ABSTRACT OF THE DISCLOSURE

A fluid cooled, polyphase electrical transformer of the core-form type, having a plurality of vertically spaced, superposed winding assemblies disposed on a magnetic core. The winding assemblies have cooling ducts therein which extend horizontally between the ends of each of the winding assemblies, with the cooling ducts being arranged to provide a diagonally upward flow of the cooling fluid between the ends of the winding assemblies.

This invention relates in general to electrical inductive apparatus, such as transformers, and more particularly to electrical transformers of the polyphase core-form type.

Polyphase transformers of the core-form type, such as three-phase transformers, conventionally utilize a magnetic core having three vertically disposed leg portions, which are horizontally spaced, and connected by two horizontally disposed, vertically spaced yoke portions. An electrical phase winding structure is disposed on each leg portion of the magnetic core, which includes concentrically disposed high and low voltage windings or coils, with certain layers of conductor turns of the windings or coils being separated by duct forming means to provide vertically disposed cooling ducts within the winding structure. The fluid insulating dielectric in the transformer, by virtue of the inherent vertical thermal head therein, flows upwardly through the cooling ducts, removing heat from the conductor turns which form the windings.

The horizontally spaced winding arrangement of the conventional polyphase core-form transformer requires a substantial amount of floor space, as well as a large enclosure or tank which requires a large quantity of dielectric insulating fluid. In an effort to reduce the floor space, tank size and amount of dielectric insulating fluid required, the electrical phase windings have been disposed one above the other, by rotating the magnetic core-winding structure 90° and standing the structure on one of the ends. This arrangement, however, has proven to be unsatisfactory because the cooling ducts through the winding structure with this arrangement are horizontally disposed, with the thermal head being substantially the same at each end of the ducts. Thus, there is very little flow of the fluid dielectric through the cooling ducts, resulting in a substantial rise in temperature of the winding turns. Thus, the rating of the transformer has to be substantially reduced, or the size of the cooling system has to be substantially increased to insure that the electrical phase windings do not exceed a predetermined maximum temperature.

Electrical phase windings have also been disposed one above the other, utilizing the same position in which they are disposed in the conventional horizontally spaced windings, which solves the cooling problem, as the cooling ducts are disposed in a vertical manner. This latter arrangement, however, while reducing the floor space, has the disadvantage of substantially increasing the length of the magnetic circuit. This latter arrangement requires a magnetic core having substantially the same configuration as a three-phase magnetic core of the shell-form type, with the substantial increase in the length of the magnetic circuit deleteriously affecting the weight and losses of the transformer. Also, with this core arrangement the magnetic circuit extends both above and below the upper and lower phase windings, which substantially increases the height of the transformer.

It would be desirable to be able to utilize the conventional core-form type of magnetic core and vertically disposed phase windings, if this structure could be utilized without de-rating the transformer, and without having to substantially increase the size of the cooling system.

Accordingly, it is an object of this invention to provide a new and improved polyphase electrical transformer of the core-form type.

Another object of the invention is to provide a new and improved polyphase transformer of the core-form type in which the electrical windings of each phase are superposed, each on a separate leg of a magnetic core.

A further object of the invention is to provide a new and improved three-phase transformer of the core-form type which has three winding sections, each disposed on a separate horizontally disposed leg of the magnetic core, with the winding sections being located vertically with respect to one another, and which will operate at substantially the same rating and temperature rise as similarly constructed windings disposed on vertically disposed, horizontally spaced magnetic core legs.

Briefly, the present invention accomplishes the above cited objects by providing a polyphase transformer of the core-form type which includes a magnetic core-winding structure disposed in an enclosure or tank containing a fluid dielectric. The magnetic core has a plurality of horizontally disposed, vertically spaced core legs, with the electrical windings being disposed on the core legs. Duct forming means are utilized in the electrical windings of each phase of the transformer, which allows a multi-directional flow of the dielectric fluid through the windings. In addition to a horizontal flow of the cooling fluid, the duct formers allow an upward, or diagonally upward flow of the fluid which takes advantage of the vertical thermal head which inherently exists in the cooling fluid between the upper and lower location of each phase winding in the dielectric fluid. Thus, each phase winding is cooled by a continuous flow of the dielectric fluid through the cooling ducts in the winding phase.

Further objects and advantages of the invention will become apparent from the following detailed description, taken in connection with the accompanying drawings, in which:

FIG. 1 is a front elevational view, partially cut away, of a transformer constructed according to the teachings of the invention;

FIG. 2 is a side elevational view, partially cut away, of the transformer shown in FIG. 1;
FIG. 3 is a plan view, partially cut away, of the transformer shown in FIG. 1.

FIG. 4 is an enlarged fragmentary view, partially cut away, of the transformer view shown in FIG. 2.

FIG. 5 is a perspective view of a duct former construction which may be used in the transformer shown in FIGS. 1–4.

FIG. 6 is a plan view of another duct former construction which may be used in the transformer shown in FIGS. 1–4.

FIG. 7 is an end view of the duct former construction shown in FIG. 5.

FIG. 8 is a plan view of still another duct former construction which may be used in the transformer shown in FIGS. 1–4.

Referring now to the drawings, and FIGS. 1, 2 and 3 in particular, there is shown front, side and plan views, respectively, partially cut away of a three-phase transformer 10 of the core-form type, which is constructed according to the teachings of the invention. Transformer 10 includes a magnetic core-winding assembly 12 disposed within a suitable casing or tank 14, which is filled with a fluid dielectric, such as oil, to a predetermined level 16, which completely immerses the magnetic core-winding assembly 12.

The magnetic core-winding assembly 12 includes a magnetic core 18 and electrical phase winding structures 20, 22 and 24. Magnetic core 18, which is preferably of the stacked type, but which may be of the wound type, if desired, includes winding leg portions 26, 28 and 30 for receiving phase winding structures 20, 22 and 24, respectively, which are horizontally disposed and vertically spaced in parallel relation on a common perpendicular plane. The ends of the leg portions 26, 28 and 30 are connected by vertically disposed, horizontally spaced yoke portions 32 and 34, which completes the three-phase magnetic core structure 18, forming two openings or windows 36 and 38 therein. Magnetic core 18 may be constructed of a plurality of stacks of metallic laminations formed of grain oriented magnetic strip material, such as silicon-stee, with each stack of laminations forming a leg or yoke portion, which are arranged in right contacting relation. The end frames 40 and 42 may extend past the ends of the magnetic core structure 18, forming means for supporting the magnetic core-winding assembly 12 within the tank 14, and providing support points for various bridging members, such as tie rods 44 and 46, which aid in mechanically bracing and supporting the various phase windings.

Solid insulating members, such as insulating members 48 and 50 may be disposed between the phase windings and the grounded portions of the structure, and also between the phase windings themselves.

The phase winding structures 20, 22 and 24 each include concentrically disposed high and low voltage windings, wound about an opening for receiving a leg portion of the magnetic core 18. Each phase winding structure 20, 22 and 24 has low voltage terminals, such as terminals 52 and 54 on phase winding 20, terminals 56 and 58 on phase winding 22, and terminals 60 and 62 on phase winding 24, which are interconnected to form a Y connection, as shown, a delta connection, or a T connection, and then connected to the low voltage output terminals 64, 66, 68 and 70.

Each electrical phase winding structure also has high voltage terminals (not shown) which are interconnected to form either a Y, or a T connection, and then connected to high voltage terminal bushings 72, 74 and 76 via electrical conductors 78, 80 and 82.

Each phase winding structure may also have a plurality of tap positions (not shown) which are brought out to the windings to a terminal board 84 via suitable electrical conductors, such as conductors 86, 88 and 90 from electrical phase winding structure 20. The tap changer (not shown) is mounted in the space above the magnetic core winding assembly 12.

Each electrical phase winding structure 20, 22 and 24 has a plurality of openings 100 which are located or disposed between certain layers of conductor turns which form the electrical coils of the phase winding structures, to allow the fluid dielectric to flow therethrough and remove heat from the electrical windings. The openings 100 are formed by suitable spacers or duct forming means, which will be described in detail hereinafter. It should be noted that the openings 100 have a length which extends between opposite ends of the phase winding structures, and they have a narrow, elongated cross-section, with the elongated dimension being oriented in a substantially vertical manner.

Summarizing to this point, there has been disclosed a new and improved polyphase transformer of the core-form type, which requires very little floor space, because the phase winding structures 20, 22 and 24 are disposed vertically one above the other, instead of the conventional horizontal spacing. Thus, the tank size is substantially reduced, as well as the amount of fluid dielectric required. This structure thus provides a substantial reduction in the size, weight and cost of the transformer.

Also, unlike other arrangements in which the phase windings are vertically disposed, the magnetic core has the same magnetic circuit length as magnetic core-winding arrangements of the core-form type in which horizontal spacing of the electrical phase winding structures is utilized. Further, the magnetic core does not extend above and below the windings, as required in certain other vertically spaced winding arrangements, thus achieving the savings in floor space, weight and fluid dielectric without an excessive increase in the overall height of the transformer assembly. Certain prior art vertically spaced electrical phase windings, in order to dispose the cooling ducts or openings 100 in a vertical position, and thus maintain the phase windings in the same orientation used in horizontally spaced electrical phase windings to provide adequate cooling of the windings by thermal siphon of the fluid dielectric, are disposed on three separate vertically disposed leg portions, all on a common center line. The return flux paths required with this arrangement provide a magnetic core structure similar in configuration to a three-phase shell-form magnetic core structure, having six openings or windows in the magnetic core for receiving the three electrical phase winding structures of a three-phase transformer. Thus, the length of the magnetic circuit is substantially increased, compared with the length of a three-phase magnetic circuit of a magnetic core of the core-form type. Also, the magnetic circuit necessarily extends above and below the upper and lower phase windings, which substantially increases the height of the overall transformer structure.

This invention makes it possible to dispose the electrical phase windings on individual horizontal disposed, vertically spaced leg portions of a magnetic core, by providing duct former means in the duct openings 100 in the electrical phase winding structures 20, 22 and 24, which allows a multi-directional flow of dielectric fluid under the influence of the thermal siphonic action of the dielectric fluid when the electrical transformer is energized.

More specifically, referring to FIGS. 4 and 5, there is shown in FIG. 4 an enlarged, fragmentary view, partially cut away, of the electrical phase winding structure 20 of the transformer 10 shown in FIGS. 1, 2 and 3, and FIG. 5 illustrates a duct former construction used in the phase winding 20 shown in FIG. 4.

Electrical phase winding structure 20 includes a winding tube 102, formed of a suitable electrical insulating material, such as multiple layers of pressboard, which
provides a form for the various coils or winding sections of electrical phase winding structure 20, as well as providing an opening for receiving leg portion 26 of magnetic core 18, and also provides electrical insulation between the electrical conductor turns, formed of copper or aluminum, or other suitable electrical conductor material, having a series of the magnetic core 18. The winding turns may be in the form of a sheet or strip, or they may be in wire form, wound about insulating tube 102. If the conductor turns are formed of sheet or strip, each layer may include only one conductor turn. If the conductor turns are formed of electrically conductive wire, each layer will include a plurality of conductor turns. Certain layers of conductor turns are separated, at opposite ends of the low voltage winding section, by duct former means 120, which form cooling ducts or openings 100 at the ends of the phase winding which extend outwardly on each side of the magnetic core 18. Duct former means 120 may also be disposed between the high and low voltage winding sections 106 and 104, as shown in FIG. 4.

In like manner, the high voltage winding section 106 includes a plurality of layers 122 of insulated sheet or wire, or other suitable solid electrical insulating material, the corrugated duct former means 120 is disposed with parallel waves and furrows extending between the two opposite ends of the winding structure, which provide a plurality of openings 124 in each of the cooling ducts 100. In the prior art, these openings 124 would be isolated from one another, and being disposed in a direction which is substantially perpendicular to the direction of the cooling layers 110 and 122 of the low and high voltage winding sections 104 and 106, there would be little difference in the thermal head which would exist at opposite ends of the horizontal openings 124. Thus, there would be very little, if any, flow of the dielectric fluid through the cooling ducts, resulting in an excessive temperature rise within the winding structures, if the windings are operated without de-rating.

FIG. 5 illustrates a perspective view of the duct former means 120, constructed according to the teachings of one embodiment of the invention. Specifically, duct former means 120 includes a plurality of layers of connecting furrows 126 and waves 128, which provide the plurality of openings 124 when disposed between the layers of conductor turns which form the high and low voltage winding sections. Thus, the corrugated edge 130 of the duct former means 120 may be the edge which may be seen in the opening 100 of the ductformer structure 20. In other words, the corrugated edges of the duct former means 120, such as edge 132, are located within the openings 100, running between the opposite ends of the phase winding structure. The layers of conductor turns, 110 and 122 of the low and high voltage winding sections 104 and 106, across the duct former means 120 in a direction which is substantially perpendicular to its straight edges, as shown by arrow 134.

In order to promote an upward flow of fluid dielectric from one end of the phase winding structure 20 to the other, the length dimension of the openings 136 and 138 should be disposed at an angle with respect to the corrugated edges, or with respect to the straight edges of the duct former means, with the angle, such as the angle A shown in FIG. 5, preferably being 45°. However, the actual angle with respect to the direction of the waves and furrows or with respect to the edges of the duct former means may vary quite widely on either side of 45°, depending upon the particular dimensions of the electrical phase winding structure.

The angled openings 136 and 138 in the duct former means may be very easily formed, for example, by saw cuts.

Thus, duct former means 120, with the plurality of openings 136 and 138 therein, allow an upward flow of cooling fluid in the duct openings 100, with the angled direction of the openings promoting a diagonally upward cross flow of the fluid dielectric, which thus takes advantage of the inherent upward flow of dielectric fluid within the transformer tank due to the heating of fluid by the magnetic core-winding assembly 12 shown in FIG. 1. The heated fluid, after circulating through the cooling ducts 100 may be circulated through external heat exchanger means (not shown), if desired, and returned to the bottom of the tank 14 for recirculation. While the dielectric fluid will circulate through the cooling ducts 100, it is recognized that due to the natural thermal siphon effect of the dielectric fluid, pumping means (not shown) may also be utilized to increase the flow of the cooling fluid through the transformer tank, through the cooling ducts 100 in the electrical phase winding structures, and through any auxiliary heat exchanger means which may be utilized.

A 500 kva. three-phase transformer was constructed according to the teachings of the invention, using the duct former means 120 shown in FIG. 5. The transformer was test loaded, both in the position shown in FIG. 1, with the electrical phase winding structures vertically spaced, and in the conventional position wherein the electrical phase winding structures are horizontally spaced. The temperature rise of the electrical conductors were within one degree of one another in the two positions, illustrating the effectiveness of the duct former means shown in FIG. 5 in promoting fluid flow through the ducts. Using duct formers similar to that shown in FIG. 5, but without the openings 136 and 138 disposed in the waves and furrows, causes a substantial increase in the conductor temperature in a transformer having horizontally spaced phase windings as shown in FIG. 1, compared with transformers having horizontally spaced windings, which makes the vertical type structure in this instance completely unsuitable. Therefore, the objections to vertically spaced phase windings have been overcome by the teachings of this invention, making it possible to achieve substantial savings in floor space, saving in the
amount of fluid dielectric required, and savings in the overall weight of the transformer structure. For example, on a 500 kva. three-phase transformer, the savings in weight of a transformer constructed according to the teachings of this invention, over the conventional horizontal position of the electrical phase windings, exceeds 20%.

The duct former means 120 shown in FIG. 5 illustrates one arrangement for achieving an upward as well as a cross flow of cooling fluid through the phase winding structures of an electrical polyphase transformer. FIGS. 6, 7 and 8 illustrate other duct former means which may be utilized to achieve this result.

Specifically, FIGS. 6 and 7 illustrate plan and edge views, respectively, of a suitable duct former means 150. Duct former means 150 is constructed of a sheet 152 formed of electrical insulating material, such as pressboard having two major opposed surfaces. A plurality of ducts or paths through the cooling duct, when it is disposed between certain layers of winding turns, are provided by the plurality of discrete insulating blocks 154 which are attached to one or both of the major opposed surfaces of the sheet member 155 in a predetermined spaced pattern. For example, the edge 156 of the duct former means 150 is assumed to be the bottom edge of the duct former means as disposed in the phase winding structure shown in FIG. 4, and with the arrows 158 indicating the direction of the phase winding turns, the blocks 154 may be disposed in spaced relation, and oriented such that the direction of the winding turns proceeds diagonally across the blocks, from one corner to the opposite corner, assuming the blocks to be square. This provides diagonally upward paths for the cooling fluid, such as shown by arrows 160 and 162.

While the discrete block members 154 are illustrated in FIG. 6 as being square, they may also be rectangular in nature in which two opposite sides have different lengths than the two remaining opposite sides.

FIG. 8 shows a plan view of still another duct former means 170 which may be utilized with the invention. Like the embodiment of FIGS. 6 and 7, this embodiment also includes a sheet member 172 of insulating material, having two major opposed sides, but instead of having discrete spaced block members, this embodiment utilizes spaced strip members 174, which are suitably attached to one or both of the major opposed surfaces of the sheet member. Assuming edge 176 of sheet 172 to be the bottom edge of the duct former means, as disposed in a phase winding structure such as that shown in FIG. 4, and with arrow 178 indicating the direction of the conductor turns of the phase winding, the strip members are disposed in spaced relation, and inclined upwardly at a predetermined angle, such as 45°. Thus, the cooling dielectric fluid may enter the openings between the strip members 174 at one edge or end of the electrical phase winding structure and flow diagonally upward to exit at the opposite end of the phase winding structure.

In summary, there has been disclosed a new and improved polyphase transformer construction of the core-form type, which requires substantially less floor space, requires less dielectric fluid, requires a smaller casing or tank, and which weighs less than similarly rated polyphase core-form transformers of the prior art. Further, the disclosed transformer construction is less costly to manufacture, due to the smaller enclosure and reduction in the amount of dielectric fluid required.

Since various changes may be made in the above described apparatus and different embodiments of the invention may be made without departing from the spirit thereof, it is intended that all matter contained in the foregoing description or shown in the accompanying drawings, shall be interpreted as illustrative, and not in a limiting sense.
ing member having two major opposed sides, said electrical insulating member having a plurality of spacer members having a predetermined shape attached to at least one of its major sides in a predetermined pattern which provides the diagonally upward dielectric fluid flow paths in said at least one cooling duct.

8. The electrical inductive apparatus of claim 7 wherein the plurality of spacer members are discrete blocks having a substantially rectangular cross section, said discrete blocks being disposed in spaced relation and oriented to provide the diagonally upward dielectric fluid flow paths in said at least one cooling duct.

9. The electrical inductive apparatus of claim 7 wherein the plurality of spacer members are strips of electrical insulating material disposed in spaced parallel relation at a predetermined angle relative to the edges of the major sides of said electrical insulating member, providing the diagonally upward dielectric fluid flow paths in said at least one cooling duct.

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