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Kubo

[11] **3,736,364**

[45] **May 29, 1973**

[54] **ELECTRIC POWER TRANSMISSION CABLE WITH EVAPORATIVE COOLING SYSTEM**

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[21] Appl. No.: **257,622**

[30] **Foreign Application Priority Data**

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June 22, 1971 Japan 46/41576

[52] **U.S. Cl.** ....**174/11 R**, 165/105, 174/14 R, 174/15 C

[51] **Int. Cl.** **H01b 7/34**

[58] **Field of Search** ....174/11 R, 14 R, 15 C, 174/15 R, 16 R; 165/105, 45; 62/514

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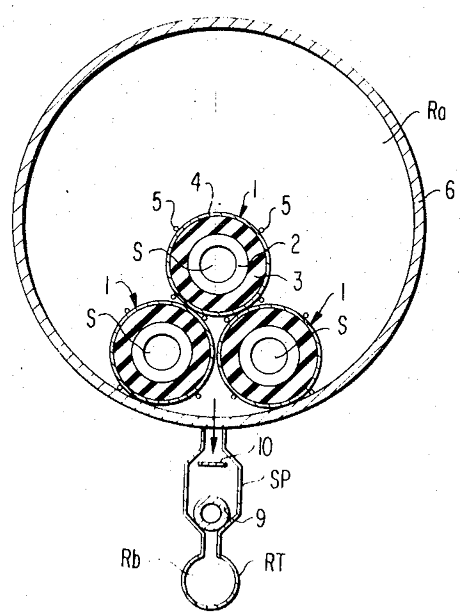
[57] **ABSTRACT**

This invention provides an electric power transmission cable with an evaporative cooling system in which a valve device is provided to separate the vapor phase coolant from the liquid and vapor phase mixture coolant or to control the amount of the whole coolant. The cooling system is divided into two types, that is, an R type arrangement and an L type arrangement. In the R type arrangement, an insulating layer is pervious to gas, and the coolant penetrates the insulating layer to flow out of the cable conductor, thus evaporative cooling may be accomplished in the radial direction during the process of the penetration. In the L type arrangement, the coolant circulates in the longitudinal direction to gradually become a gas-liquid mixture and finally a vapor phase coolant, thereby accomplishing refrigeration. The valve device according to this invention may function to separate the vapor phase from the liquid and vapor phase mixture coolant, and also to control the amount of the whole coolant in either the R or L type arrangement.

9 Claims, 14 Drawing Figures



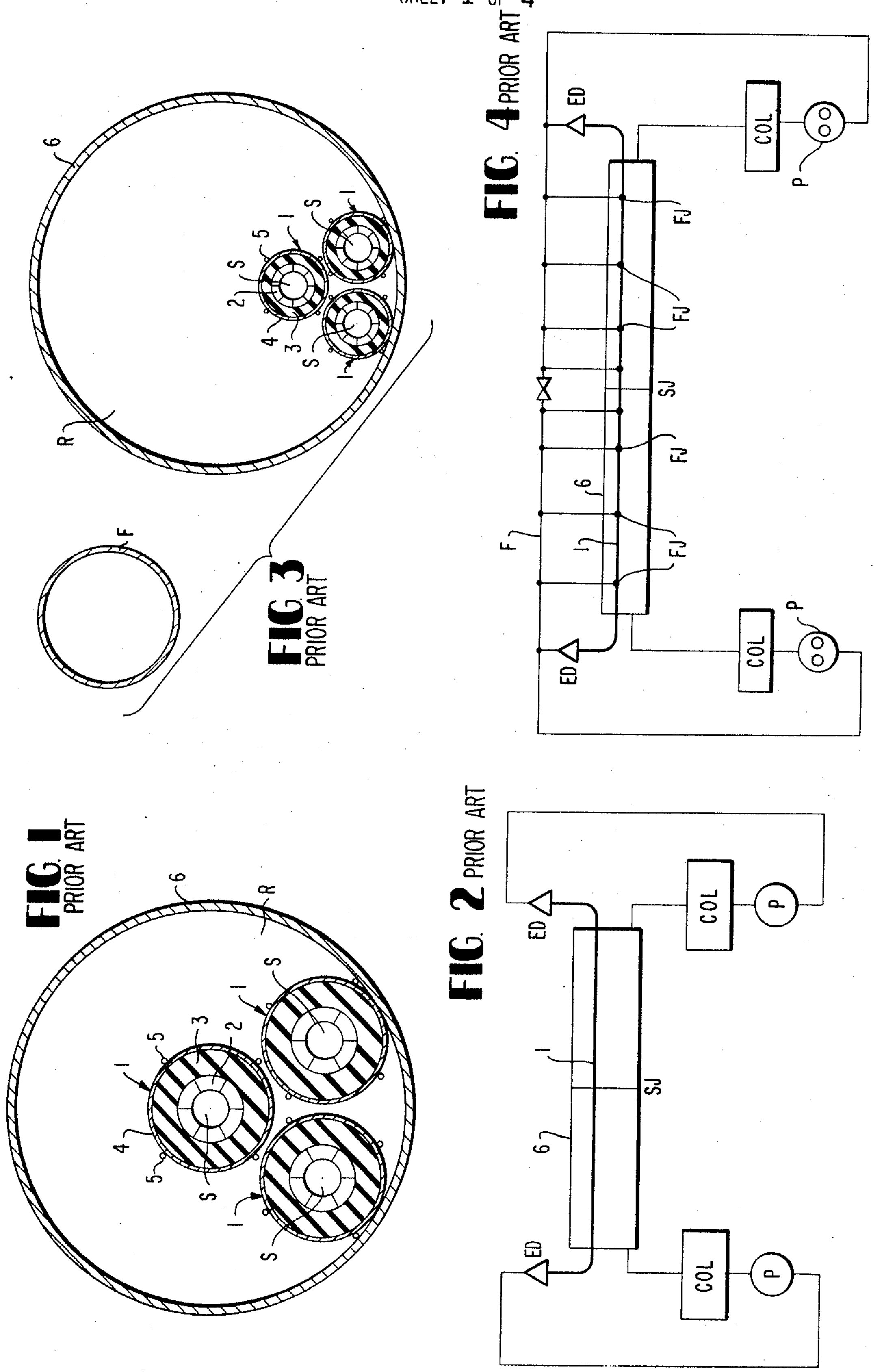


FIG 1 PRIOR ART

FIG 2 PRIOR ART

FIG 3 PRIOR ART

FIG 4 PRIOR ART

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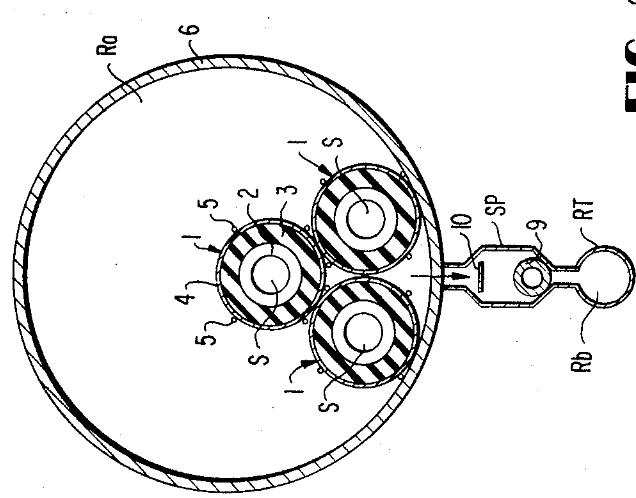


FIG. 7

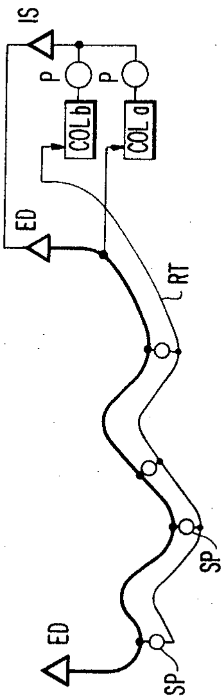


FIG. 8

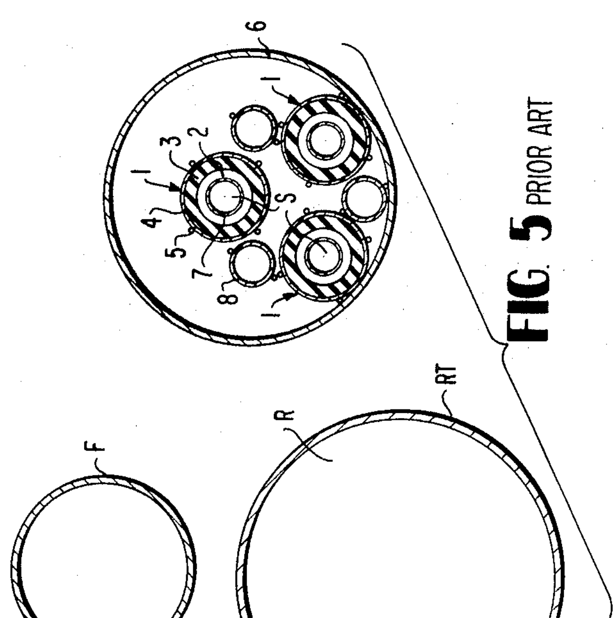


FIG. 5 PRIOR ART

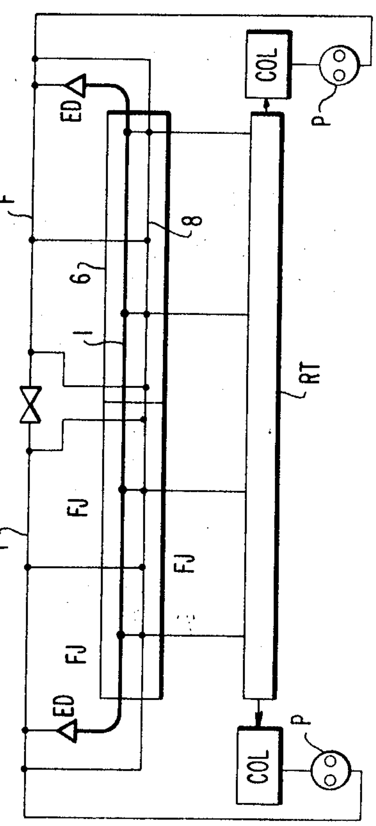


FIG. 6 PRIOR ART

FIG 9

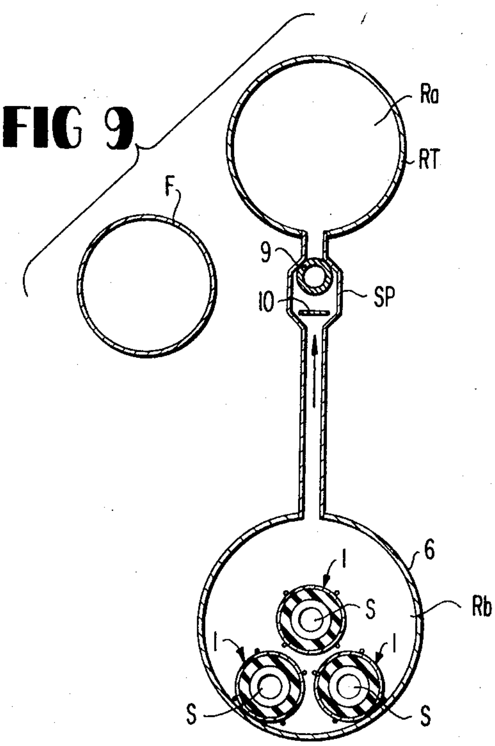


FIG 10

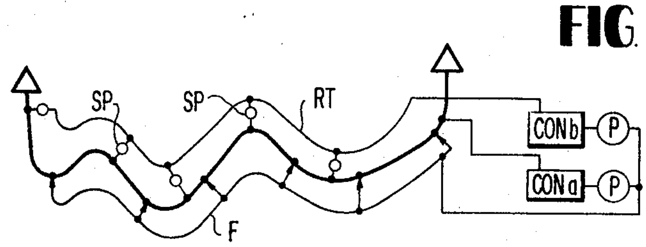


FIG 11

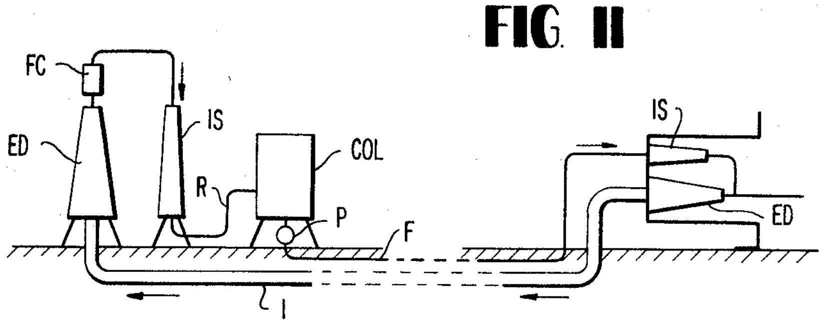
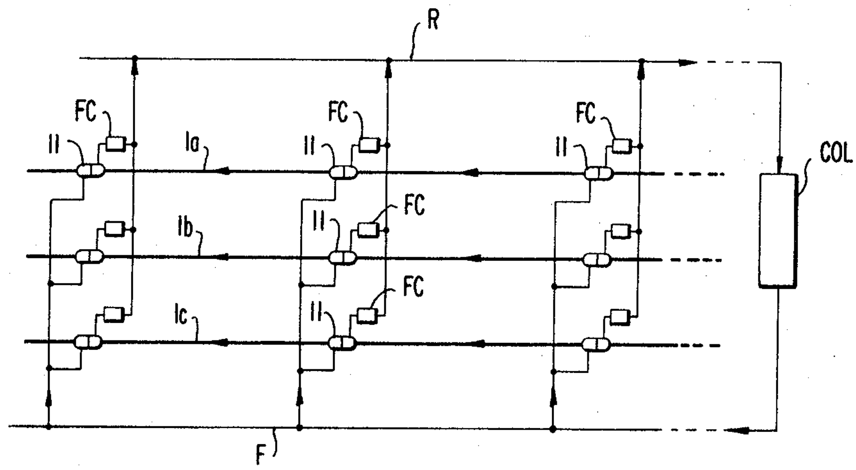


FIG. 12



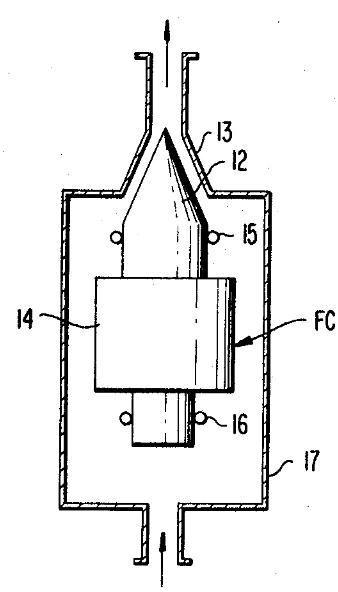


FIG. 13

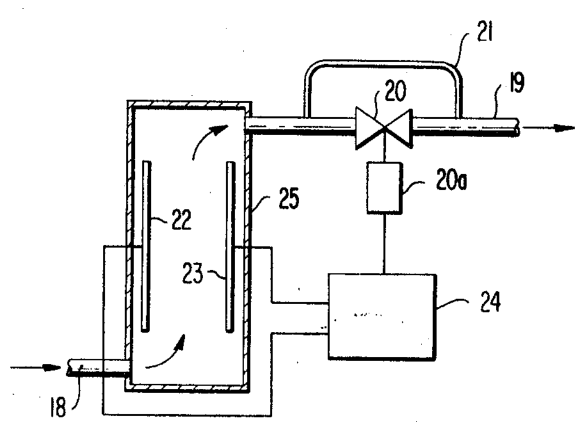


FIG. 14

ELECTRIC POWER TRANSMISSION CABLE WITH EVAPORATIVE COOLING SYSTEM

BACKGROUND OF THE INVENTION

1. Field of the Invention

The present invention is directed to an electric power cable with an evaporative cooling system, and more particularly to an electric power cable, the cooling of which may be effected by the evaporation of an insulating and liquescent gas coolant.

2. Description of the Prior Art

It has already been proposed and practiced in the prior art to provide an evaporative cooling system by utilizing freon or sulfur hexafluoride (SF6), which is an insulating and liquescent gas coolant, for various electric apparatus such as, for example, a power transformer. Application of such an evaporative cooling system to an electric power cable, however, has not been achieved in practice. This may be due to the existence of substitute techniques, such as, for example, forced cooling by water from the outside of the cable or oil circulation at the interior of the center channel of the cable. More and more, however, higher capacity power cables have been required recently.

In order to meet such demand, I have conducted research in the practical application of an evaporative cooling system to power cables of higher capacity than permitted by the limitations in the prior art systems, such as a water cooled cable, with the result that, though there is no particular problem in the practice of evaporative cooling for a cable of comparatively short range, that is, 100 to 200 meters, problems are encountered in a power transmission cable of medium or long range, i.e., more than 500 meters. For example, it has been found that when transmission of great amounts of power, such as 500 KV, 8,000 to 12,000 A, is required at 5,000 meters' distance, problems in practice arise from the economic point of view and from cable laying conditions. These problems will be described in detail hereinafter.

Generally, in the evaporative cooling of a cable, it is desirable to make the coolant contact the cable conductor directly. Accordingly, there is usually provided in the center of the conductor a channel for the passage of the cooling agent, and liquid phase coolant is directed into a high voltage conductor via an insulating coupling from one end, via desirable portions of the cable, or via one end or desirable portions of a unit cooling section. When the laying length of the cable is longer and there are not sufficient dimensions for a coolant path in the conductor, it may be possible to supply the coolant into the conductor through feeding joint portions. This kind of electric power cable with an evaporative cooling system may be classified roughly into two types according to the arrangement for treatment of the vapor phase cooling agent generated in the conductor, that is, an R type arrangement and an L type arrangement.

The R type arrangement is a system in which the insulating layer is pervious to gas, and the coolant penetrates the insulating layer to flow out of the conductor. Evaporative cooling may be accomplished during the process of the penetration; consequently, the interior of the conductor is usually filled only with liquid phase coolant and is maintained under higher pressure than the outer side of the insulating layer, thereby resulting in approximately uniform flow-out throughout the complete length of the cable.

The R type arrangement is available for the insulated cable type which has a wrapped tape insulating layer or a gas insulating layer with insulating spacer.

On the other hand, in the L type arrangement, the coolant does not flow out through the insulating layer but circulates in the longitudinal direction to gradually become a gas-liquid mixture and finally a vapor phase coolant, thereby accomplishing the refrigeration.

As a further example, various arrangements could be made between the R and L type arrangements, and there is no essential difference among them for cooling function. In every case, the coolant path in the conductor may be termed the "out-going path" or "feeding pipe," wherein the coolant directed into the conductor from refrigerating devices may flow to the top end of the cable to be cooled. The outside of the insulating layer should be termed the "in-coming path" or "return pipe," whereby the vaporized coolant returns to the refrigerating device. Thus, the coolant circulates along the interior and along the exterior of the conductor.

Generally, since the out-going path is formed within the insulating layer such as, for example, in the inside of the conductor, there is a limitation on its dimensions due to cable fabrication. It may be, therefore, more desirable for the evaporative cooling of a long range cable to provide an auxiliary supply pipe parallel to the cable and to connect the auxiliary supply pipe to the coolant path in the cable through feeding joints in every appropriate unit section. Since common steel pipes can be utilized for the auxiliary supply pipe, it is very easy to obtain pipe having a diameter large enough to supply the coolant required.

In the case of pipe type cable, the steel pipe in which the cable is placed can be used for in-coming path, and it is also possible to provide, as the auxiliary supply pipe mentioned above, an auxiliary steel pipe having larger diameter.

FIG. **1** to FIG. **6** illustrate three examples of the application of an evaporative cooling system to a high power transmission line designed for 500 KV, 12 KA at a distance of 5 kilometers. Compressed Gas Insulation Spacer Cable (C.G.I. cable) is also applicable as an evaporative cooling system for a high capacity transmission line, although it is not shown in these examples. Every cable line is provided with two refrigerating devices, one at each end.

FIG. **1** and FIG. **2** illustrate the simplest arrangement of an R system using freon-12 ($C\ Cl_2\ F_2$) as the coolant. The out-going path S in which liquid phase coolant flows is formed in the inside of a conductor **2** of a cable **1**. Reference numeral **3** designates an insulating layer, and numeral **4** denotes an outer shielding and mechanical reinforcement layer. Reference numerals **5** and **6** designate, respectively, skid wires and a steel pipe which is utilized for the in-coming path R. At the mid-point of the steel pipe **6** and the cable **1**, a stop joint SJ is provided to form cooling circulation paths including refrigerating devices COL and pumps P in the left and right sides thereof. The coolant may circulate in the direction indicated by the arrows. Reference character ED designates a terminal box. The dimensions of the respective portions are as follows: internal diameter of the conductor - 180 mm; external diameter of the conductor **2** - 220 mm; external diameter of the insulating layer 3 - 320 mm; finished external diameter - 330 mm; and internal diameter of the steel pipe 6 - 1,000 mm. A novel arrangement for fabrication and layering of the cable may be required because of the thickness of the cable.

FIG. 3 and FIG. 4 illustrate another arrangement of an R system in which a cable having a smaller diameter than that of the cable described above is used, so that fabrication and transportation thereof is possible with ordinary equipment. In FIGS. 3 and 4, like reference numerals and characters designate parts corresponding to those shown in FIG. 1 and FIG. 2. Since the outgoing path S is smaller, a feeding pipe F is provided in parallel with the cable line and is connected to the coolant path in the cable 1 through feeding joints FJ provided in every 800 m. In this case, we can consider that the feeding pipe F is an out going path provided on the outer side of the conductor. The dimensions of the respective portions are as follows: internal diameter of the conductor 2–70 mm; external diameter of the conductor 2–160 mm; internal diameter of the steel pipe 6–800 mm; and internal diameter of the feeding pipe F-300 mm.

FIG. 5 and FIG. 6 illustrate an arrangement of the L type system in which the insulating layer 3 is composed of oil impregnated paper separated from the coolant by an air-tight pipe 7 disposed inside of the conductor 2. The steel pipe 6 is filled with insulating oil. The coolant is directed into the air-tight pipe 7 from the terminal box ED through a feeding joint FJ. There is provided a return pipe RT which performs the roll of the incoming path, and through which the coolant returns. The coolant flows out from another feeding joint, which functions as an outlet for the coolant, and returns through the return pipe RT to the refrigerating device COL wherein the vapor phase coolant is liquefied. Reference numeral 8 designates a cooling pipe which refrigerates the outside of the cable 1, and in which the coolant flows in parallel with the cable 1. When the feeding joints FJ are separated by a distance of 400 meters, the dimensions of the respective portions are as follows: internal diameter of the air-tight pipe -70 mm; external diameter of the conductor 2-100 mm; external diameter of the insulating layer 3-150 mm; finished external diameter of the cable 1-160 mm; internal diameter of the steel pipe 6-500 mm; internal diameter of the supply pipe F-300 mm; internal diameter of the return pipe RT-550 mm; internal diameter of the cooling pipe 8-70 mm; and external diameter (corrugation) of the cooling pipe -80 mm.

The operating conditions have been discussed about these three examples of the evaporative cooling system with the result that unexpected temperature rising and/or local temperature rising tend to occur in the state where the whole coolant is vaporized completely, and consequently it is required to maintain some unvaporized portion of the coolant. Generally, a large amount of current often occurs in a cable. In such case, if the flow control for the coolant does not have good response characteristic, it may be over-heated in the portion where there is only vapor phase coolant. Therefore, the safest and simplest design is one in which the amount of circulating coolant corresponds to the maximum calorific value. Furthermore, the flow control should be such that at least a small amount of liquid phase coolant remains except under full load condition. That is, in the in-coming path, even if there is only vapor phase coolant under the maximum calorification, a gas-liquid mixture of coolant should flow under normal condition. It may be, however, often the case that a cable has undulations in its laying state, or the refrigerating device must be installed at higher place than the cable. When the cable has undulations, the unvaporized portion of coolant or liquid phase coolant may collect in the lower portion of the cable. Although the collected coolant is not any inconvenience electrically, there should be enclosed a margin of coolant at least equal to the quantity of collected coolant. For example, in the instance shown in FIG. 1, when there is lower portion of 1 Km of length, the amount of the coolant supplied in the portion may be approximately 700 m^3, assuming that the internal diameter of the steel pipe 6 is 1,000 mm. Thus, the amount of coolant required to fill the lower portion may become much larger than for the case in which the lower portion is filled with only vapor phase coolant. This is very uneconomical; that is, for example, if the unit price of the liquid phase coolant is about $1.62 per liter, 700 m^3 of the coolant would cost approximately $ 1.134 million. Furthermore, the coolant gathered in the lower portion may prevent the circulation of the coolant depending on the laying condition of the cable, thereby resulting in overheating and damage to the insulation due to insufficiency of cooling at maximum current.

It has also been recognized that during the coldest season, when little current flows in the cable, the pressure of the coolant in the cable may decrease due to lowering of the temperature of the whole cable, thereby raising the problem of the insulating power of the cable. One solution to the problem is to make the dimensions of the cable larger; however, this is very uneconomical. The three examples described above are designed for the following conditions: 1) the cable is laid underground; 2) flow is utilized as coolant; 3) the pressure of the coolant is above 5 Kg/cm^2. The cable is not, however, necessarily always laid underground; that is, the cable is often laid on or deeply under the ground where very low temperatures may occur. Consequently, the pressure of the coolant may decrease further in those cases. On the other hand, it has become apparent that, if the pressure of the coolant could be maintained at more than 10 or 15 Kg/cm^2, those three examples mentioned above may be designed more compactly.

In the L type arrangement shown in FIG. 5 and FIG. 6, when the laying length of the cable is long, it is difficult to cool the whole length of the cable by means of a single circulation of the coolant. Accordingly, it may be advantageous to divide the circulation path into plural circulating sections, wherein a plurality of cooling pipes may be connected in parallel for the circulation of the coolant. In that case, if every cooling section is not provided respectively with a flow control device, an increase in the amount of liquid phase coolant may occur only in a certain section when an unexpected rise in temperature occurs in the section. Thus, flow resistance in the circulation path will increase, that is, the amount of flow of circulating coolant will decrease; therefore, cooling will be even further reduced in the section, thereby resulting in a malfunction.

This phenomenon is specific to an evaporative cooling system, and it is the point which discriminates the evaporative cooling system from other types of cooling systems, such as circulation cooling by refrigerating oil.

In the case of circulating cooling by insulating oil, the more the temperature rises, the more the viscosity of the oil decreases, and becomes fluidal naturally so as to keep the temperature rise at a minimum.

By contrast, in the evaporative cooling system, the amount of liquid phase coolant increases as temperature rises. Since the density of the liquid phase coolant is smaller, the flow resistance becomes larger for the flow of same amount of the coolant, that is, the amount of coolant flow decreases substantially. This leads to a shortage of cooling and dangerous results. In order to prevent such an inconvenience, it may be required to make the lengths of the respective cooling sections approximately the same as well as to increase the amount of coolant flow so as to give a margin in cooling capacity.

From the foregoing, it is apparent that in a long range electric power transmission cable both the R and L type arrangements have some inconveniences. These inconveniences are ultimately due to the specific operation principle of an evaporative cooling system in which the coolant circulates in the state of a gas-liquid mixture.

SUMMARY OF THE INVENTION

Therefore, noticing the specific phenomenon of an evaporative cooling system, I have provided an economically improved evaporative cooling system for a long range power transmission cable, which system features a novel valve device. More specifically, the valve device is provided in the in-coming path of the coolant so as to operate in response to the amount of liquid phase or vapor phase coolant in the cooling circulation path.

In accordance with the present invention, the valve device is used in two ways; that is, 1) the valve device is used to separate the vapor or liquid phase from the vapor and liquid mixture phase as much as possible, and 2) it is used to control the amount of flow of the whole coolant when in the state of a gas-liquid mixture. The former is applicable both to the R and L type arrangements, and the latter is applicable only to the L type arrangement.

The objects, features and advantages of the present invention will become more apparent from the following description when taken in connection with the accompanying drawings.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 to FIG. 6 illustrate the principle of a cable with an evaporative cooling system, wherein:

FIG. 1 is a cross-sectional view of an embodiment of a cable in the R type arrangement;

FIG. 2 is a schematic illustration of a cooling system using the cable shown in FIG. 1;

FIG. 3 is a cross-sectional view of another embodiment of a cable in the R type arrangement;

FIG. 4 is a schematic illustration of a cooling system using the cable shown in FIG. 3;

FIG. 5 is a cross-sectional view of an embodiment of a cable in the L type arrangement, and

FIG. 6 is a schematic illustration of a cooling system using the cable shown in FIG. 5;

FIG. 7 to FIG. 14 illustrate the embodiments of a novel and improved cable with an evaporative cooling system in accordance with the present invention, wherein:

FIG. 7 is a cross-sectional view of an embodiment of a cable in the R type arrangement;

FIG. 8 is a schematic illustration of a cooling system using the cable shown in FIG. 7;

FIG. 9 is a cross-sectional view of another embodiment of a cable in the R type arrangement;

FIG. 10 is a schematic illustration of a cooling system using the cable shown in FIG. 9;

FIG. 11 is a schematic illustration of a cooling system in the L type arrangement having a single cable and a single cooling section;

FIG. 12 is a schematic illustration of another cooling system in the L type arrangement having a plurality of cables and a plurality of cooling sections;

FIG. 13 is a cross-sectional view of the structure of a valve device for the cooling systems shown in FIG. 11 and FIG. 12; and

FIG. 14 is a schematic illustration of another valve device for the cooling systems shown in FIG. 11 and FIG. 12. The valve devices shown in FIG. 13 and FIG. 14 may be used with other evaporative cooling systems.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

First, there will be described embodiments of the invention for the R type arrangement in which there are provided a plurality of in-coming paths and valve devices used to separate the vapor phase from the gas-liquid mixture phase coolant, thereby efficiently accomplishing recovery of the coolant.

Referring to FIG. 7 and FIG. 8, cables **1** are placed in a steel pipe **6** which provides an in-coming path Ra for the vapor phase coolant. A return pipe RT which is part of the in-coming path provides an in-coming path Rb for the liquid phase coolant. A plurality of valve devices SP are provided between the in-coming paths R*a* and R*b*. Each valve device SP may be of any type which can separate the vapor phase from the liquid phase coolant. Differences in properties, such as density, viscosity, heat conductivity, or dielectric constant, may be utilized for detection or control.

In this embodiment, a float valve is used as an example of making use of the difference in density. The float valve is simple and practical because it does not require any additional outside power source. The float valve comprises a ball shape float **9** and stopper **10.** When the unevaporated liquid phase coolant in the steel pipe **6** flows into the valve device SP, the ball shape float rises up to cause the coolant to flow into the return pipe RT. The stopper functions to prevent the float **9** from closing the entrance of the device. The valve device may be located in any place, however, it is desirable that it be provided in lower portion of the cable.

A main refrigerating device COL*a* is provided primarily for the in-coming path R*a*, and an auxiliary refrigerating device COL*b* for the in-coming path R*b*. Both the refrigerating devices COL*a* and COL*b* supply the liquid phase coolant into the out-going path S in the cable **1** from terminal boxes ED through an insulating coupling IS by pumps P. In order to facilitate direction of the liquid phase coolant into the return pipe RT, the cooling temperature of the auxiliary refrigerating device COL*b* is kept lower than that of the main refrigerating device COL*a*, or the pressure in the return pipe RT is kept lower than that in the steel pipe **6** by utilizing a blower.

When the dimensions of other portions are the same as for the system shown in FIG. 1, an approximately 200 mm internal diameter is sufficient for the return pipe RT. Accordingly, even if the liquid phase coolant fills up the full length of 5 Km of the return pipe RT, the total amount of the coolant would be $150m^3$ at the most, which is approximately 20 percent of the $700m^3$ in the example described above, and, therefore, the improved system is economical enough for practical applications. Besides, even for a cable portion laid in lower place, since the steel pipe if filled only with vapor phase coolant, circulation of the coolant will not be prevented.

Since imperfection of the separating function in the valve device SP does not matter for practical usage, it is possible to use such a simple float valve. However, when a fractionating device having a relatively complete separating function produced by a pump or the like is employed, a return pipe RT having an internal diameter as small as 100 mm may be sufficient.

The dielectric strength depends upon the pressure of the coolant in the steel pipe **6**. Accordingly, as mentioned above, under light load in the coldest season, the temperature in the cable decreases, thereby reducing the pressure of the coolant and decreasing the insulating power. Though there have been proposed several different means for preventing this inconvenience, one easy solution is to heat the coolant on its way from the refrigerating device to the interior of the cable through the pump so that the heated coolant in the liquid phase or the gas-liquid mixture increases the temperature of the cable. Even when the cable is heated in this manner, it is necessary to maintain the amount of circulating coolant at the predetermined value. However, it may be practically impossible to heat the cable at its terminal portion in the prior art cable which does not have an individual in-coming path Rb through which the coolant returns to the pump in the liquid phase state as occurs in the present invention, because in the cable of the prior art the returning of the coolant takes place only in the vapor phase and consequently the evaporative cooling is inevitably affected.

It is possible to omit the installation of the return pipe RT at the elevated portion in the terminal end of the cable, because the unevaporated part of the coolant will not collect there. However, the return pipe RT should be provided in the portion of the cable in which the unevaporated coolant collects abundantly, to avoid the otherwise resulting increased cost for additional coolant or increased resistance to the circulation of the coolant.

Referring now to FIG. **9** and FIG. **10**, there is illustrated another embodiment of the R type arrangement according to the present invention. In contrast to the embodiment shown in FIG. **7** and **8**, the steel pipe is made as thin as possible to function as the in-coming path for the liquid phase coolant, and the return pipe RT is the in-coming path for the vapor phase coolant. The valve device SP will close when the liquid phase coolant rises up and will open when only the vapor phase coolant rises up. This embodiment corresponds to the embodiment shown in FIG. **3** and **4**, and the dimensions of the respective portions are as follows: internal diamter of the steel pipe -400 mm; internal diamter of the supply pipe F-300 mm; and internal diameter of the return pipe RT-500 mm.

In order to increase the dielectric strength, it may be convenient to provide a pressure regulating valve between the main refrigerating device and the steel pipe **6** so as to maintain the pressure in the steel pipe **6** at a predetermined value. In this embodiment, since it is possible to apply pressure by means of the pump P, the inconvenience may be eliminated without heating the coolant in the coldest season.

From the foregoing, it is apparent that the electric power transmission cable line with an evaporative cooling system according to the present invention eliminates the problems of undulation in cable laying and obstruction of circulation of the coolant due to the gathering of the unevaporated liquid phase coolant in the lower cable portions resulting from installation of the refrigerating device in a higher location. Since the diameter of the in-coming path for the liquid phase coolant cable is made smaller, efficient cooling is economically obtained at the expense of only a relatively small increase in the amount of coolant flowing through the in-coming path. Furthermore, it is easier to increase the pressure of coolant for the cable so as to increase the dielectric strength to permit the cable to be designed compactly and independently of the cable laying conditions.

The present invention is not limited to the embodiments described above but is also applicable to the example shown in FIG. **5** and **6**. The term "electric transmission cable" includes all kinds of insulated wire for electric energy transmission such as, for example plastic tubing insulated cable, compressed gas insulation spacer cable, bus duct, and various types of bus. Furthermore, it is also possible to provide several incoming paths, some portions of which are used as the incoming path for liquid phase coolant and others for vapor phase coolant.

Next, there will be described the embodiments of the invention for the L type arrangement in which the valve device is used to control the amount of flow of the whole coolant. These embodiments provide the means for solving the specific problems of the L type arrangement.

FIG. **11** illustrates an embodiment having a single cooling section for a single cable section. Reference numeral **1** designates a cable, and the reference character ED denotes terminal boxes. Character FC designates a flow control valve device, and reference character IS denotes insulating couplings. Reference character R denotes a returning pipe, and character COL designates a refrigerating device. Reference character P denotes a pump to circulate the coolant, and character F designates a feeding pipe.

The coolant is condensed in the refrigerating device COL and is circulated by the action of the pump P via feeding pipe F through the right hand terminal box ED and insulating coupling IS, the left hand terminal box ED, flow control valve device FC, the left hand insulated coupling IS, return pipe R, and back to refrigerating device COL, thus cooling the cable I. In the electric power transmission cable with the evaporative cooling system, as the amount of circulating coolant decreases and cooling begins to become insufficient, the amount of vapor phase increases in the coolant flowing out of the outlet of the cable **1**. Furthermore, when all the liquid phase coolant has evaporated, the temperature of the cable starts to increase. On the other hand, when the amount of circulating coolant is excessive, the amount of liquid phase is larger and the vapor phase smaller. Therefore, when the ratio of the liquid phase to the vapor phase is appropriate, cooling is accomplished most efficiently with the minimum amount of coolant circulation.

In order to satisfy the condition, the valve device according to the present invention may control the amount of flow automatically, that is, when the amount of vapor phase coolant becomes larger, the valve device operates to increase the amount of circulating coolant. FIG. 13 shows a cross-sectional view of an embodiment of such a valve device in which reference numerals **12, 13, 14, 15, 16** and **17** respectively designate in the order of the numerals, a valve, a valve seat, a float, guide ring (both **15** and **16**), and a valve casing. The coolant is directed to flow into the valve device from the outlet of the cable in the direction of the arrows. The float **14** rises up and falls down on the liquid phase coolant, thereby opening and closing the valve **12** to control the amount of flow of coolant. However, there is no necessity of closing the valve **12** completely, but it is rather desirable to permit the coolant to flow in the minimum quantity. The reason for this is that when the flow control unit is placed in the higher position of the cable **1** as shown in FIG. **11**, it doesn't matter anyhow. However, when it is located in other places, there must be flow of coolant to some extent even in the case of no heat generation. That is why there may be a time delay until the vapor phase coolant evaporated by an abrupt generation of heat reaches the flow control unit resulting in blunting the response to abrupt change in load current.

This type of flow control unit tends to be affected by the flow rate of the coolant. Consequently, it is required to reduce the flow rate in the vicinity of the float **14**; therefore, the valve casing **17** should desirably be made in relatively larger size. It is also required for the valve not to be affected by the pressure difference in its opening and closing operation when the valve **12** is closed and the pressure in the valve casing **17** is higher than that in the returning pipe R connected to the upper portion of the valve device; therefore, the buoyancy of the float **14** should be larger.

Referring to FIG. **14**, there is an illustration of another embodiment of the flow control unit according to the present invention, in which the coolant flow, as indicated by the arrow, from an entrance pipe **18** to the returning pipe R (shown in FIG. **12**) through a vessel **25** and via an outlet pipe **19.** The amount of flow is regulated by a magnetic value or electric valve **20**, and a by-pass pipe **21** is provided to secure a minimum amount of coolant flow. An operating unit **20***a* for the magnetic or electric valve **20** is controlled by the output from an electrostatic capacity detection device **24** which detects an electrostatic capacity between the opposing electrodes **22** and **23** between which the coolant flows in the vessel **25.** The dielectric constant of the liquid phase coolant is in the range of 1.7 to 6.2 and for the vapor phase is in the range of 1.01 to 1.03, depending upon the kind of coolant. Accordingly, the amount of vapor phase coolant can be detected by measuring the electrostatic capacity between the electrodes **22** and **23.** In the case of using, for example freon –12 as coolant, if the valve **20** is set to open fully when the dielectric constant is approximately 1.0 and to close completely when approximately 1.7, the amount of coolant flow will be regulated automatically as in the embodiment shown in FIG. **13.** Although the flow control unit of this embodiment needs an external power supply, the advantage of this unit is that it is not affected by the flow rate of coolant or difference of pressure.

Referring to FIG. **12**, there is an illustration of another embodiment of the evaporative cooling system in an L type arrangement according to the present invention, in which the circulation path is divided into a plurality of circulating sections, and the coolant circulates in parallel. A three-phase transmission cable I includes three cables **1***a*, **1***b* and **1***c*, each of which is connected by way of feeding joint boxes **11.** The section between two feeding joint boxes forms a unit circulating section. Comparing FIG. **12** with FIG. **5** and **6**, the three incoming paths S in FIG. **5** correspond to the three cables **1**a, **1**b and **1**c in FIG. **12** from the view point of the coolant circulation path. Though the three cooling pipes **8** in FIG. **5** are not shown in FIG. **12**, it should be understood that there is not any essential difference between them but just a difference in number of circulation paths. In the respective cooling sections, the coolant is supplied in parallel from the feeding pipe F, which is part of the out-going path, through the feeding joint junction boxes **11** as indicated by the arrows, and is returned from the other feeding joint boxes, which function as outlets for the coolant, through the flow control valve device FC to the return pipe R which is part of the in-coming path, and then condensed in the refrigerating device COL. If this invention is applied to a C.G.I. cable, the insulating gas area may be useful as the returning pipe R. As described above, the flow control unit operates so as to increase the amount of coolant flow as the amount of the vapor phase coolant increases. Therefore, even if an increase of the amount of heat generation occurs only in a certain section, the amount of coolant circulation will increase automatically only in that section resulting from increase of vapor phase due to the heat generation. Thus, efficient cooling may be accomplished in the whole cooling system so as to prevent a malfunction.

With the provision of the valve device which controls the amount of circulating coolant in correspondence to the amount of vapor phase coolant, the present invention accomplishes an efficient cooling, and thus the capacity of the pump for coolant circulation can be reduced to approximately one-third. In the case of cooling in divided sections, since the distribution of the amount of flow to the respective sections corresponds automatically to the amount of heat generation therein, cooling of the cable is carried out uniformly in every section. The valve device in the embodiment shown in FIG. **13** does not need any external power source; accordingly an unattended cooling system can be provided by utilizing this valve device. The valve device can easily be placed in the high voltage charging portion of the cable.

The reason why the flow control unit is provided at the outlet side from cable conductor is as follows. If the flow control unit is placed in the entrance side of the cable conductor so as to control the amount of coolant flow, the control of the cooling circulation must be carried out by detection of the current in the cable by means of a current transformer or the like, or by detection of the temperature in the outlet side from cable conductor. In those cases, the control system may become complicated due to a long distance between the detection part and control part. Besides, when the valve installed in the entrance side is closed, the liquid phase coolant decreases, and the vapor phase coolant increases. Consequently, the temperature may exceed the permitted limit temporarily during the abrupt flow of large current. These are so undesirable that the flow control unit should be installed in the outlet side of the cable conductor. In the embodiment shown in FIG. **12**, the coolant is in the state of a gas-liquid mixture in the returning pipe R. Accordingly, the valve device can be operated so as to separate the vapor phase from the liquid phase coolant. Thus the valve device may function both as a fractionating device and as a flow control device for an electric power transmission cable.

It is most desirable to use the valve device for these two functions in a long range cable having undulations in an L type arrangement. In FIG. **12**, even though only one valve device is shown for each respective cooling section, it is needless to say that two or more devices can be used to reduce the vapor content of the coolant in the out-going path through the whole length of a cooling section.

The invention providing many valve devices in a cooling section is useful to cool the C. G. I. cable. As such a cable usually has a large diameter conductor, a parallel out-going path, such as feeding pipe F in FIG. **12** is not usually needed if the vapor content is not so rich. If the vapor content in the out-going path in the conductor of C. G. I. cable is not kept diluted, then a parallel feeding pipe may be needed because the pressure drop for circulation with two phase flow becomes very large.

From the foregoing, it may be readily understood that the present invention provides economically a long range electric power transmission cable with an evaporative cooling system in which specific problems are resolved by using a valve device as described above.

While the invention has been particularly shown and described with reference to the preferred embodiments thereof, it will be understand by those skilled in the art that various changes in form and details may be made therein without departing from the spirit and scope of the invention.

I claim:

1. In an electric power transmission system with an evaporative cooling system having an insulating and evaporative liquid coolant and means for circulating the coolant to cool the cable conductor, a power transmission cable comprising at least one valve device provided in an incoming path for the coolant or the outlet side from cable conductor, the valve device operating so as to open and close in response to the amount of vapor phase or liquid phase of the coolant.

2. A power transmission cable with an evaporative cooling system according to claim **1** comprising a plurality of incoming paths for the coolant, at least one of which is the incoming path for the vapor phase coolant and another of which is the incoming path for the liquid phase coolant, and at least one said valve device coupled between the incoming path for the vapor phase coolant and the incoming path for the liquid phase coolant.

3. A power transmission cable with an evaporative cooling system according to claim **2** in which one of said incoming paths for the coolant is the interior of a pipe in which the cable is placed, and another incoming path for the coolant is a return pipe extending parallel to said pipe.

4. A power transmission cable with an evaporative cooling system according to claim **1** in which said valve device is disposed in the cable conductor outlet side for the coolant, said device operating to increase the amount of coolant flow in response to an increase in the amount of the vapor phase coolant.

5. A power transmission cable with evaporative cooling system according to claim **1** in which said valve device operates to detect the differences in at least one property of the vapor phase and the liquid coolant, the properties being density, viscosity, heat conductivity, and dielectric constant, so as to control the circulation of the coolant.

6. A power transmission cable with an evaporative cooling system according to claim **1** in which the valve device is a float valve comprising a float and a stopper.

7. A power transmission cable with an evaporative cooling system according to claim **1** comprising a pair of electrodes through which the coolant flows, means for measuring the electrostatic capacity between said electrodes, and valve means responsive to said measuring means for controlling the circulation of the coolant.

8. A power transmission cable with an evaporative cooling system according to claim **5** in which the valve device is a float valve comprising a float and a stopper.

9. A power transmission cable with an evaporative cooling system according to claim **5** comprising a pair of electrodes through which the coolant flows, means for measuring the electrostatic capacity between said electrodes, and valve means responsive to said measuring means for controlling the circulation of the coolant.

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