ABSTRACT: An electrical bushing assembly including a hollow electrically conductive member, an electrical lead disposed through the opening in the hollow electrically conductive member, and insulation surrounding the conductive member. The electrical conductive member defines a chamber having a volatile fluid disposed therein which is cycled between its liquid and gaseous phases by the natural temperature differential along the conductive member when the bushing is in service.
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1 ELECTRICAL BUSHING ASSEMBLY WITH
EVAPORATIVE HEAT PUMP DISPOSED BETWEEN
INSULATION AND ELECTRICAL LEAD

BACKGROUND OF THE INVENTION

1. Field of the Invention

The invention relates to electrical bushings for electrical apparatus, such as transformers and circuit breakers.

2. Description of the Prior Art

One of the major problems in the design and application of electrical bushings is hot spot temperature control. In an electrical power transformer, the encased end of the electrical bushing is subjected to the hot transformer oil, and the conductor is heated directly by the FR losses of the current it is carrying.

Transformer windings have a relatively long thermal time constant due to the heat sink provided by the cooling dielectric fluid, enabling the transformer to withstand heavy overload for short periods of time. The bushings, however, do not have as long a thermal time constant. Thus, it is important that the maximum hotspot temperature be controlled to avoid thermal damage to the bushing insulation and gaskets during permissible overloads on the transformer. If the maximum hotspot temperature could be reduced for a given bushing conductor size and current rating, the bushing current rating could be increased accordingly; or, the size of the conductor could be reduced and still maintain the same current rating without exceeding the prior art maximum hotspot temperature.

SUMMARY OF THE INVENTION

Briefly, the present invention is a new and improved electrical bushing assembly for encased electrical apparatus, such as power transformers and power circuit breakers. The electrical bushing assembly includes a hollow electrically conductive member, an electrical lead disposed through the opening in the hollow conductor and electrical insulating means disposed about the electrically conductive member. The electrically conductive member has first and second concentrically disposed tubular members, spaced to define a cavity or chamber between them which contains a volatile fluid. The volatile fluid evaporates from its liquid state to its gaseous state adjacent the high heat input regions of the conductive member, such as at the hotspot of the bushing assembly, absorbing thermal energy according to the latent heat of vaporization of the fluid. The vaporization of the fluid increases the vapor pressure in the region of the cavity or chamber, causing the vapor and its stored heat energy to move to regions of the chamber which are at a lower pressure and temperature. When the vapor reaches the regions of lower temperature, it condenses, releasing the stored thermal energy and reducing the vapor pressure in this region, to maintain the pressure imbalance in the chamber. The condensed liquid then returns to the high-temperature region by gravity, or by a wick disposed in the chamber, depending upon the construction and orientation of the chamber. The volatile fluid efficiently pumps heat from the high-heat input areas of the conductor to areas or regions of the conductor which may more easily dissipate the heat, such as portions of the conductor which extend outside the casing of the apparatus. The temperature gradient along the conductor is substantially reduced, compared with similarly rated bushings of the prior art, reducing the maximum hotspot temperature, compared with these prior art bushings, for the same conductor dimensions and similar current flow.

BRIEF DESCRIPTION OF THE DRAWING

The invention may be more readily understood when considered in view of the following detailed description of exemplary embodiments thereof, taken with the accompanying drawing, in which the single FIGURE is an elevational view, in section, of an electrical bushing constructed according to the teachings of the invention.

DESCRIPTION OF PREFERRED EMBODIMENTS

Referring now to the single FIGURE, there is shown an elevational view, in section, of a bushing assembly 10 constructed according to the teachings of the invention. Bushing assembly 10, which may be used with power transformers or power circuit breakers, includes an axially extending electrical conductor 12 having first and second ends 14 and 16, respectively, and opening 18 which extends between its ends.

Conductor 12 is formed of inner and outer concentrically disposed, spaced tubular metallic members 26 and 28, with the outside diameter of the inner tubular member 26, and the inside diameter of the outer tubular member 28, being selected to provide a chamber 42 having a predetermined volume, which chamber is closed at its lower and upper ends 14 and 16 by members 44 and 46, respectively. A predetermined volume of volatile fluid 50 is disposed in chamber 42, which fluid pumps heat from the hotspot to the cooler portions of the bushing assembly, as will be hereinafter explained.

Bushing assembly 10 is of the feed-through lead type, in which a lead or cable 20 from the encased apparatus is directed through the axial opening 18 in the conductor 12.

An insulating member 22 may be disposed about conductor 12, which section may include capacitor plates 23 if desired. Member 22 may be formed of layers of insulating material having a plurality of spaced metallic foil sheets disposed therein to form the cylindrical capacitor plates 23 to grade the radial and longitudinal voltage distribution in the bushing. The insulating or capacitor section 22 may be formed by winding a high-quality paper on the electrical conductor 12 while under a predetermined uniform tension, and feeding in metallic foil sheets to form the capacitor plates 23 at predetermined intervals to provide a plurality of series capacitors. The capacitor section 22 may be oil impregnated to fill all of the voids in the structure and prevent the formation of corona, and also to provide a minimum power factor to minimize dielectric heating of the structure, or, as illustrated, the capacitor plates 23 may be embedded in a cast solid resin system 26, such as an epoxy resin system. However, whether or not the bushing is of the capacitor type, the principles of the invention may be used.

A grounded metallic flange assembly 28 is disposed intermediate the ends of bushing 10, and adjacent the capacitor section 22, providing means for mounting the bushing 10 through an opening 30 in the casing 32 of a transformer or circuit breaker, with the lower end of bushing assembly 10 extending into the transformer coolant 51, such as mineral oil. An annular groove in the flange and gasket 33 cooperate to seal the opening 30. Shell-like insulating member 24, constructed either of an electrical grade of porcelain having a glazed, corrugated outer surface for providing additional creep distance, or of a suitable resin system, such as an epoxy resin system, is disposed between the flange assembly and the upper terminal 34. Terminal 34 includes means 36 for fastening an electrical lead thereto. Shell member 24 provides weatherproof insulating means for the weather end of the bushing, and also provides a container for an insulating and cooling fluid, such as mineral oil, when the bushing 10 is of the oil filled type.

The design of bushing 10 is influenced by the hotspot temperature, with the hot oil 51 surrounding the encased end of the bushing 10, the FR losses in cable 20, and the dielectric losses in the capacitor section 22, all providing heat inputs to the bushing assembly.

In the operation of bushing 10, the encased end is immersed in oil 51, which may rise to a temperature of 95° C., and the heavy currents which the cable 20 must carry heat the conductor 12 by the FR losses in the cable. The hot oil and losses in cable 20 provide a high-heat input to the encased end of bushing 10, creating a well defined hotspot or maximum temperature point in the bushing at some point between the ends of body member 22. This hotspot is the limiting factor in the design of a bushing, as a certain maximum temperature must not be exceeded, such as 105° C. at rated current. Thus, while
the remaining portion of the bushing may be well below the hotspot temperature, and the bushing could have a higher current rating, except for the hotspot, or the conductor could be designed with smaller dimensions, except for the hotspot, the conductor size and current rating of the bushing are determined by the hotspot. If the maximum temperature of the hotspot could be economically reduced, for a given conductor size and current rating, compared with a similar bushing of the prior art, it would enable the same bushing to have a higher current rating without exceeding the maximum hotspot temperature, or, for the same current rating, the bushing conductor dimensions may be significantly reduced while still not exceeding the maximum hotspot temperature.

The FIGURE illustrates how the hotspot temperature of bushing assembly 10 may be substantially reduced, with little additional manufacturing cost, by efficiently pumping the heat energy from the hotspot region of the bushing to the cooler ends of the bushing assembly.

In certain embodiments of the invention a wick 60 is disposed within chamber 42, adjacent to and in contact with the inner walls of the chamber, even when the bushing is substantially vertically mounted. The volume of volatile fluid 50 in its liquid state will usually be insufficient to extend from the bottom or lower end of the chamber to the bushing hotspot, which is at a predetermined point between the ends of the chamber. As the hotspot reaches the vaporizing temperature of the volatile fluid, the volatile fluid is in the relatively cooler lower end of the chamber, and the heat exchange cycle is not initiated. Thus, even though it would not be evident that a wick should be used when the liquid will return to its reservoir by gravity, the peculiar temperature gradient characteristics of a bushing may require a wick for proper functioning of the heat exchange cycle. Thus, in certain applications, a wick 60, extending from the lower end 44 of the chamber to the bushing hotspot, is essential. The wick 60 need only extend to the hotspot, such as to a point 62, as the condensing fluid will return from the upper end of the chamber to the hotspot by gravity. In the embodiments of the invention where the wick is used it is essential that the volatile fluid completely wet the wick. "Pumping" from the reservoir of volatile fluid at the lower end of the chamber to the hotspot. Thus, care must be taken that the distance from the reservoir to the hotspot does not exceed the height that the wick will pump fluid against the force of gravity. In certain applications it will be necessary to use a chamber which does not extend completely to the lower end of the conductor, in order to provide the desired distance between the lower end of the chamber and the hotspot.

The embodiment of the invention in which a wick is used in spite of the fact that one end of the chamber is lower than the other, may be applied to any type of electrical bushing, as well as the cable-type bushing illustrated in the FIGURE. The wick 60 may be formed of any suitable material which will withstand the maximum operating temperature of the bushing assembly, such as fiberglass, metallic mesh or metallic fibers formed in a matlike structure, or sintered porous metallic matrices which are affixed to the walls of the chamber.

The function of the volatile fluid is to absorb the heat energy input into the bushing, with the liquid vaporizing under the influence of this heat input and absorbing large amounts of heat energy, according to the latent heat of vaporization of the selected fluid. The vapor formed at the hotspot increases the vapor pressure in this portion of the chamber, which causes the vapor and its heat energy to move toward cooler portions of the chamber, where the pressure is lower. The temperature at the lower pressure portions of the chamber is also lower than it is at the encased end, so upon reaching the cooler portions of the chamber the vapor condenses, releasing the stored thermal energy. Thus, the heat has been pumped from the hotspot of the bushing assembly 10 to the cooler portions, such as the weather end. The condensing vapor reduces the vapor pressure, preserving the pressure differential which perpetuates the heat transfer cycle from the hotspot to the cooler portion of the bushing.

The vapors condense back to the liquid phase of the volatile fluid, and the liquid returns by gravity, or when a wick is used, the fluid is absorbed by the wick and capillary action of the wick pumps the liquid back to where the liquid is being evaporated from the wick, with the driving force through the bushing being the surface tension of the liquid. The capillary action will work against gravity, as long as the weight of the liquid column being lifted does not exceed the capillary lifting force.

Thus, the volatile fluid preferably should have a high latent heat of vaporization, in order to provide a high heat flow rate through the vapor, and it should have a high-surface tension and low viscosity when used with a wick, to promote pumping of the returning liquid through the wick structure. It should also have a vapor pressure versus temperature curve which will provide the desired operating temperature for the bushing. The particular volatile fluid selected should be operated in the steeply sloped portion of its vapor pressure curve, in order to provide a small temperature differential across the length of the conductor. The chamber may be at, below, or above atmospheric pressure, as desired, to provide the desired operating temperature range for the particular fluid selected.

The fluorinated hydrocarbons, such as perfluorobutyrofurane, with the principal constituent being alpha butyl, which has a boiling point in the range of 99°-107° C. at atmospheric pressure, is suitable, or one of the products sold under the trademark Freon may be used. However, even water will operate satisfactorily.

The vaporized fluid at the evaporating section of chamber 42 stores heat energy at the temperature at which the vapor is formed, and the vapor remains at that temperature until reaching the condensing section of the chamber, where the vapor returns to its liquid phase. Thus, the hotspot portion of the conductor 12 is held near the vaporizing temperature of the fluid, and this same temperature extends substantially across the entire length of the chamber 42, with only a few degrees temperature differential. The evaporation and condensation of the volatile fluid take place at substantially the same temperature. Variations in the heat energy input to the fluid, due to oil temperature and the FR losses in the conductor, affect the rate of evaporation and the pressure within the chamber. The temperature will increase with pressure to sustain the increased rate of evaporation. The temperature gradient within the bushing will remain small with the hotspot being only slightly above the average temperature of the bushing. Thus, the conductor 12 of the bushing 10 provides a heat pumping device, pumping heat at rates much greater than those possible through the conductor and the temperature curve across the length of the conductor. For a given physical conductor size, the invention substantially reduces the maximum bushing temperature, enabling the bushing to carry more current without exceeding the hotspot temperature of a similarly dimensioned prior art bushing. Or, the conductor dimensions of a bushing constructed according to the teachings of the invention may be substantially reduced, compared with a prior art bushing having the same current rating.

As hereinbefore stated, the function of a wick is to return the condensed liquid to the evaporating section of the chamber, and it will do this without regard to gravity, as long as the weight of the column of fluid does not become greater than the pumping force. The chamber may even have a plurality of evaporating and condensing sections, depending upon the heat input characteristics to the bushing. For example, the liquid may evaporate at a region near the flange 28 and the vapor may flow toward each end of the chamber 42, condensing near each end and returning to the evaporating region via the wick 60.

In summary, there has been disclosed a new and improved electrical bushing assembly which includes highly efficient heat pumping means disposed adjacent the conductive cable of the bushing. A hollow conductor defines an opening for the electrical lead or cable, and it also defines a cavity in which a
volatile fluid is disposed. The volatile fluid cycles between its liquid and gaseous states, to pump heat from the regions of high-heat energy input, to regions of the bushing where the heat may be easily and efficiently dissipated. The volatile fluid operates near its boiling point for the particular pressure selected for the chamber, maintaining the conductor and its surrounding insulation near this temperature. Thus, the temperature gradient across the bushing is very small, and the hot-spot temperature is not a critical design factor. Using the teachings of the invention, the bushing conductor may be constructed with smaller dimensions, compared with bushings of the prior art having like current ratings, or the bushing current rating may be substantially increased, compared with prior art bushings having the same conductor dimensions.

I claim as my invention:

1. An electrical bushing comprising:
   electrical conductor means having first and second ends,
   said electrical conductor means including inner and outer concentrically disposed, spaced tubular members,
   an electrical lead disposed through the opening of the inner tubular member and connected to one end of said electrical conductor means,
   electrical insulating means disposed about said electrical conductor means,
   said electrical conductor means defining at least one chamber, between the outer wall of the inner tubular member and the inner wall of the outer tubular member, volatile fluid means disposed in said at least one chamber, with the volume of said volatile fluid means in its liquid phase being less than the volume of said at least one chamber,
   said electrical conductor means having different temperature regions during the operation of the electrical bushing, said volatile fluid means being selected such that it pumps heat from the regions of higher temperature to the regions of lower temperature in said electrical conductor means, by evaporating from its liquid phase to its vapor phase adjacent the regions of higher temperature in said electrical conductor means, moving through said at least one chamber in its vapor phase to regions of lower temperature in said electrical conductor means, condensing from its vapor phase to its liquid phase adjacent the regions of lower temperature in said electrical conductor means, and returning through said at least one chamber in its liquid phase to the regions of higher temperature in said electrical conductor means.

2. The electrical bushing of claim 1 wherein the at least one chamber defined by the electrical conductor means is disposed such that the movement of the volatile fluid means in its liquid state is by the force of gravity.

3. The electrical bushing of claim 1 including wick means disposed to line the inner walls of the at least one chamber, with the movement of the volatile fluid means in its liquid phase being through said wick means.

4. The electrical bushing of claim 1 wherein the bushing is adapted for mounting with the second end of the electrical conductor means higher than the first end, and including wick means disposed to line the inner walls of the at least one chamber, starting at the first end of the electrical conductor means and extending at least to the hotspot of the bushing.