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(72) Inventors: JARLE SLETBAK
ARILD BOTNE

(54) ELECTRIC POWER CABLES

(71) We, JARLE SLETBAK, of Rimfakseveien 2, 7000 Trondheim, Norway and ARILD BOTNE, of Sigurd Bergs allé 8, 7000 Trondheim, Norway both Citizens of Norway, do hereby declare the invention for which we pray that a patent may be granted to us, and the method by which it is to be performed, to be particularly described in and by the following statement:-

The present invention relates to electric power cables and in particular to power cables provided with extruded polymeric insulation. It is a well known problem, in particular with power cables for higher voltages, that so-called water trees or electrochemical trees, which are formed in the insulation, may impair the electrical characteristics of the insulation. It is believed that impurities and voids stimulate the growth of trees which may cause breakdown of the insulation. Many remedies have already been suggested to eliminate or reduce the formation of such water trees.

The problem of eliminating or reducing the formation of voids and trees in polymeric cable insulation has mostly been studied in connection with crosslinking processes. Such processes include passing the insulated conductor through a high temperature, high pressure, zone and thereafter through a cooling zone which may also be pressurized. It has been shown that when polymeric insulation is subjected to a wet and hot atmosphere as in a steam crosslinking tube, a large number of voids will occur in the cable insulation.

While the problem of impurities in the insulation may be solved by improving the raw material, the problem of voids arises during the cable manufacturing process. Several methods have been suggested, by which the conventional steam curing method is replaced by inert gas curing, by long die curing means, and even by silicone oil curing. Methods of heating have been varied. Additional methods attack the use of conventional water cooling systems to eliminate water and moisture also at this stage. However, none of the known processes guarantees a void-proof insulation in the final product. This is partly due to the fact that water molecules are present in the raw material, partly due to the fact that a small amount of water molecules is usually produced during the crosslinking process by chemical reaction within the polymeric insulation, and partly due to the fact that water molecules will most probably enter the insulation if the cable is not installed in completely dry surroundings.

An attempt to solve the problem of preventing or at least limiting the entrance of water into an installed cable has been made by introducing water tight or impervious metal sheaths around the insulated cable core. Such sheaths can be of the extruded lead or aluminium type, or there may be used steel or other metal tapes and bands which are folded and welded around the cable core.

During and after installation of metal sheathed cables there is always a risk that the sheath may be damaged mechanically so that water or moisture may penetrate the sheath. Several remedies have been suggested to prevent water from flowing longitudinally within the cable so causing the cable core to be subjected to water or moisture not only at the damaged spot, but also for a considerable length on each side of this spot. For this purpose so-called water blocks have been placed at regular intervals along the cable, and proposals have also been seen for completely filling all the intersticies of the cable with a water-repellant compound. In order to make such filling compounds as efficient as possible, the metal sheaths may be corrugated or provided with certain patterns or indentions. Finally, pipe or conduit type cable installation methods should be mentioned.

It would appear that it was not until 1974 that the detrimental effect of moisture on extruded insulation was discovered and the designation "water trees" was created at that time. A different type of "tree formation" was, however, detected previously, in connection with the installation of power cables with copper conductors in environments rich in hydrogen sulfide (H_2S). It was already known in 1969 that in a strong electrical field there could be formed "trees" and these were called "sulfide trees" to distinguish them from the well known electrical trees.

It has already been described how hydrogen sulfide (H_2S) which is formed at the sea bed, penetrates the polymeric cable insulation to the copper conductor, where there are formed copper sulfides. These sulfides result in the formation of sulfide trees in the insulation, whereby the insulation is caused to deteriorate.

While formation of "sulfide trees" is dependent on the cable having a copper conductor and the environment being rich in sulphur, "water trees" are formed independently of the conductor material and the sulphuric contents of the environment. It appears, however, that the growth of water trees is stimulated by salt solutions. Both types of tree formation (sulfide trees and water trees) may of course be dealt with by using a water-tight metal sheath.

It has further been suggested to deal with the problem of sulfide trees by arranging a layer of water-non-soluble salts directly on the copper conductor or outside the insulation. The purpose of these layers of salt is to provide a sulfide barrier so that possible water-soluble sulfides from the surroundings interact with the salt layer and form a layer of water-non-soluble sulfides. Such a sulfide barrier will, however, neither prevent nor reduce the permeation of water into the insulation, so that water trees may still be formed.

One reason given for the formation of water trees is as follows: In insulations formed of plastics material there are small voids which take up water from the surroundings, and when the chemical potential of the water is reduced by an electrical field, the small water filled voids will increase so as to form water trees. In order to reduce the electrical field and thereby the tree formation there has been mixed into the insulation material an electrolyte. It is important that the electrolyte be distributed as evenly as possible in the insulation material, and there has been mentioned a ratio of mixture of 10^{-7} – 1weight % of the insulation material. This solution must be considered to be rather risky, as the addition of electrolytic material to the insulation will most probably stimulate the growth of water trees.

As previously mentioned, there have been suggested several alternative crosslinking methods for reducing the formation of voids in the insulation material. Conventional steam crosslinking followed by water cooling does, however, represent an economical and simple process, and the crosslinking process may be speeded up, in order to reduce the time during which the insulation material is subjected to moisture, by using ultrasonic wave during the process itself, so that the insulation material is protected by an undefined moisture-absorbing layer during the crosslinking and cooling process.

It has been stated that the moisture absorbing agent calcium oxide (CaO) is very efficient. Other possible moisture-absorbing agents are MgO, $CaSo_4$ (.$2H_2O$) and SiO_2-gel. All these agents have a very low solubility in water, and the relative humidity above a saturated solution is near 100%. That means that when a layer containing CaO or one of these agents is saturated, the layer and its surroundings will have a relative humidity of 100%. The main purpose of using these agents is to prevent the entry of steam into the insulation during the steam crosslinking process, so that there are not formed micro-voids in the insulation. This is based on the theory that if the formation of micro-voids is prevented in the insulation during the crosslinking process, there will not be formed water trees in the finished cable even if it is installed in moist or wet surroundings. It is therefore prescribed that the CaO layer is arranged prior to the steam crosslinking process, and the layer does not have any effect when said process has been completed because the active agent will be saturated with steam and will no longer have any moisture-absorbing capability. The thickness of the moisture-absorbing layer should be adjusted to the time during which the cable is in the crosslinking stage, i.e. the longer the time the cable insulation is in the steam crosslinking tube the thicker must the layer be. This is in order to ensure that the layer is efficient as long as the steam crosslinking process lasts. Experiments have been made with a cable provided with a combined semiconductor/CaO layer outside the cable insulation (and between the conductor and the cable insulation), where the insulation did not show water trees after the 30 days the cable sample was immersed in water. The testing time must, however, be considered to be much too short to provide convincing evidence that the method will give an efficient long time protection of the cable if it is installed in moist surroundings. Furthermore, CaO must be considered to be unsuitable in giving long time protection due to its high relative humidity. It has even been suggested that the outer moisture-absorbing layer may be removed after crosslinking of the insulation, and that if the layer is maintained, it should be covered by a sheath, presumably a moisture-proof sheath. In contrast to what has just been described, the present invention aims at the provision of a cable which is independent of moisture-proof sheaths, but which still protects the insulation against the formation of water trees during the whole life of the cable, i.e. at least 30 years.

According to the invention in its broadest aspect there is provided an electric power cable comprising a conductor covered by one or more layers of extruded polymeric insulation material as well as an inner and an outer semiconductive layer, in which outside the outer semiconductor layer there is arranged an active layer containing water soluble material which limits and stabilizes the relative humidity of the conductor insulation to a value not exceeding 70%.

Experiments have shown that if the relative humidity in the insulation is lower than a certain limit, water trees will not start growing even if there are voids and contaminants in the insulation. This limit seems to be about 70%, which corresponds to the humidity in air above water which is saturated with NaCl.

One of the advantages of power cables provided with a layer according to the present invention is that the formation of water trees in the insulation is greatly reduced, even if the insulation contains voids and impurities. The invention does not make the methods used to reduce voids and impurities unnecesaary, but adds substantially to the task of providing better and safer power cables.

Furthermore, by implementing the present invention it will not be necessary to provide the cables with expensive water-tight metal sheaths.

To provide the desired effect the humidity reducing material should constitute an even distribution covering the whole surface of the cable.

There are known several materials which have the capability of reducing relative humidity. The following can be mentioned:-

1. Non-volatile materials which, when dissolved in water, reduce the vapour pressure above the solution relatively to what it would have been for pure water at the same temperature. Salts soluble in water are an example of suitable materials.
2. Salts forming stable hydrates, as e.g. $CaCl_2 + 2H_2O = CaCl_2 \cdot 2H_2OMgCl_2$ and $Mg(ClO_4)_2$.
3. Acid and base anhydrides, as e.g. $P_2O_5 + 3H_2O = 2H_3PO_4$ $H_2S_2O_7 (= H_2SO_4 + SO_3) + H_2O = 2H_2SO_4$.
4. Materials capable of physical adsorption as e.g. Silicagel and so-called "molecular sieves" which adsorb water on the surface.

The last mentioned group of materials, namely Silicagel and "molecular sieves", which have a very large surface or porosity, do have the drawback that once the surface is saturated with water they no longer have a humidity-reducing effect. These materials are therefore not suitable when long-time efficiency is desired.

When long-time efficiency is concerned, experiments have shown that the first two groups of materials are most suitable. Experiments have also shown that these materials have a high resistance against being washed out.

Examples of salts which will have the desired effect are mentioned in an article by R.G. Wylie "The properties of water-salt systems in relation to humidty", published in 1965 in a book by A. Wexler: "Humidity & Moisture", Volume III, Chapman and Hall. Of the salts mentioned only those having a relative humidty lower than 70% will be suitable, but the list of such water soluble salts cannot be considered to be complete.

The water soluble materials which are useful according to the present invention are as mentioned placed in a layer outside the outer semiconductive layer of the cable, and do not provide a water tight barrier. The purpose of these materials is to reduce the relative humidity in the insulation to a predetermined percentage. The relative humidity of the insulation will in the presence of water be reduced to a value which is characteristic for the material used, i.e. the relative humidity will be the same as in the atmosphere above a saturated solution in water of the material used.

An embodiment of the invention will now be described with reference to the accompanying drawings in which:-

Fig. 1 shows a cross section of a cable according to the invention, and

Fig. 2 schematically shows a plant for manufacturing a cable in accordance with Fig. 1.

The core 1 of the electric power cable for which the present invention is useful, can be of any conventional type, i.e. a metallic conductor of any configuration and material covered with a layer of semiconducting material 2, followed by one or more layers of extruded polymeric insulation 3 of the desired thickness and an outer layer of semiconducting material 4.

A layer 5, containing a material which is capable of reducing and stabilizing the relative humidity of the surroundings to a value determined by that material, will in the following be called the active layer. The active layer 5 may be extruded as a fourth layer of polymeric material. Further there may be provided more than one active layer extruded or placed on top of each other. Alternatively the active layer may be provided in the form of a tape which is wound or folded around the cable. Again, there could be two or more tape foldings or windings or a combination of extruded layers and wound or folded layers. Outside the active layer there is arranged a covering layer 6 preferably of polymeric material.

The thickness of the active layer relative to the cable diameter can be the same as that of semi-conducting layers. What is important for the life of the humidity-stabilizing layer is that the cable should have a sufficient amount of active material per surface unit. The amount of the active material must therefore be dimensioned to obtain a desired length of life under specific conditions (temperature, moisture of surroundings, water permeability for the covering layer material). A content of 0,01 - 0,1 g/cm^2 is as an example considered to provide good results for the lifetime of the cable. It should be mentioned that even if the active material is saturated by being subjected to moisture, the humidity stabilizing and reducing action will be present as long as there is active material left. The relative humidity of the insulation material will only gradually increase to values where water trees grow as the active material is gradually diluted.

Fig. 2 schematically illustrates an advantageous method for manufacturing a power cable according to the present invention. The cable core 1 is supplied from a pay-off reel 10 to one or more extruders 11, 12, 13 for applying the inner semiconductor 2, insulation 3 and outer semiconductor 4, whereupon the crosslinkable layer (s) is (are) crosslinked and cooled in a crosslinking plant 14.When the cable has been provided with a humidity stabilizing layer 5 it is provided with a cover layer 6 in an extruder 15, whereupon the cable is wound on a take up reel 16. If steam is used during the crosslinking process, the humidity stabilizing layer 5 is applied in e.g. an extruder 17 just after the cable with insulation 3 and semiconducting layers 2, 4 has passed the crosslinking plant. It is thereby assured that the layer is fully efficient as soon as the cable is finished. If the cross-linking process does not make use of steam and perhaps not even water cooling, it will be possible to apply the humidity stabilizing layer 5 in tandem with the application of the outer semiconductor prior to the crosslinking process, as indicated by the extruder 18.

The active material may be added to an extruder in the form of a finely divided power or granulate. A layer of such active powder may also be provided by passing the cable through a container or box containing such powder prior to the extrusion of the outer cover or the application of a covering tape. Alternatively the active material may be dissolved in a solution through which the extruder granulate is passed prior to extrusion. Such an active solution may also be adsorbed in an insulation layer extruded over the outer semiconducting layer by passing the cable through such solution. The active layer may, however, also be made semiconducting. An active windable tape may also be made this way. The material may also be sintered on, with a wound tape or extruded layer over, in order to prevent rapid washing out. Experiments have shown that the washing-out time of the active material under such conditions is substantially longer than the expected life time of the cable.

As a practical test of the principle of using water soluble materials according to the present invention as humidity stabilizing layer there have been performed long time tests on cables. The test cables were rated 12 kV nominal voltage with 35 mm^2 Al conductor, extruded inner semiconductor, 3,4 mm insulation of steam crosslinked polyethylene and extruded outer semiconductor (triple extruded). Over the outer semi-conductor there was wound one layer of creped carbon black paper with 75% overlap. The active layer on cable No. 1 was provided by passing the finished wound cable through a container having a saturated water solution of $CaCl_2$, which had been dried, whereupon a 0,5 mm thick shrinkable hose was pulled over the cable and shrunk to provide a test cable. For cable No. 2 the space between the dry carbon black paper tape winding and the shrinkable hose was filled with a saturated water solution of $CaCl_2$ before the hose was shrunk. Cable No. 3 was a reference cable similar to cable No. 2 and prepared correspondingly, except that pure water was used instead of the $CaCl_2$ solution. All three cables were immersed in water and tested at room temperature. At intervals shown in Table 1, 5 mm long samples taken from the insulation were studied under a microscope to count water trees and measure their lengths. The mean size x is given in μm, s being the distribution.

Cable tests in water at room temperature (20°C)
Voltage 20 kV. Frequency: 50 Hz.

			Trees in insulation			*Tree formation from semiconductors*					
			"bow ties"			inner			outer		
No.	Active Layer	Test interval (h)	No. per mm	*length* μm x	s	No. per mm	*Length μm* x	s	No. per mm	*Length μm* x	s
1	Dry $CaCl_2$	5312	0			0			0		
2	Saturated $CaCl_2$	8602	0			0			0		
3	None	1921	21,6	20	13	0,8	50	14	0		
		9495	15	50		0,5	160		0,5	260	

Table 1.

The results of Table 1 show that the active layer is fully efficient against water tree formation. Taking into consideration that in Cable No. 2, $CaCl_2$ is only present in saturated water solution, this represents a considerable ageing condition, so it is seen that even such a simple embodiment will have a considerable life time.

WHAT WE CLAIM IS:-

1. An electric power cable comprising a conductor covered by one or more layers of extruded polymeric insulation material as well as an inner and an outer semiconductive layer, in which outside the outer semiconductor layer there is arranged an active layer containing a water-soluble material which limits and stabilizes the relative humidity of the conductor insulation, to a value not exceeding 70%.

2. Power cable according to claim 1, in which the material is a salt soluble in water.

3. Power cable according to claim 1, in which the material is taken from the group of salts forming stable hydrates.

4. Power cable according to claim 3, in which the material is $CaCl_2$.

5. Power cable according to claim 3, in which the material is $MgCl_2$.

6. Power cable according to any one of the preceding claims, in which the active layer is semiconducting.

7. Power cable according to any one of the preceding claims, in which over the active layer there is provided an insulating layer of polymeric material.

8. Power cable according to any one of the preceding claims, in which the active layer is provided in the form of a helically wound tape.

9. Power cable according to any one of the preceding claims, in which the amount of active material is at least 0,01 g/cm^2 of the active layer surface.

10. Method for manufacturing an electric power cable according to claim 1, where an electrical conductor is passed through one or more extruders for the application of an inner semiconducting layer, one or more polymeric insulation layers and an outer semiconducting layer, at least one of the layers consisting of crosslinkable polymeric material, whereupon the cable is treated during a crosslinking process so that one or more of said layers are cross-linked, and in which the cable is provided, outside the outer semiconducting layer, by winding or by extrusion, with a humidity stabilizing active layer containing a water soluble material which limits and stabilizes the relative humidity of the conductor insulation to a value not exceeding 70%.

11. Method according to claim 10, in which the humidity-stabilizing active layer is applied after crosslinking of said layers and prior to the crosslinking process, if this process does not make use of steam.

12. Method according to claim 10, in which the active layer comprises finely divided crystals added to granulated polymeric material before extrusion of the layer.

13. Method according to claim 10, in which the active layer comprises a saturated solution adsorbed by granulated polymeric material before extrusion of the layer.

14. Power cable according to claim 1, in which the material used is capable of reducing the relative humidity of the conductor insulation to 50%.

15. An electric power cable substantially as described with reference to the accompanying drawings.

16. A method of making an electric power cable substantially as described with reference to the accompanying drawings.

P.G. RUFFHEAD
Chartered Patent Agent
For the Applicants

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1584501 COMPLETE SPECIFICATION

1 SHEET *This drawing is a reproduction of the Original on a reduced scale*

Fig.1.

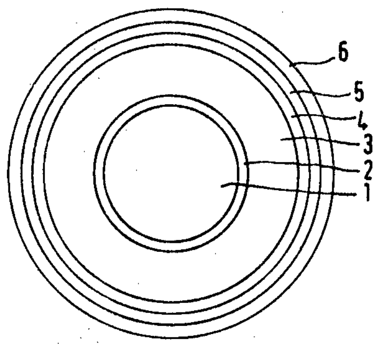

Fig. 2.