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Bahder et al.

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[54] **HIGH VOLTAGE SOLID EXTRUDED INSULATED POWER CABLES**

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[52] **U.S. Cl.**........ **174/36;** 174/102 SC; 174/120 SC; 174/120 AR

[51] **Int. Cl.** **H01b 9/02**

[58] **Field of Search**.... 174/102 SC, 120 R, 120 SR, 174/120 SC, 110 AR, 110 R, 110 PM, 120 AR, 36, 106 SC, 105 SC

[56] **References Cited**

UNITED STATES PATENTS

3,066,180	11/1962	Virsberg et al.	174/106 SC
3,187,071	6/1965	Padziejowski	174/120 AR
3,412,200	11/1968	Virsberg et al.	174/120 R X
3,485,939	12/1969	Brown et al.	174/120 R X
3,666,876	5/1972	Forster	174/105 SC
3,792,192	2/1974	Plate	174/120 SC
3,792,409	2/1974	Smart et al.	174/105 SC X
3,828,115	8/1974	Hvizd, Jr.	174/106 SC X

FOREIGN PATENTS OR APPLICATIONS

576,411	4/1946	United Kingdom	174/25 R

Primary Examiner—Arthur T. Grimley

[57] **ABSTRACT**

This electric power cable, and method of making it, relate to high voltage cables with solid extruded insulation, and the life of the cable is lengthened by protecting the insulation from localized voltage stresses which cause emission of electrons into the insulation. An emission shield is used between a semi-conducting conductor shield and the insulation that surrounds the conductor shield; and preferably, for higher voltage cables, an emission shield is used between the outside of the insulation and a semi-conducting insulation shield.

14 Claims, 5 Drawing Figures

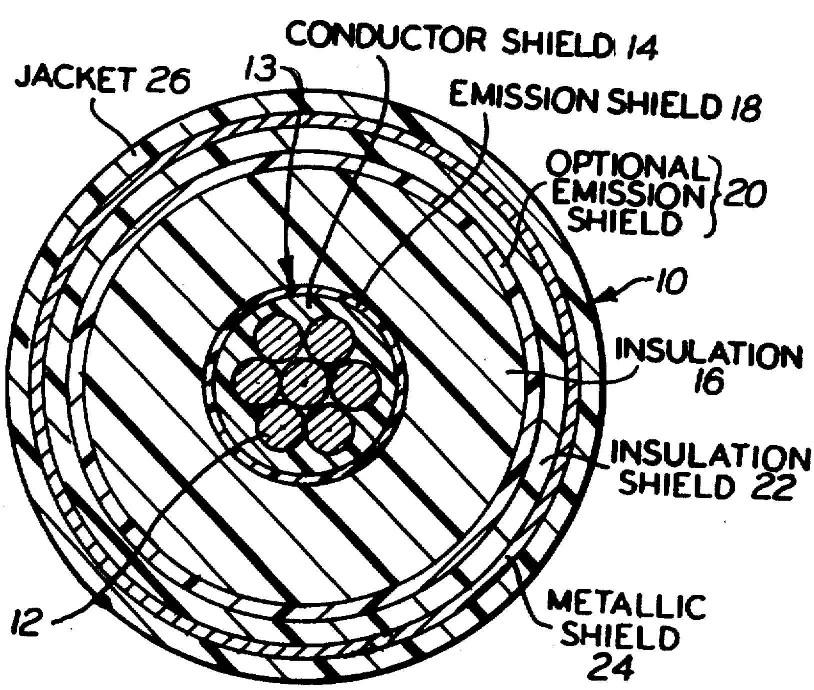


FIG. 1.

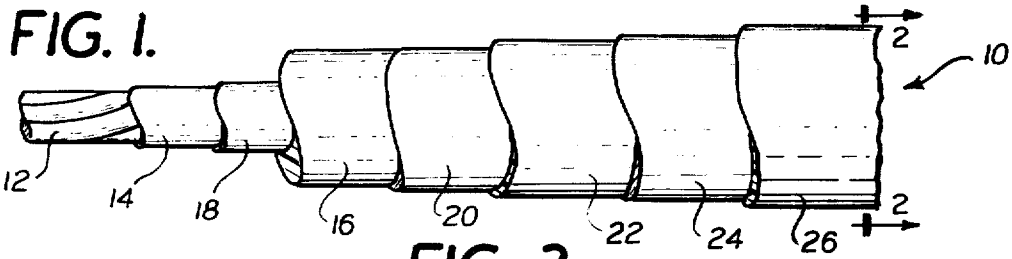


FIG. 3.

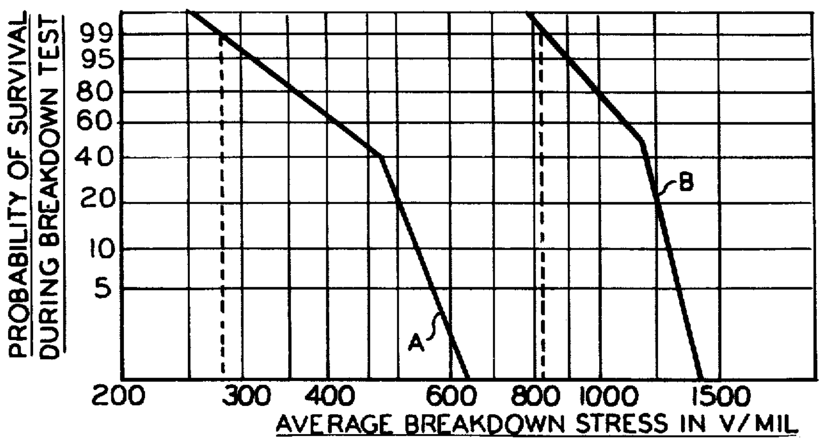


FIG. 4.

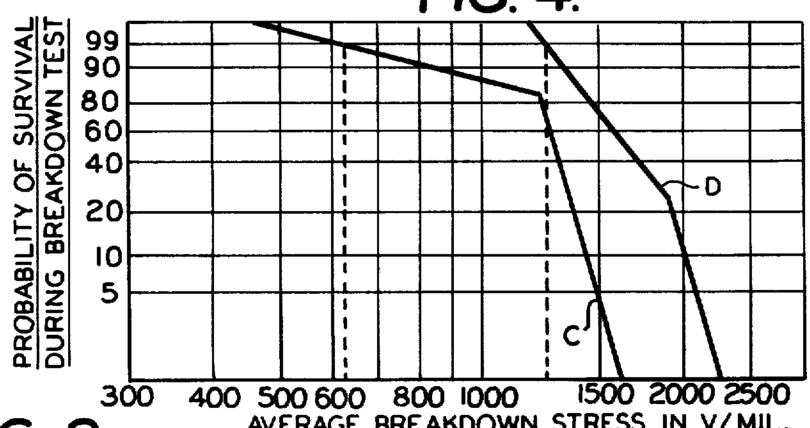


FIG. 2.

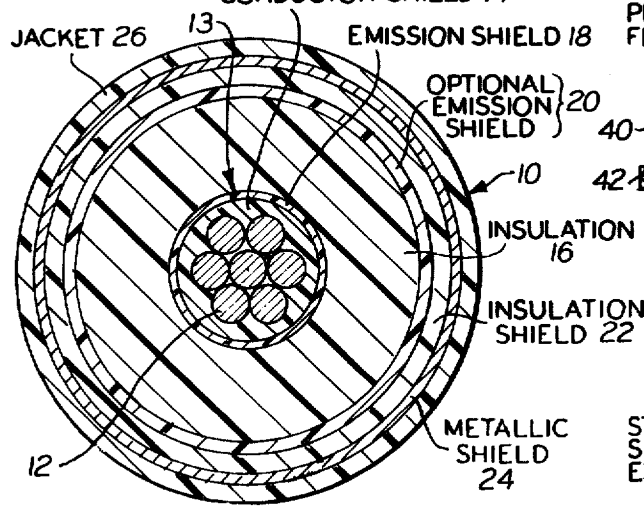
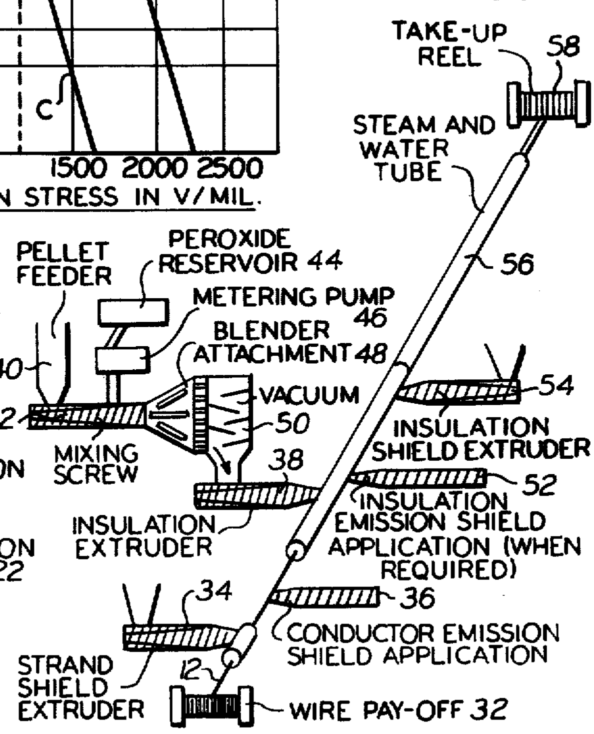


FIG. 5.



HIGH VOLTAGE SOLID EXTRUDED INSULATED POWER CABLES

BACKGROUND AND SUMMARY OF THE INVENTION

This invention is a new construction for solid extruded insulated power cable and a corresponding new method of manufacture. The preferred insulation is cross-linked polyethylene, but the invention is applicable to other polyethylene and other extruded polymeric insulation. The applicable voltage range is 5 kilovolts through 345 kilovolts, and may be extended to higher voltages. The cable is preferably made by utilizing a new technology in the treatment of the pelletized insulation material received from material suppliers. This treatment consists of "crushing" contaminants, and in the case of cross-linked polyethylene, more extensively dispersing the peroxide curing agent. The treatment alternately can include straining through small dies of the polyethylene insulation prior to extrusion or in the case of chemically cross-linked polyethylene straining prior to the addition of di-cumyl peroxide, the curing agent. This results in higher dielectric strength and consequently permits the use of thinner insulation thickness. This treatment is the subject matter of a patent application referred to later in this specification.

In connection with such treatment for improving the dielectric strength of insulation, the term "contaminants" is used to designate voids and similar imperfections in the plastic material; and also to designate impurities and concentrations of curing agent.

Extruded high voltage cables made with polyethylene and cross-linked polyethylene should have a minimum of imperfections in order to have a life span as long as 30 years or more. Such imperfections also affect other plastic materials which are used for insulation such as ethylene-propylene rubber.

The semi-conducting conductor shield commonly used on our cables is modified in this invention by placing over it an emission shield comprising a layer of material such as neoprene chlorosulfonated polyethylene (Hypalon) or polyethylene containing a high dielective constant (SIC) material such as titanium dioxide which contains no electrical conducting particles. For power cables that are to be used above about 35 kilovolts it is desirable to also place an emission shield between the insulation and the semi-conducting insulation shield that surrounds the insulation of a high voltage cable. These emission shields function to increase the dielectric breakdown voltage of the insulation by eliminating electron emissions into the insulation from high electrical stress areas of the semi-conducting conductor and insulation shields. We have discovered that by controlling the imperfections in the raw material of which the insulation is made, and preventing electron emission into the insulation, significant increase in the dielectric strength of the cable is obtained and a structure capable of operating in the range of between 200 and 300 volts per mil, average stress. Just as the improvement of reducing the size of imperfections can be used alone, so can the improvement of providing emission shields; but combining both of these improvements in the same power cable provides outstanding results.

Other objects, features and advantages of the invention will appear or be pointed out as the description proceeds.

BRIEF DESCRIPTION OF DRAWING

In the drawing, forming a part hereof, in which like reference characters indicate corresponding parts in all the views:

FIG. **1** is a side elevation of a cable made in accordance with this invention with layers successively broken away to illustrate underlying layers;

FIG. **2** is an enlarged sectional view taken on the line **2—2** of FIG. **1**;

FIG. **3** is a Weibull diagram showing a difference between a conventional power cable with extruded insulation and a power cable which has insulation extruded from material where the imperfections have been reduced to a diameter of less than 0.001 inches;

FIG. **4** is a Weibull diagram showing the difference between a power cable having extruded insulation with the reduced size imperfections of FIG. **3** compared with a cable having the same reduced size imperfections with an emission shield located between a semi-conducting conductor shield and the insulation of the cable in accordance with the invention; and

FIG. **5** is a diagrammatic view showing apparatus for making a cable in accordance with this invention and also illustrating the method of making such a cable.

DESCRIPTION OF PREFERRED EMBODIMENT

FIGS. **1** and **2** show a cable **10** made in accordance with this invention. The cable has a conductor **12**, which is shown as a stranded conductor. A shield **13** is extruded over the conductor **12** in two layers. The inner layer **14** is a semi-conducting shield and the outer layer **18** is an emission shield. The cable **10** has an extruded insulation **16** that is applied over the shield **13**.

In conventional cable constructions the insulation **16** contacts with and is fused to the semi-conducting shield that surrounds the conductor; but in the illustrated construction the emission shielding layer **18** separates the semi-conducting conductor shield **14** from the insulation **16**. This emission shield **18** has a dielectric constant which is higher than several times that of the insulation **16** and the emission shield serves to smooth out electrical stresses which would otherwise exist at the interface between the semi-conducting conductor shield and the insulation, in a conventional cable which has the insulation applied directly over the semi-conducting conductor shield.

The emission shield is preferably made of neoprene, Hypalon, polyethylene filled with a high dielectric constant (SIC) material such as titanium dioxide, or other flexible thermoplastic or thermosetting materials which have a dielectric constant several times higher than that of polyethylene or such other material as may be used for the insulation **16**. The neoprene or hypolon, or other emission shield material should be free of any carbon black or other electrically conducting particles. The emission shield **18** is preferably bonded to both the semi-conducting conductor shield **14** and to the insulation **16**.

The dielectric constant of the emission shield **18** should be six or more. The insulation **16** is preferably made of polyethylene or cross-linked polyethylene because of the good electrical characteristics of these materials. Other insulating material can be used in place of polyethylene, such as ethylene-propylene rubber or polyvinyl chloride. Both of these latter materials are well known insulating materials. If the insulation **16** is cross-linked, it may be cross-linked either chemically or by radiation, and the degree of cross-linking should be sufficient to raise the softening point of the insulation but not enough to produce a rigid layer since it is important that the cable be capable of bending without injury.

If the cable **10** is to be used on power lines which operate in excess of 35 kilovolts, it is desirable to place an emission shield **20** between the outside surface of the insulation **16** and the inside surface of an insulation shield **22** which is a semi-conducting layer surrounding the insulation **16.** The cable **10** has a metallic shield **24** surrounding the insulation shield **22**; and there is an overall plastic jacket **26** extruded over the outside of the metallic shield **24.** This plastic jacket **26** may be polyvinyl chloride or any other tough plastic such as is commonly used for mechanical protection for power cables.

The inner emission shield **18** should have a thickness in the range of 5 to 30 mils. It must be flexible and should be mechanically strong. It can be applied to the semi-conducting conductor shield **14** by painting it on the outside of the shield **14** or by extruding it over the shield **14.**

The semi-conducting shield **14** haas surface irregularities and can have non-uniform distribution of carbon black particles at local areas. Both of these deficiencies lead to regions of high electrical stress. This high stress reduces the dielectric strength of the insulation. These high stress areas result in electron emission which causes aging of polyethylene or cross-linked polyethylene in cables which have no emission shield between the semi-conducting conductor shield and the insulation. The aging is responsible for lower values of voltage breakdown of the cable and this reduces the useful life of the cable.

With the emission shield **18,** between the semi-conducting conductor shield **14** and the insulation **16,** the voltage stress is reduced at the surface irregularities at the interfaces and in regions of irregular carbon black distribution and this increases the breakdown voltage of the cable.

The outer emission shield **20,** between the insulation **16** and the insulation shield **22** is further removed from the conductor **12** and is of larger area at a location where voltage stresses are not as high as at the first emission shield **18.** However, if the cable is used for voltages over about 46 kilovolts, it is desirable to have the emission shield **20** as well as the inner emission shield **18.** This outer emission shield **20** may be thicker or thinner than the inner emission shield **18.** It is ordinarily somewhat thinner if the cable is made with the overall metal shield **24** and the outer plastic jacket **26** around the outside of the emission shield **20.** If the cable is made without the shield **20** and jacket **26,** then the emission shield **20** is preferably thicker than the inner emission shield **18.** The range of thickness for the shield **22,** depending upon the conditions already described, is between 5 and 30 mils.

Extruded insulations such as polyethylene have an inherent a-c 60 Hz electrical breakdown strength in the range of 10,000 volts/mil. A statistical study of commercial cables shows an average breakdown strength in the range 200 to 700 volts/mil. This is about one-thirteenth to one-fiftieth the potential of the material used. The major cause of the extremely low values compared to the potential values is imperfections. These imperfections are in the form of contaminants (which include poorly distributed ingredients) and voids in the insulation and in the form or irregularities of conductor and insulation shields. The former can be reduced so as to be nearly harmless by minimizing the size of the contaminants so that they are less than about 1 to 3 mils. This technique also disperses the peroxide in cross-linked polyethylene so that the voids caused by concentration of peroxide are less than 1 mil. In the case of polyethylene which is not chemically cross-linked the peroxide does not exist so that the requirement only is to reduce the size of the contaminants.

This improvement in the breakdown strength of extruded insulation is the subject matter of a patent application by Eager, Riley and Destito, Ser. No. 477,426 filed June 7, 1974. This improvement in the breakdown strength of insulation is still further improved by the use of the electron emission shields of this invention; but it will be understood that the electron emission shields of this invention are also useful with power cables which do not have the insulating material treated so as to reduce the contaminants and voids to extremely small size.

With a perfect polyethylene or cross-linked polyethylene insulation, the dielectric strength of the insulating system with the emission shield will depend on the breakdown strength of the emission shield which can be expressed as follows:

Ees is approximately equal to $Ei \cdot ki/kes$

where

Ees = the voltage breakdown in volts/mil of the emission shield

Ei = the voltage breakdown in volts/mil of the insulation

ki = the SIC (dielectric constant) of the insulation

kes = the SIC of the emission shield

This equation is valid for *Ees* which is less than or equal to *Ei*.

The stranded conductor **12** may be copper or aluminum and an unstranded conductor can be used if desired. Instead of extruding the semi-conducting conductor shield **14** over the conductor **12,** a semi-conducting tape may be placed around the conductor and the semi-conducting conductor shield **14** can be placed over the tape, or the semi-conducting tape can be used in lieu of the shield **14.**

In either case, the emission shield **18** should adhere to the underlying semi-conducting layer and should be of a range of thickness from 5 to 30 mils so as not to be damaged during handling of the cable.

The insulation shield **22** is preferably extruded, but can be made from a semi-conducting tape, if desired. The metallic shield **24** can be made of copper folded longitudinally and with a lap seam which has edges free to move circumferentially over one another during heat cycling of the cable. In place of such a metallic shield **24,** helically applied copper wires, copper tape, copper ribbons or a lead sheath may be applied.

The emission shields **18** and **20** must not only be flexible so as to bend with the cable but should be made of material which ages as well as the polyethylene or cross-linked polyethylene or other material used for the insulation. The emission shields should adhere to the insulation **16** and where the various layers are extruded, the heat of extrusion will usually provide the necessary fusion bonding for good adherence. It is, of course, necessary that the emission shields **18** and **20** be made of material which is compatible with the insulation 16 and the semi-conducting shields 14 and 22. Neoprene and Hypalon compounds, and polyethylene filled with titanium dioxide which do not contain carbon black or other conducting ingredients, are examples of material which is particularly suitable for use with polyethylene insulation and with semi-conducting shields made of polyethylene through which carbon black has been dispersed to obtain the semi-conducting quality.

FIG. 3 shows a Weibull diagram with curve A illustrating the results obtained with a conventional production sample of a power cable having insulation made of polyethylene but without any special treatment to reduce the diameter of imperfections in the polyethylene.

FIG. 3 shows a curve B which illustrates the results obtained with a comparable cable, to that of curve A, but with the insulation treated so that it contains no imperfections greater than about 3 mils in diameter. This is the improvement obtained by the Eager, Riley and Destito patent application previously referred to.

FIG. 4 shows another Weibull diagram in which a curve C represents a sample power cable having the imperfections of small size in accordance with the Eager, Riley and Destito patent application. This curve C of FIG. 4 differs from curve B of FIG. 3 in that a different sample was used for the Weibull diagram of FIG. 4. The technique used for reducing the size of imperfections was different for the insulation of curve C than for curve B and the characteristics are somewhat different though the actual values are not far apart over most of the range of the curves.

Curve D of FIG. 4 illustrates the results obtained by the addition of the emission shields of this invention to a cable such as represented by curve C. Although the differences between Curves A and B of FIG. 3 and curves C and D of FIG. 4 may seem quite pronounced in viewing the diagrams of FIGS. 3 and 4, it should be recognized that the scales along the abscissa in both diagrams are logarithmic scales and that divisions of the scales toward the right represent progressively greater values of breakdown stress in volts per mil.

FIG. 5 is a diagrammatic showing of apparatus for making the cable shown in FIGS. 1 and 2. The conductor 12 is supplied from a wire payoff 32. The conductor 12 passes through an extruder 34 which extrudes the semi-conducting conductor shield 14 over the conductor 12. The conductor with the semi-conducting shields passes through a first emission shield applicator 36 which applies the emission shield 18. The insulation 16 is then applied by an insulation extruder 38.

Insulation for the extruder 38 is supplied from a pellet feeder 40 to a mixing screw 42. If the insulation is to be cross-linked chemically, then a cross-linking agent, such as peroxide is supplied from a peroxide reservoir 44 through a metering pump 46 to the insulating material which is being advanced by the mixing screw 42. The insulation and the peroxide are thoroughly blended in a blender 48 from which the insulation is advanced through a chamber 50 to the extruder 38.

Beyond the extruder 38, the conductor with the insulation applied to it travels through an emission shield applicator 52 in which the second emission shield 20 is applied over the insulation 16. The insulation shield 22 is then extruded by an extruder 54 over the outer emission shield 20 and the cable continues its travel through a continuous vulcanizer and curing apparatus 56. Heat is applied to the cable in the apparatus 56 for the purpose of vulcanizing the neoprene and Hypalon or other materials used for the emission shields, and which require vulcanization or curing. The apparatus 56 also activates the peroxide or other chemically cross-linking ingredients of the insulation, if the insulation is to be cross-linked.

Stations for applying the metal shield 84 and the outer plastic jacket 26 can be located beyond the apparatus 56; but in the illustration of FIG. 5 the cable is shown winding on a take-up reel 58, driven by suitable motor means (not shown) and if a metal shield and outer jacket are to be applied, this is done in a subsequent operation.

The preferred embodiment and some modifications have been illustrated and described, but other modifications can be made and different features can be used in other combinations without departing from the invention as defined in the claims.

What is claimed is:

1. An electric power cable including in combination a conductor, a conductor shield surrounding the conductor, insulation around the conductor shield, the shield including an inner layer made of semi-conducting material and the shield having an outer layer of material that prevents emission of electrons into the insulation from regions of high electrical stress in the semi-conducting inner layer.

2. The electric power cable described in claim 1 characterized by the material of the semi-conducting shielding layer being made with electrically conducting material dispersed through the inner layer and with some non-uniformity in the dispersion of the conducting material through the other material of the inner layer of said shield, the said emission shielding layer serving to prevent electron emission into the insulation from regions of higher than average concentration of the conducting material in the semi-conducting layer.

3. The electric power cable described in claim 1 characterized by the insulation being polmeric material of low dielectric constant, and the emission shielding layer of the conductor shield being of material having a dielectric constant higher than that of the insulation.

4. The electric power cable described in claim 3 characterized by the emission shielding layer being made of flexible material and having a dielectric constant several times as great as that of the insulation.

5. The electric power cable described in claim 4 characterized by the dielectric constant of the emission shielding layer being more than five times that of the insulation.

6. The electric power cable described in claim 1 characterized by the emission shielding layer being made of material from the group consisting of neoprene, chlorosulfonated polyethylene and polyethylene filled with titanium dioxide compounds.

7. The electric power cable described in claim 6 characterized by the neoprene, chlorosulfonated polyethylene and polyethylene compounds being free of carbon black and other electrically conducting ingredients.

8. The electric power cable described in claim 1 characterized by the emission shielding layer being adhered to the semi-conducting inner layer of the conductor shield and being flexible for bending with the cable, said emission shielding layer being between 5 and 25 mils in radial thickness.

9. The electric power cable described in claim 1 characterized by the insulation being made with contaminants and other imperfections limited in size to 0.003 inch in diameter whereby the breakdown stress in volts per mil of insulation thickness is substantially increased.

10. The electric power cable described in claim 9 characterized by the insulation being from the group consisting of polyethylene and cross-linked polyethylene.

11. The electric power cable described in claim 1 characterized by an insulation shield around the outside of the insulation including an emission shielding inner layer in contact with the insulation and a semi-conducting outer layer, the emission shielding layer of said insulation shield being made of material that is free of electrical conducting particles, a metallic shield around the semi-conducting outer layer of the insulation shield, and a plastic outer jacket around the metallic shield for mechanical protection of the metallic shield.

12. The electric power cable described in claim 11 characterized by the insulation being an extruded insulation with contaminants and other imperfections limited in size to 0.003 inch in diameter.

13. The electric power cable described in claim 11 characterized by the insulation being of substantially greater radial thickness than the emission shielding layers.

14. The electric power cable described in claim 1 characterized by the insulation being made of material from the group comprising polyethylene and cross-linked polyethylene, and the dielectric constant of the insulation being substantially less than that of the emission shielding layers.

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