coating of 2 mm thickness	failed at 32 minutes
2 Core X 1.5 Sq.mm, Silicon Rubber Insulated, LSZH Sheathed 300/500 V Cable	BS 6387, Protocol C	Silicone Rubber Insulation	Withstood for 3 hrs
2 Core X 1.5 Sq.mm, Silicon Rubber Insulated, Overall Shielded, LSZH Sheathed 300/500 V Cable	BS 6387, Protocol C	Silicone Rubber Insulation	Failed to withstand 3 hours
3.5 C X 35 Sq.mm, 1100 V, Armoured Cable	IEC 60331-11and 21	Fire Retardant Cable Coating of 3.5 mm thickness	Withstood for 3 hrs
3.5 C X 240 Sq.mm, A2XFY, XLPE ATR 1100 V, Armoured Cable	IEC 60331-11and 21	Fire Protection Coating of 3 mm thickness	Withstood for 90 minutes
1X2X1.5 Sq.mm, Cu/XLPE/LSZH/SWA/LSZH/ UV/AR FS Cable	BS 6387, Protocol C	Glass-Mica Tape Insulation	Withstood for 3 hrs
2 C X 1.5 Sq.mm and 2CX2.5 Sq.mm, 300/500 V, FR insulated FR Sheathed, Fire Alarm Shielded Cables with drain wire	IEC 60331-11and 21	Synthetic Fiberglass Mica Tape	Failed to withstand 90 minutes
2 C X 1.5 Sq.mm and 2CX2.5 Sq.mm, 300/500 V, FR insulated FR Sheathed, Fire Alarm Shielded Cables with drain wire	IEC 60331-11and 21 Flame temperature of 950°C	Synthetic Fiberglass Mica Tape	Withstood 90 minutes
5 Triples X 1.5 Sq.mm, MICA Taped, XLPE Insulated, LSHF Bedded, SWA, LSHF Sheathed 500 V Cable	IEC 60331-11and21	Glass-Mica Tape Insulation	Withstood for 90 minutes

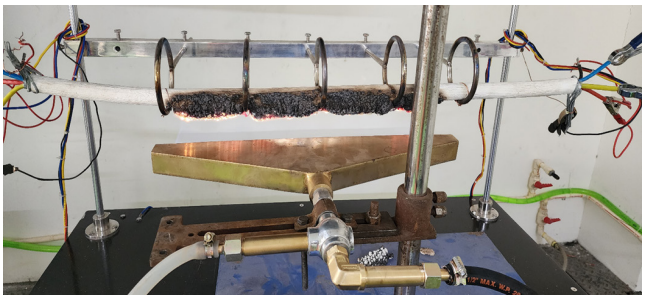

Figure 1. Resistance to fire alone on fire retardant coating/ paint-coated cable.

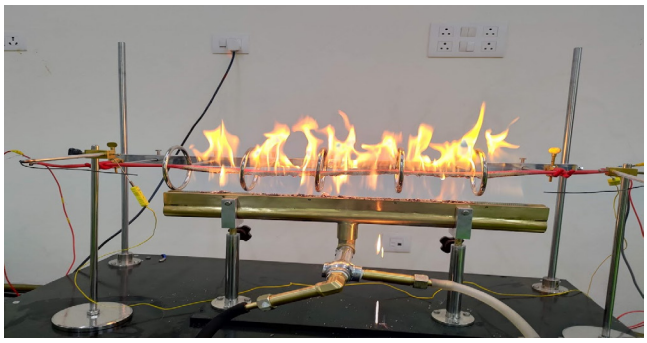

Figure 2. Resistance to fire alone on silicone rubber insulated cable.

Figure 2 shows the resistance to fire alone test carried out on a two-core silicone rubber insulated 300/500 V cable as per category C of BS 6387.

2.3 Fire Resistance Test with Fire and Water

This particular test is carried out as per category W of BS 6387. In this test, the total duration of the test is 30 minutes and for the first 15 minutes of the duration flame at a temperature of 650°C ± 40°C and voltage are the applied stresses. Further for the next 15 minutes duration, the cable is subjected to three stresses such as fire, voltage and water sprinkling. The cable has to maintain the circuit integrity throughout the 30-minute duration.

Table 3. Results of fire with water test on fire-resistant cables

Particulars of Cable	Standard	Fire Resistance Material	Result
1PX1.5 Sq.mm, CU/ XLPE/LSZH/SWA/ LSZH/UV/AR FS Cable	BS 6387, protocol W	Glass-Mica Tape Insulation	Withstood
2 Core X 1.5 Sq.mm, Silicon Rubber Insulated, LSZH Sheathed 300/500 V Cable	BS 6387, protocol W	Silicone Rubber Insulation	Failed to withstand

For this particular protocol, testing has been carried out for two types of fire-resistant insulation. From Table 3, it is observed that the cable Glass-mica tape insulation passes the test, however, the silicone rubber-insulated cable failed to meet the requirement. The silicone rubber insulation forms an ash-like residue which provides the necessary fire resistance but the residue may not provide an adequate water impermeability.

Figures 3 and 4 show the resistance to fire with water test carried out on glass mica tape insulated and silicon rubber insulated cables as per protocol W of BS 6387.

Figure 3. Resistance to fire with water on glass mica tape insulated cable.

Figure 4. Resistance to fire with water on glass mica tape insulated cable.

2.4 Fire Resistance Test with Fire and Mechanical Shock

This particular test is carried out as per protocol Z of BS 6387 for cables of a diameter less than 20 mm. As per this category, the cable is mounted on a heat-resistant board in a Z shape and subjected to flame of 950°C ± 40°C and voltage application. Along with flame and voltage stresses, the board with cable is subjected to a mechanical shock every 30 seconds for a test duration of 15 minutes. As per BS EN 50200 standard the cable, the cable should be less than 20 mm in diameter and bent to form an approximate 'U' shape with the normal bending radius. The maximum duration of the test is 120 minutes and the mechanical shock is applied for every 5 minutes interval. Table 4 shows the results of cables tested for fire with mechanical shock.

Table 4. Results of fire with mechanical shock test on fire-resistant cables

Particulars of Cable	Standard	Fire Resistance Material	Result
1PX1.5 Sq.mm, CU/XLPE/LSZH/ SWA/LSZH/UV/ AR FS Cable	BS 6387, protocol Z	Glass-Mica Tape Insulation	Withstood
2 Core X 1.5 Sq.mm, Silicon Rubber Insulated, LSZH Sheathed 300/500 V Cable	BS 6387, protocol Z	Silicone Rubber Insulation	Withstood
2 Core X 1.5 Sq.mm, Silicon Rubber Insulated, LSZH Sheathed 300/500 V Cable	BS EN 50200 – 2015 PH 120	Silicone Rubber Insulation	Withstood

From Table 4, it is visible that both glass mica and silicone rubber insulations are capable of withstanding mechanical shock while burning. Figures 5 and 6 show the fire resistance test with mechanical shock as per BS 6387 and BS EN 50200 respectively. The brittleness property of the fire-resistant materials and the residue of the insulation materials play an important role in achieving fire resistance along with the mechanical shock.

Figure 5. Resistance to fire with mechanical shock on silicone rubber insulated cable as per BS 6387.

Figure 6. Resistance to fire with mechanical shock on silicone rubber insulated cable as per BS EN 50200.

3. Conclusion

In this paper, the concept of fire-resistant cables and the various fire-resistant insulating materials used in the construction of the cables to achieve circuit integrity of the cable are discussed. The results obtained in different assessment techniques for various cables are also discussed and the following conclusions are drawn:

- Fire-resistant materials are incorporated either in the construction of the cable or externally in order to make the cable fire-resistant.
- The property of resistance to fire with water depends upon the property of water impermeability of the residue formed after the burning of the fire-resistant insulation.
- The property resistance to mechanical shock depends upon the strength of the fire-resistant materials.

4. Acknowledgement

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