The following statement is a full description of this invention, including the best method of performing it known to us:

PIRELLI GENERAL CABLE WORKS LIMITED

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431428 (35143/68) 48.3-5, 03.2, 48.1

ELECTRIC CABLE SCREENING PAPER
This invention relates to electric cables and more particularly to paper for use in forming screening layers in electric cables.

During cable manufacture, as is well known, paper having semi-conducting properties and in tape-form is commonly wound around the cable conductor in lapped-manner to form an electric screening layer or screen in contact with that conductor. Also, at a later stage when the insulation has been applied to the screened conductor, such semi-conducting paper tape is commonly wound around the insulation, again in lapped-manner, to form a further screen which is to contact a subsequently-applied metal sheath.

One originally-proposed paper for use in forming such screens comprises plain paper loaded with carbon-black, the latter imparting semi-conducting properties to the otherwise insulating plain paper. A difficulty with this paper is that, in cables having screens formed from it, a substantial dissipation of energy takes place in the insulating dielectric, particularly in liquid-impregnant films facing the screens.

A paper which was proposed some time ago for alleviating this difficulty, and which has met with considerable success, is a two-ply laminated paper, one ply being of carbon-black loaded semi-conducting paper and the other ply of plain insulating paper. In cables having screens formed from this paper, a substantial reduction was found in the energy-dissipation occurring in the insulating
dielectric. Such a two-ply paper is described in the Complete Specification of British Patent Serial No. 815394.

It has been usual for the two plies in this screening paper to be of similar impermeabilities. This is because it has until relatively recently been standard practice, when making multi-ply papers, for the plies to be of similar characteristics, including density and impermeability, as this minimises paper manufacturing difficulties.

By way of explanation, the "impermeability" of a paper is a measure of the paper's resistance to the flow therethrough of liquid or gas. Later in this specification reference will be made to specific values of impermeability and these will be quoted in Emanueli Units (E.U.). The Emanueli Unit is well known in the art, but a definition thereof is to be found in the publication TAPPI (Technical Association of the Pulp and Paper Industry), Volume 44, No. 10, October 1961, pages 176A to 182A, where there is also to be found a description of a modified Emanueli porosimeter for measuring the air impermeability of paper, in Emanueli Units.

Also, by the term "density" as applied to paper throughout this specification is meant the apparent density, namely that obtained by dividing the mass of a given volume of the paper by the overall volume itself, the overall volume comprising both the volume of the fibres of the paper and of the air trapped between those fibres.
Recent trends towards the transmission of electric power at voltages up to 500 kV has made heavy demands upon the dielectric characteristics of the paper which is used for the insulation-proper of the cables. This insulating paper has been required to withstand much greater potential gradients and to have a much lower loss factor than necessary formerly, when electricity was transmitted at much lower voltages. These demands have led to the introduction of a multi-ply insulating paper, preferred forms of which comprise plies of substantially dissimilar characteristics. Thus, in preferred forms of this insulating paper, there is at least one ply of relatively high impermeability and at least one ply of relatively low impermeability. Generally, a relatively high impermeability paper has a high dielectric strength, but also a high loss factor, whereas a relatively low impermeability paper has a low loss factor, but also a low dielectric strength. However, it is found that the multi-ply insulating paper exhibits very good all-round dielectric characteristics, having a high dielectric strength (almost as high as that of the high impermeability ply) and a low loss factor (almost as low as that of the low impermeability ply). Generally also, in this paper, the higher impermeability ply is of higher density than the other ply.

The production of these multi-ply insulating papers, having such dissimilar characteristics between the various plies, has been made possible by improved paper-making techniques which have become
available since the two-ply screening tape discussed previously was first introduced. Such multi-ply insulating papers are described in the Complete Specification on British Patent Serial No. 1 190 962.

In cables insulated with either this multi-ply insulating paper or with standard paper, it is the dielectric properties of the screens, particularly the screen which contacts the conductor, which are of critical importance, and it is found that some improvement on the dielectric characteristics exhibited by the two-ply screening paper is desirable in order to obtain a higher dielectric strength in the cable insulation as a whole, particularly where the cable is for use at voltages approaching 500 kV. It is to be noted that the conductor-contacting screen, particularly the insulating ply of the screening paper where the two-ply screening paper is used, is subjected to the highest electrical stress of the cable insulation and is therefore the most critical part of that insulation.

It is therefore an object of the present invention to provide paper for use in forming screening layers in electric cables, which will enable the attainment of a higher dielectric strength in the insulation of cables in which it is used than would be possible by using the presently-available two-ply screening paper in the same cables.

Accordingly, as seen from one aspect, the present invention provides paper for use in forming screening layers in electric cables, which comprises

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two plies, one being a semi-conducting paper ply and
the other an insulating paper ply, the impermeability of
the paper of the insulating paper being at least $20 \times 10^6$ E.U.

The semi-conducting paper ply of this screening paper
according to the invention may comprise plain paper loaded
with carbon black, the latter imparting semi-conducting
properties to the otherwise insulating plain paper. By
way of example, the semi-conducting ply may be of a density
and of an impermeability which are both common-place for
such semi-conducting plies found per se in the cable making
industry; typical values for density range from 0.84 to
0.90 gm/cm$^3$ and typical values for impermeability range
from $10^6$ to $2 \times 10^6$ E.U.

It is found that a considerably higher impulse
dielectric strength is obtained in the insulation of electric
cables where the screens are formed of the screening paper
according to the invention as defined in the last-but-one
preceding paragraph, in place of the prior art two-ply
screening paper previously discussed. For example, using
one screening paper in accordance with the invention, a
value of 115 MV/m for the maximum electrical stress at
breakdown has been obtained in the insulation of an oil-
filled cable where, with a screen formed of the prior art
two-ply paper, a value of only 100 MV/m was possible.
Similar improvements are found in the power frequency di-
electric strength, an increase from 43 MV/m to 52 MV/m
being typical.

However, one other major improvement has been found,
relating to the power factor. One
important test which is made on an oil-filled cable after its manufacture is a comparison of the power factor when measured at half, full and twice the working voltage; desirably the power factor should rise as little as possible with increase in voltage. Now, in cables having screens formed of paper in accordance with the invention, a very substantial improvement is found in that the power factor is slightly less at half working voltage and rises very much less as the voltage is increased to twice working voltage, as compared with cables having screens of the prior art two-ply paper. For example, in 66 kV oil-filled cables, for half, full and twice working voltage, power factor values of $23 \times 10^{-4}$, $27 \times 10^{-4}$ and $32 \times 10^{-4}$ respectively are obtained at room temperature in cables having the prior art two-ply paper, but corresponding values of $21 \times 10^{-4}$, $22 \times 10^{-4}$ and $24 \times 10^{-4}$ have been obtained in identical cables having screens formed of paper in accordance with the invention.

It is found that the improvements detailed above are enhanced if the density of the insulating ply paper in the two ply paper according to the invention is not less than 1.0 gm/cm$^3$. By way of example, typical values for the insulating ply density in screening papers according to the invention which have been made and tested experimentally range from 1.1 to 1.2 gm/cm$^3$, as against the normal density of 0.84 to 0.90 gm/cm$^3$ quoted previously for the semi-conducting ply.
By way of example also, typical values for the impermeability of the insulating ply in screening papers according to the invention which have been made and tested experimentally range from $200 \times 10^6$ to $750 \times 10^6$ E.U., whilst a value as high as $2000 \times 10^6$ E.U. is possible (in which case the density could be as high as $1.31 \text{ gm/cm}^3$) Typical values for the density and impermeability of the finished screen paper in such papers according to the invention which have been made and tested experimentally range from 1.0 to $1.15 \text{ gm/cm}^3$ and from $100 \times 10^6$ to $300 \times 10^6$ E.U., whilst values of $1.25 \text{ gm/cm}^3$ and $1000 \times 10^6$ E.U. respectively prevail where the insulating ply has the highest density and impermeability values quoted above, although an impermeability as low as $5 \times 10^6$ E.U. is also possible where the two plies are of lower impermeability. Typically also in the screening papers according to the invention which have been made and tested experimentally, each ply is at least 0.025 mm thick, with the overall thickness of the finished paper not exceeding 0.20 mm and a ratio between the thickness of the two plies not exceeding 1 to 3 (in either sense). Preferred ranges of values are from 0.030 to 0.080 mm for the thickness of each layer, from 0.050 to 0.140 mm for the overall thickness of the finished paper, and from 0.5 to 2 for the ratio between the thicknesses of the semi-conducting and insulating plies.

It is clear from the various figures quoted above that very often the two plies of screening papers according to the invention are of very dissimilar characteristics, both density and impermeability, but as is mentioned above this is nowadays feasible because of improved paper-making
techniques now available. Also, the insulating paper ply of the screening paper according to the invention is often of very high density, and this is typically obtained by supercalendering the finished screening paper.

In forming screens in electric cables, the above-disclosed paper according to the invention is wound, in tape form, around the conductor in lapped manner with the semi-conducting ply facing and in contact with the conductor, or, for the outer-screen, around the insulation with the insulating ply facing the insulation.
THE CLAIMS DEFENDING THE INVENTION ARE AS FOLLOWS:

1. Paper for use in forming screening layers in electric cables, which comprises two plies, one being a semi-conducting paper ply and the other an insulating paper ply, the impermeability of the insulating ply paper being at least $20 \times 10^6$ E.U.

2. Paper as claimed in claim 1, wherein the density of the insulating ply paper is not less than $1.0 \text{ gm/cm}^3$.

3. Paper as claimed in claim 2, wherein the density of the insulating ply paper is in the range $1.1$ to $1.2 \text{ gm/cm}^3$.

4. Paper as claimed in claim 1 or 2, wherein the impermeability of the insulating ply paper is in the range $20 \times 10^6$ to $2000 \times 10^6$ E.U.

5. Paper as claimed in any one of claims 1 to 3, wherein the impermeability of the insulating ply paper is in the range $200 \times 10^6$ to $750 \times 10^6$ E.U.

6. Paper as claimed in any one of claims 1 to 3 or 5, wherein the overall density thereof is in the range $1.0$ to $1.15 \text{ gm/cm}^3$.

7. Paper as claimed in any one of claims 1 to 3, 5 or 6, wherein the overall impermeability
thereof is in the range $100 \times 10^6$ to $300 \times 10^6$ E.U.

8. Paper as claimed in any one of the preceding claims, wherein each said ply is at least $0.025$ mm thick.

9. Paper as claimed in claim 8, wherein the thickness of each said ply is in the range $0.030$ to $0.080$ mm.

10. Paper as claimed in claim 8 or 9, having an overall thickness not exceeding $0.20$ mm.

11. Paper as claimed in claim 10, having an overall thickness in the range $0.050$ to $0.140$ mm.

12. Paper as claimed in any one of claims 8 to 11, wherein the ratio between the thicknesses of the two plies does not exceed 1 to 3, in either sense.

13. Paper as claimed in claim 12, wherein the ratio of the thickness of the semi-conducting ply to that of the insulating ply is in the range 0.5 to 2.

14. Paper as claimed in claim 1 and substantially as herein described, for use in forming screening layers in electric cables.

15. An electric cable having at least one
screening layer formed from paper as claimed in any one of the preceding claims wound, in tape-form, in lapped-manner, with the insulating ply facing the insulation of the cable.

DATED this 18th day of APRIL 1972
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