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OIL-FILLED CABLE

The present invention relates to oil-filled cables, both single and multi-core cables, and more particularly to the insulation of the conductors thereof.

With paper insulated oil-filled cables operating
5 at high voltages, for example at 500 kV and above, forced cooling of the cable is necessary to reduce dielectric losses. This requires the provision of pumping stations for carrying out the forced cooling which may not be convenient, or even possible, for example in the case of
10 long lengths of submarine cables where the only suitable locations for such pumping stations is on land at each end of the cable.

In order to avoid the need for forced cooling, it has been proposed to form the insulation with tapes of
15 synthetic materials such as plastics film which have a dielectric loss factor which is less than that of cellulose paper tapes presently used. But, owing to the difference in the mechanical characteristics between the cellulose paper tapes and the plastics film tapes it has
20 been impossible to make an oil-filled cable with insulation formed only by windings of plastics film tape. In fact, besides the difficulties met in lapping the plastics film tape, the resulting cables have an insulation devoid of the required transversal softness essential for mechanical flexibility which is found in the known cables
25 where the insulation is formed only by windings of cellulose paper tapes. The insulation of cables formed only by windings of plastics film tape is, in fact, very compact and so inflexible as to give the cable an inadmissible bending stiffness. Moreover great difficulties
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have been found in impregnating such a cable with insulating fluid oil owing to the permeability of the plastic film tape forming the insulation. Also, it is observed that the plastics film tape swells to a greater or lesser extent depending on the type of the plastics material used with the usual insulating oils for cables and that the swelling of the tape produces a further increase in the bending stiffness of the insulation and consequently of the cable.

Even if this swelling of the plastics film tape is very small so as to be considered negligible, the compactness of the insulation formed with just plastics film tapes caused the cable to have too great a bending stiffness for practical use.

To avoid this bending stiffness problem it has been proposed to use transversally corrugated plastics film tapes or tapes made with mixtures of cellulose fibres and plastics fibres, but these proposals have not met with success due to the negative mechanical characteristics of these forms of tapes and in the case of tapes of corrugated plastics film also due to the presence of the large number of cavities filled with oil which form in the cable in correspondence of the corrugations of the tapes.

It has also been proposed to use tapes formed by a laminate of cellulose paper and plastics film closely joined. But this proposal also has drawbacks, as the laminate which is usually constituted by a film of plastics material sandwiched between two layers of cellulose paper, wrinkles at the planes of union of the paper and plastics film every time that, for any whatsoever cause, one of the components expands or contracts, for instance in consequence of moisture or absorption of oil, due to the different nature of the paper and plastics film.

The presence of such wrinkles in the tapes of

plastic-cellulose paper laminate forming the insulation of a cable produces a reduction in its dielectric strength and this renders the use of such laminate tapes suspect in cables to be used for high voltages. In this connection it will be understood that it is very difficult to avoid the presence of wrinkles in such laminate tape in the manufacturing of oil-filled cables which involves drying and subsequent impregnation with an insulating fluid oil, of the insulation. It will be appreciated that during the drying process, there are greater variations in the dimensions of cellulose paper than in the plastic component of the tape laminate. On the other hand during the impregnation process swelling takes place, i.e. an increase of the dimensions of the plastic component. These two phenomena are the cause of undulations in the laminate tapes of the insulation. Moreover it is difficult to operate in such a way that the reduction in the dimensions, which takes place in the cellulose paper component of the laminate during the drying process, is perfectly counterbalanced by an equal increase of the dimensions which takes place in the plastic component of the laminate in consequence of the swelling that this latter suffers during the impregnation with the insulating fluid oil.

Unsatisfactory attempts have been made to form the insulation of a cable with plastic-cellulose paper laminates where the paper component is damp so that the reduction in the dimensions suffered by it during the drying process is equalized by the increase of dimensions of the plastic component during the swelling that takes place through the subsequent impregnation with the insulating fluid oil.

Also the unavoidable imperfections of the plastic component of the laminate, for example the presence of microscopic bubbles or foreign particles and the like

therein, that give rise to a non-uniform dielectric strength, suggest not to use laminates at those portions of the cable insulation where the electric field is more intense, i.e. near the semiconductive screen covering
5 the cable conductor.

The present invention aims to enable plastics material to be used in the insulation of an oil-filled cable so as to lower the dielectric losses and the dielectric constant whilst avoiding or at least reducing
10 the above indicated drawbacks associated therewith.

The invention — includes an oil-filled cable having at least one conductor which is provided with insulation formed with alternate independent layers formed respectively from cellulose paper tape and plastics film
15 tape, each layer comprising a winding of at least one tape, wherein the plastics film tape has been applied in a condition in which it has been swollen with insulating oil of the same specification as that used for impregnating the cable.

20 The invention also includes a method of manufacturing a cable as defined in the last preceding paragraph, wherein the material of the plastics film tape is swollen before being applied to the cable in the formation of the insulation thereof by the steps of:

25 immersing a plastics film in an insulating oil of the same specification as that to be used for impregnating the cable for a time sufficient to cause swelling of the plastics film of a predetermined amount, or at least said predetermined amount; and

30 removing excess insulating oil from the surfaces of the plastics film.

The step of removing excess insulating oil from the surfaces of the plastics film may comprise washing that film with a detergent to remove the oil and thereafter removing any detergent remaining on the film
5 surfaces with air jets.

The film may have the width corresponding to that of a single plastics film tape or it may have a width corresponding to a multiple of that of a single plastics film tape, in which latter case the film is cut into
10 respective single tapes after said step of removing excess insulating oil from the surfaces of said film.

Preferably the innermost layer or layers of said insulation is or are formed from cellulose paper tape.

Also, advantageously, the thickness of the plastics
15 film tape is greater than the thickness of the cellulose paper tape in adjacent layers.

In order that the invention may be well understood, an embodiment thereof, which is given by way of example only, will now be described, reference being had to the
20 accompanying drawings, in which:

Figure 1 is a perspective view of an oil-filled cable length with parts partially broken away to show its structure;

Figure 2 is a lateral view partially in section of
25 the cable of Figure 1;

Figure 3 shows to a larger scale than Figure 2 a detail of the insulation of the cable; and

Figure 4 is a schematic view of apparatus for carrying out swelling of a plastic material film prior to
30 application to the cable.

Whilst Figures 1 and 2 show a single-core oil-filled cable it will be appreciated that the present invention is applicable to all oil-filled cables, for example multi-core cables and so called "pipe" cables.

5 As shown in Figures 1 and 2 the illustrated cable comprises a metallic conductor 1, for instance of copper, formed by a plurality of wires 2 stranded together so as to define a tubular cavity 3 constituting a cable oil duct. Around the conductor 1 there is a first semi-conductive screen 4 obtained by winding semi-conductive
10 paper tapes, typically carbon paper tapes, around the conductor. Over the semi-conductive screen 4 there is a solid stratified insulation 5, which will be described in detail hereinafter, and above this insulation 5 there
15 is a second semi-conductive screen 6 formed as the first semi-conductive screen, by windings of semi-conductive paper tapes.

 All the previously described elements are enclosed within a metal sheath 7, for instance of lead or aluminium,
20 and are impregnated with an insulating fluid oil which also fills the tubular cavity 3 constituting the cable oil duct.

 In its more general aspects the insulation 5 has the following structure. It is entirely constituted by
25 a plurality of independent alternate overlapped layers formed by windings of cellulose paper tapes and by windings of plastics material film tapes. More specifically, as shown in Figure 3, each layer 8 formed by a winding of
30 at least one tape 9 of plastics material film is surrounded and therefore separated from the contiguous layers 8 by layers 10, formed by a winding of at least one tape 11 of cellulose paper.

 The windings of tapes 9 forming the layers 8 and the windings of the tapes 11 forming the layers 10 are
35 made according to the usual constructive technique of

the cable so as to leave a space, or so-called "gap", between adjacent turns. In this way in the layers 8 there are the gaps 12 and in the layers 10 there are the gaps 13. All these gaps are filled with the insulating fluid oil in the finished cable.

In general the thickness S_1 of the tapes 9 of plastics material film and the thickness S_2 of the tapes 11 of cellulose paper can be any value. However, in the case in which possible collapse of the tapes 9 of plastics material have to be avoided in the gaps 13 of the adjacent layers 10 formed by windings of cellulose paper tapes, it is preferred that the thickness of the tapes 9 is greater than the thickness of the tapes 11.

For instance, using as plastics material for tapes 9, high crystallinity polythene tapes, their thickness S_1 is 0.15 mm, while the cellulose paper tapes have a thickness S_2 of 0.11 mm.

Any plastics material having a dielectric loss factor lower than 1/5 with respect to that of the cellulose paper tapes and a dielectric constant lower than at least 30% with respect to that of the impregnated cellulose tapes, can be used for the tapes 9 in the embodiment.

Plastics materials having these characteristics are for example polyolefines such as polyethylene and the polypropylene, and fluorinated plastics material such as polytetrafluoroethylene.

For the cellulose paper tapes 11, it is preferred to use those having an apparent density (i.e. the density referred to the volume occupied by the paper whose structure comprises cellulose fibres and interposed empty spaces) of between 0.7 gr/cm^3 and 1 gr/cm^3 and having a permeability of between 2×10^6 and 2×10^8 Emanuelli unit.

In the particular embodiment shown in Figures 1 and 2, the innermost layer of the solid stratified insulation 5 of the cable, that is the layer adjacent the

first screen 4, is formed of cellulose paper tape, and as illustrated comprises a plurality of windings of paper tape. The remainder of the insulation 5 comprises alternate independent layers formed from plastics film tape and cellulose paper tape. As illustrated these latter layers comprise windings of one tape. They may however comprise windings of more than one tape. Figure 2 shows three overlapped windings of cellulose paper tapes in the layer adjacent the first semi-conductive screen 4, but the number of windings in this layer may comprise, for example from 1 to 4.

For the formation of the layer of windings of cellulose paper tapes adjacent the first semiconductive screen it is preferable that their apparent density is 0.85 gr/cm³ and their permeability is of 10⁷ Emanuelli unit.

As previously said, the main characteristic of the illustrated oil-filled cable is that its solid stratified insulation is formed with alternate independent layers formed respectively of plastics film tape and cellulose paper tape, and that the plastics film tape is applied in a condition in which it has been swollen with insulating oil of the same specification as that used for impregnating the cable.

Another characteristic of the illustrated embodiment is that the cellulose paper tapes have, when applied to the cable, a moisture content whose value is a function of the amount of swelling which will occur in the plastics film tapes on impregnation of the cable with insulating oil.

Owing to the great variability of the types of cellulose paper tapes which can be used and the great variability of the types of plastics film tapes and of

the impregnating oils that can be used, it is impossible to give a mathematic expression for the above indicated function.

5 The relationship between the moisture content of the cellulose paper tapes and the swelling degree of the plastic material film tapes can be experimentally defined as follows.

10 The moisture content of the cellulose paper tapes should be of such a value so that the reduction in their thickness during the drying process is of a value equal to the increase in thickness which there will be in the plastics film tapes due to the swelling, or further swelling, thereof which occurs on impregnation of the cable.

15 For example, the cellulose paper tapes forming the layers 10 may be applied in an almost dry condition having a moisture content not higher than 2% by weight, while the plastics film tapes forming the layers 8 are prior to application swollen a maximum amount with insulating oil.

The pre-swelling of the plastics material film tapes for the formation of the layers 8 of the insulation 5 in the illustrated embodiment is carried out using the following steps.

- 5 A plastics material film tape is completely immersed in insulating fluid oil, which is preferably heated, for example to a temperature of 80°C, and left in contact with the insulating fluid oil for a pre-established time related to the amount of swelling
10 that it has been determined is required. Then, after having removed the tape from the oil bath, all the insulating oil existing on the surface of the tape itself is removed.

- 15 The step of removing the insulating oil from the surface of the plastics film tape can be carried out mechanically, for instance by means of brushes, or chemically, through use of a detergent.

- 20 In this latter case the method also comprises the steps of removing excess insulating oil (that is oil which has not been taken up by the plastics material) from the surfaces of the tape through a washing process with a detergent; and thereafter removing any detergent remaining on the surfaces of the tape with air jets.

- 25 For carrying into effect the above-mentioned method it is possible to use the apparatus in Figure 4.

As shown in Figure 4, a coil 14 contains a tape 9 of plastics material, for example polypropylene, to be used after swelling in the formation of the layers 8 of the insulation 5 of the cable illustrated in Figures 1 and 2.

5 Downstream of the coil 14, there is a tank 15 filled with a hot insulating fluid oil, for instance a fluid alkylate at a temperature of 80°C. Within the tank 15 there are two rollers 16 freely rotatable about their axes and mounted at a set distance from the bottom of the
10 tank itself. About the tank 15 there is a heating jacket 17 provided with inlet and outlet conduits 18 for a heating fluid. Downstream of the tank 15 there is a tank 19 filled with a detergent liquid, for instance
15 two rollers 20 freely rotatable about their axes and mounted at a set distance from the bottom of the tank itself.

Between the tank 15 and the tank 19 there is a return roller 21 freely rotatable about its axis to permit the removal of the tape 9 from the tank 15 and the
20 forwarding of the same into the tank 19.

Downstream of the tank 19 there is a collecting coil 22 and between the tank 19 and coil 22 there are nozzles 23 connected to reservoirs of compressed air for
25 providing air jets for removing any trace of detergent from the tape 9 coming out of the tank 19.

Motorization means, not shown in Figure 4, are moreover incorporated in the apparatus in order to advance the plastics film tape 9 at a speed of such a value
30 as to leave the polypropylene film in contact with the fluid alkylate for some hours, which is the time sufficient for obtaining maximum pre-swelling of the tape.

When the tape 9 leaves the coil 14 it penetrates into the tank 15 filled with a hot insulating oil, passing
35 below the rollers 16 so as to be entirely immersed in the insulating fluid oil. The tape 9 coming out of

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the tank 15 passes over the roller 21 which conveys it into the tank 19 filled with a fluid detergent. In the tank 19, the tape 9 passes below the rollers 20 which maintain it immersed in the detergent fluid. On coming
5 out of the tank 19 the tape 9, before being collected on the coil 22 passes between the compressed air jets from nozzles 23 which remove any trace of detergent from the tape itself. On the coil 22 the tape treated as indicated by way of example above, is in a maximum pre-
10 swelling condition.

Instead of treating individual single tapes 9, having a width equal to that determined for the formation of the layers 8 of the insulation, the treatment could be applied to film material of transversal dimensions equal to a multiple of the width of a single tape
15 9, a cutter being provided to obtain from the coil 22 of treated film rolls of tape 9 of the required width.

The use of independent and alternate layers of windings of cellulose paper tapes and plastics film tapes for the formation of a cable solid stratified insulation avoids the formation of wrinkles in the tapes, which is
20 always a risk when the insulation is formed with windings of tapes of cellulose paper-plastics film laminates closely joined to one another.

Moreover, the use of distinct layers formed by windings of plastics film tapes separated by independent layers of windings of cellulose paper tapes permits, with respect to the use of tapes of cellulose paper-plastic film laminates, a reduction of the dimensions
25 of the gaps filled with oil in the insulation, both because the distinct tapes have a thickness smaller than those of a laminate formed with them, and because the use of distinct tapes permits to these latter to have a thickness smaller than the ones required for the formation
30 of laminates. In fact, while in a typical laminate in which the plastics film is disposed between, and connected to, two paper layers, the minimum thickness that can be
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achieved is about 0.12 mm and therefore the gaps have this value as minimal radial dimension, by using separate tapes it is possible to obtain minimum radial gap dimensions down to 0.06 - 0.08 mm for a winding of plastics film between two adjacent independent layers, each of which is formed by a winding of a cellulose paper. This fact, producing a reduction of the thickness of the gaps among the tapes of a solid stratified insulation filled with oil produces an increase of the dielectric strength, and a lowering of the dielectric losses of the cable and a lowering of the electrophoresis losses in the insulating oil filling said gaps.

An oil-filled cable with very good mechanical flexibility is obtained using alternate independent layers of paper tape and plastics film tape due to the flexibility of the cable insulation formed thereby. The flexibility is better than that of the known cables in which the insulation is formed by windings of tapes of cellulose paper-plastic film laminate and is comparable with that of oil-filled cables in which the solid stratified insulation is formed only by windings of cellulose paper tapes. This is because the friction coefficient between the layers of cellulose paper and the plastics material is lower than the friction coefficient between the above-mentioned laminate tapes or between the paper tapes.

By applying the plastics film tape in a pre-swollen condition uncontrolled or excessive swelling of the plastics tapes in the insulation during cable impregnation, and the consequent reduction in cable flexibility, is avoided.

Finally, the formation with cellulose paper tapes of the layer of the insulation nearer the first semi-conductive screen covering the cable conductor where the electric field has a greater intensity, reduces the risk of insulation breakdown resulting from the unavoidable imperfections of the plastics material film tapes, and a better dielectric strength is thus obtained for an oil-filled cable.

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CLAIMS:

1. An oil-filled cable having at least one conductor which is provided with insulation formed with alternate independent layers formed respectively from cellulose paper tape and plastics film tape, each layer comprising
5 a winding of at least one tape, wherein the plastics film tape has been applied in a condition in which it has been swollen with insulating oil of the same specification as that used for impregnating the cable.
- 10 2. A cable as claimed in claim 1, wherein the innermost layer or layers of said insulation is or are formed from cellulose paper tape.
3. A cable as claimed in claim 1 or 2, wherein the
15 thickness of the plastics film tape is greater than the thickness of the cellulose paper tape in adjacent layers.
4. A method of manufacturing a cable as claimed in claim 1, wherein the material of the plastics film tape
20 is swollen before being applied to the cable in the formation of the insulation thereof by the steps of:
immersing a plastics film in an insulating oil of the same specification as that to be used for impregnating the cable for a time sufficient to cause swelling of the
25 plastics film of a predetermined amount, or at least said predetermined amount; and
removing excess insulating oil from the surfaces of the plastics film.
- 30 5. A method as claimed in claim 4, wherein said step of removing excess insulating oil from the surfaces of the plastics film comprises washing that film with a detergent to remove the oil and thereafter removing any detergent remaining on the film surfaces with air jets.
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6. A method as claimed in claim 4 or 5, wherein the said film has a width corresponding to that of a single plastics film tape.

5 7. A method as claimed in claim 4 or 5, wherein the said film has a width corresponding to a multiple of that of a single plastics film tape, and said film is cut into respective single tapes after said step of removing excess insulating oil from the surfaces of said film.

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8. An oil-filled cable substantially as herein described with reference to Figures 1 to 3 of the accompanying drawings.

15 9. A method of manufacturing an oil-filled cable, substantially as herein described with reference to the accompanying drawings.

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