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HIGH VOLTAGE D.C. ELECTRIC CABLE

The present invention relates to an electric cable having a dielectric which comprises compound-impregnated insulation tapes which are either fully impregnated or under pressurized gas, the cable being
5 for carrying direct current at working voltages between 200 and 1000 kV. The invention relates particularly but not solely to submarine cables for covering large distances underwater (for example over 100 km).

As is known in the art, a critical condition
10 in a high voltage (H.V.) cable arises upon the formation of voids or bubbles in the insulation during operation of the cable, owing to thermal cycles during the cooling phase. Hitherto, oil-filled (O.F.) cables, having their insulating tapes impregnated with a liquid dielectric of
15 low viscosity, have offered the best protection against bubbles being formed: when the temperature is increased in such cables, the liquid dielectric or fluid oil expands into compensation tanks, preferably at a variable pressure, which are provided at one or both ends of the
20 cable. During cooling, fluid oil flows back into the cable from the tanks. Accordingly, in the insulation of these O.F. cables, no bubbles can form: the O.F. cables are independent of any variations in temperature - or in other words they are thermally stable. Moreover, since
25 the fluid oil normally used has a specific gravity very

close to that of the water, the pressure inside the O.F. cable is approximately equal to that of the ambient in which the cable is laid. The O.F. cable therefore does not have any practical limits as regards the depths at which it may be laid.

In the cooling phase the fluid oil must flow from the end or ends of the cable towards its middle. Owing to hydraulic resistances and, in part, to the viscosity of the oil, considerable pressure drops are generated along the cable length. It will be appreciated that these pressure drops will be in proportion to the length of the O.F. cable itself. Hence in the case of very long cables, for preventing any excessive pressure reduction within the cable during the cooling phase it is necessary to increase the feed-pressure of the fluid oil. Clearly however, this feed pressure cannot be increased indefinitely, and therefore the O.F. cable has some practical limitation as to its length.

For great distances to be covered by cables, there has been proposed the use of cables having paper tapes pre-impregnated with a compound that is non-migrating in a pressurized gas atmosphere. In particular, these cables (known in the art as Glover type cables) comprise paper pre-impregnated with compound, and disposed in a pressurized gas atmosphere - for example N_2 , between 14 and 15 atm.

These cables with pressurized gas are not appropriate for laying at great depths: they cannot be laid at working pressure, because under such conditions they would not be flexible. Moreover, whenever the external water pressure exceeds the internal gas pressure, the cable could collapse. Experience has shown that, with a cable having an internal gas pressure, depths of over 250 meters cannot be exceeded.

Moreover, in a cable of the Clover type, bubbles

can be formed during the cable manufacture, in the gaps between adjacent turns of the insulating tapes. The tapes impregnated in compound, when wound and stretched tightly over the cable, squeeze out the compound and the issuing compound just partially fills the gaps between the tapes - leaving small cavities. This is not critical for alternating current (a.c.) where the distribution of potential gradient takes place as a function of the dielectric constant of the insulation. However, for d.c. cables, it is known that the potential distribution depends upon resistivity, and bubbles in the gaps between adjacent turns of the insulating tapes would present considerable risks for electrical discharge. In fact, the resistivity of the voids or bubbles being practically infinite, there arises a localized gradient which is very high compared with the gradient that would otherwise exist if the volume of the bubbles were filled with the insulating compound.

Cables that can function well for long distances and also at great depths, are fully compound-impregnated and lead sheathed, with either a circular or an elliptical cross-section. These cables do not have any substantial flow of oil in the longitudinal sense, but only in the radial sense. During the thermal cycles, there are alternate thermal expansions and contractions of the insulating compound; for a given external pressure, during the heating and consequent thermal radial expansion of the compound, there is an increase in internal pressure. During the cooling and consequent thermal contraction, the internal pressure reduces until at certain points reaching an absolute vacuum. At these points, voids can form in the compound, and in d.c. cables electrical breakdown of the insulation can occur. D.c. cables fully compound-impregnated, were used in the past for voltages below 200 kV and usually around about 100 kV. However, the working

voltages of d.c. cables have gradually been increased. With the increases of the working voltages, there has been a gradual adaptation of the insulation to meet the increased stresses, involving increasing the insulation thickness and employing compounds having improved insulating characteristics.

In spite of this, the occurrence of electrical breakdowns, as a result of thermal cycles, has not been obviated. Indeed, it has been found by experiment that whereas in a sample of d.c. cable insulated with a compound-impregnated cellulose paper and having a thickness of 9 mm, electrical discharges occurred at an applied testing voltage of about 400 kV, for a d.c. cable with the same insulation but of a thickness of 18 mm, electrical breakdown occurred with a testing voltage of only about 600 kV instead of the expected 800 kV.

This phenomenon can be correlated with the formation of voids which become verified to a greater extent and with more serious effects, according to a greater amount of compound involved, and this increases the possibility of breakdowns taking place as a consequence.

If a submarine, fully-impregnated cable is laid at a sufficient depth (say over 120 m), the external pressure due to the water can be transmitted through the plastics sheath of the cable to the insulation, thus preventing the above phenomena. But, unfortunately, for depths of less than 120 m, the effect of the external pressure is insufficient, and any good results with high voltage fully-impregnated d.c. cables of considerable length, are purely by chance.

We have now devised a high voltage d.c. cable, particularly but not exclusively for long distances underwater, giving good performance even when not aided by the pressure of the water in which it is laid.

In accordance with the present invention, there

is provided an electric cable for carrying direct current at a working voltage between 200 and 1000 kV, comprising at least one conductor, an inner semi-conductive screen, a dielectric comprising one or more layers of cellulose paper insulating tapes wound helically around said inner semi-conductive screen and impregnated with impregnant, an outer semi-conductive screen disposed around the dielectric, and a metal sheath, said impregnant including at least one substance containing polar groups to impart to said impregnant at the operating temperature foreseen a sufficiently low resistivity (and at least 100 times lower than that of said cellulose paper tapes) such as to exercise an electrically screening effect on any eventual voids or bubbles formed in said impregnant.

Embodiments of this invention will now be described, by way of examples only, with reference to the accompanying drawings, in which:

Figure 1 is a schematic view of a length of fully-impregnated d.c. cable;

Figure 2 is a schematic view of a length of gas pressurized d.c. cable;

Figure 3 is a diagram which illustrates the resistivity-with-temperature variations of certain impregnants relative to that of the paper; and

Figure 4 is a diagram to illustrate the discharge intensity in a test cable impregnated with an impregnant according to the invention, with respect to the electrical discharge intensity in a test cable impregnated with an impregnant previously known in the art.

Figure 1 shows a cable for carrying d.c. (direct current), comprising a conductor 10 which is provided with an inner semi-conductive screen 11 formed for example by winding a semi-conductive tape around the conductor 10. Over the semi-conductive screen 11, there is provided a dielectric comprising one or more layers of

cellulose paper insulating tape 12 wound helically around the screen 11 and impregnated with an insulating substance.

5 Over the layer or layers of insulating tape 12, an outer semi-conductive screen 13 is provided and this may comprise, for example, a wound semi-conductive tape. The cable elements 10-13 are enclosed within a lead sheath 14. The latter may be covered with a protective layer, which is either known in the art or
10 else dictated by particular circumstances. In the example shown in Figure 1, the lead sheath 14 is covered by a corrosion-protective sheath 15.

We have surprisingly found that it is possible to obviate the risks posed by voids or bubbles in the
15 impregnant, whether formed during the cable manufacture or as a result of the thermal cycles during service, if the impregnant presents at the operating temperatures foreseen, a sufficiently low resistivity which is maintained constant throughout the working life. We
20 have found that an impregnant with these characteristics is able to screen electrically any eventual voids or bubbles therein. We have found experimentally that, for achieving an effective screening effect, it is necessary for the impregnant to have a resistivity at least 100
25 times lower than that of the cellulose paper insulating tapes which it impregnates. Preferably but not exclusively, the resistivity will be about 1000 times lower than that of the paper tapes. An appropriate impregnant can be obtained by adding to the hydrocarbon
30 oil, which is commonly used for impregnating electrical cables, at least one substance (usually organic) containing one or more polar groups. A definition of what is meant by a "substance containing polar groups" is to be found in Samuel Glasstone's 'TRATTATO DI
36 CHIMICA-FISICA' from the American Edition - page 114-115

of the Italian translation (1956) by Carlo Manfredi Editors. (See also Textbook of Physical Chemistry by Samuel Glasstone, 2nd Edition 1960 (Macmillan & Co., London) pages 107-109.)

5 One example of this impregnant comprises viscous hydrocarbon oil in the proportion of at least 60 parts per 100 by weight of impregnant and one or more organic compounds containing polar groups such as carboxylic acid groups, in an amount of up to 40 parts per 100 by weight. 10 of the impregnant. In addition to these two main components of the impregnant, other substances can also be present, for example for controlling the viscosity of the impregnant, in proportions up to about 15% of the total weight of the two main components.

15 In particular, a preferred impregnant composition which has given excellent results, comprises 63 parts by weight of a hydrocarbon oil having an index of viscosity 75 and a viscosity at 38°C of 800 cSt., 27 parts by weight of an organic composition consisting 20 essentially of a natural resin with an abietic acid base, and 10 parts by weight of microcrystalline wax having a melting point of 103° - 107°C. This particular impregnant composition has proved itself to be particularly effective not only for the cable shown in Figure 1, but also for 25 the cable shown in Figure 2. The cable shown in Figure 2 has a conductor 16 covered by an inner screen 17 and a dielectric which comprises cellulose paper insulating tapes 18 wound helically around the screen 17. An outer screen 19 covers the layer of insulating tapes 18. The 30 cable elements 16-19 are enclosed by a metal sheath 20, - for example a corrugated aluminium sheath. As shown, the sheath may be covered by one or more protective sheaths 21. The insulating tapes of the cable in Figure 2 are impregnated with the impregnant under gas pressure - 35 for example N₂ up to 25 atm. In Figure 3, there is shown

at (a) the variation of the resistivity of the impregnant as a function of temperature, and at (b) the variation with temperature of the resistivity of the paper impregnated with it.

5 Said preferred impregnant has given very satisfactory results compared with the product ILO3 (white vaseline) supplied by the company WITO (U.S.A.) and previously and commonly used (curve d) and having a resistivity close to and above that of the paper which it
10 impregnates (curve c).

Vaseline is a Registered Trade Mark
X Figure 4 shows the intensity of electrical discharges in pico-Coulomb (pC) at 14 atm as a function of the applied voltage gradient E (KV/mm) for voids in test cables impregnated with the respective impregnants:
15 even up to a gradient three times greater than that at which discharges occur in the cable impregnated with the ILO3, no discharges occur in the cable impregnated with the preferred impregnant in accordance with the invention.....
(curve a).

20 Other preferred impregnants are those constituted by - apart from a hydrocarbon oil having a viscosity at 38° of about 800 cSt. - also one of the following organic acids, in proportions up to 10% by weight:

25 oleic acid, linolic acid, recinoleic acid, palmitic acid, stearic acid, various naphthenic acids and various terpenic acids.

Other impregnant compositions which may be used in accordance with the invention comprise, for
30 example, viscous hydrocarbon oils to which have been added salts of organic acids having a good solubility in the hydrocarbons. An example of an impregnant composition of this type comprises a hydrocarbon oil having a viscosity at 38°C of about 600 cSt in the proportion of
35 95 or more parts by weight per 100 parts by weight of

impregnant, and copper naphthenate in an amount up to 5 parts by weight.

Another type of impregnant composition for use in the invention comprises a hydrocarbon oil -
5 such as described in the previous examples, and one or more compounds containing polar groups, which compounds have originated from the cellulose paper tapes themselves, when said tapes are of an aqueous extract having a conductivity of from 50 to 200 ~~μ~~SIEMENS. For determining
10 the aqueous extract and for measuring its conductivity, reference is made to the ASTM D 202-62T method. The conductivity of the aqueous extract of the paper can be defined as a measure of the amount of electrolytes which are soluble in warm water and which are found in the
15 paper.

While we have specifically described certain types of impregnants, by way of example only, the invention extends to all types of impregnants which provide the desired characteristics, either for use with fully
20 impregnated cables or for cables having an external pressure.



CLAIMS

1. An electric cable for carrying direct current at a working voltage between 200 and 1000 kV, comprising at least one conductor, an inner semi-conductive screen, a dielectric comprising one or more layers of cellulose paper insulating tapes wound helically around said inner semi-conductive screen and impregnated with impregnant, an outer semi-conductive screen disposed around the dielectric, and a metal sheath, said impregnant including at least one substance containing polar groups to impart to said impregnant at the operating temperature foreseen a sufficiently low resistivity (and at least 100 times lower than that of said cellulose paper tapes) such as to exercise an electrically screening effect on any eventual voids or bubbles formed in said impregnant.

2. An electric cable according to Claim 1, in which said impregnant has a resistivity substantially 1000 times lower than that of said cellulose paper tapes.

3. An electric cable according to Claim 1 or 2, in which said substance containing polar groups is an organic substance.

4. An electric cable according to Claim 3, in which the polar groups comprise carboxyl groups, and wherein the impregnant comprises up to 40 parts of said substance(s) and at least 60 parts of a viscous hydrocarbon oil, per 100 parts by weight of impregnant.



5. An electric cable according to Claim 3, in which said organic substance is a natural resin based upon abietic acid, and said impregnant comprises about 63 parts by weight of a hydrocarbon oil with a viscosity index of 75 and viscosity at 38°C of 800 cSt., 27 parts by weight of the organic substance, and 10 parts by weight of a micro-crystalline wax having a melting point of 103° to 107°C, per 100 parts by weight of impregnant.
6. An electric cable according to Claim 1 or 2, in which said impregnant comprises a hydrocarbon oil having a viscosity at 38°C of 600 cSt. in the proportion of 95 parts by weight or more, and copper naphthenate in an amount up to 5 parts by weight, per 100 parts by weight of impregnant.
7. An electric cable according to Claim 1 or 2, in which said impregnant comprises a hydrocarbon oil having a viscosity at 38°C from 600 to 800cSt. and at least one substance containing polar groups, said substance originating from the cellulose paper tapes which present an aqueous extract having a conductivity from 50 to 200 μ SIEMENS.
8. An electric cable according to Claim 3, in which said organic substance is an organic acid, and the impregnant comprises up to 10 parts by weight of the acid per 100 parts of impregnant, the impregnant also comprising a hydrocarbon oil having a viscosity at 38°C of 800 cSt.



9. An electric cable according to Claim 8, in which said organic acid is oleic acid.
10. An electric cable according to any preceding claim, in which said compound is aided by a gas pressure.
11. An electric cable substantially as herein described with reference to Figure 1 or Figure 2 of the accompanying drawings.