This invention relates to sheath bonding means, and more particularly to sheath bonding transformers of this type for use on single-conductor high-voltage lines and the like.

The present invention makes possible a substantial reduction in the induced voltage between the sheaths of single-conductor alternating current underground cable and ground, as compared to the induced sheath voltage to ground when ordinary means of bonding are employed to eliminate sheath losses.

It has heretofore been the practice, in a number of utility companies, to employ bonding methods where some sheath sections have one end grounded and full induced voltage for the section between the sheath and ground at the opposite end of the section. A common system of this type is known as the "Kirke-Searing" system. In this system the cables are usually solidly bonded in every third manhole, and bonding connections are installed at the intermediate manholes. The induced voltages on the lengths of the three phases in a given metallic circuit from solid bond point to solid bond point cause practically no current to flow, since these voltages are practically 120 degrees apart and form a delta-vector diagram. Laboratory tests and field experience indicate that an allowable maximum of 12-volt sheath to ground induced potential is permissible from the standpoint of eliminating troubles due to alternating current corrosion. With such methods in cables carrying large currents the induced potentials will reach 12 volts when the distance between insulating sleeves or manhole joints is as small as 300 feet or possibly less, and when cross-bonding is employed.

The devices covered by the present invention are also usable in the continuous cross-bonding system with star grounding through bonding transformers as covered in United States Letters Patent No. 1,809,591 issued to the present inventors on June 9, 1931.

In the present invention, with the use of sheath-bonding transformers constructed as disclosed heretofore, the sheath is at ground potential midway between insulating sleeves, and the induced voltage between the sheath and ground is approximately one-half of that in methods such as the "Kirke-Searing" method. Thus, for a given allowable maximum voltage between sheath and ground, the use of the present invention enables the distance between insulating sleeves or manholes to be increased to substantially twice that formerly found permissible. Thus we are able to reduce the number of manholes to about one-half of that formerly necessary for a given installation, with a consequent material reduction in the cost of the installation.

In previous sheath bonding transformers, there were not only the coils connected directly to the sheath of the cable, but also a set of delta-connected secondary coils or loops of heavy copper bar around the entire transformer for the purpose of making the voltage drop across the transformer a minimum when single phase current from a fault on the line passes through the transformers in going back to the station. Except for the metallic case which continues to act as a secondary, we eliminate the use of such secondary coils or copper loops. The main coils in our present transformer consist however of zig-zag windings whereby the voltage drop with a single phase fault current passing through the transformer is materially reduced, thus effecting a considerable reduction in the voltage that is built up on the sheath incidental to the return of fault currents. A considerable saving in the cost, size and weight of the transformer is thereby effected.

Our present invention has as one of its primary objects the reduction of the maximum induced sheath potential to ground to about 50% of that obtained in previous systems. We also provide for more effectively withstanding voltage surges on the sheath incidental to switching of unloaded lines. Likewise, for a given exciting current, there is more uniformity in voltages across coils in a given lot of transformers over that which has been obtained in the past. Thus when the exciting current flows between two consecutive neutral points of transformers connected at each end of the sheath of one length of cable, then the voltage across the two coils involved is nearly identical and the reduction of the voltage induced in the cable length from sheath to ground is close to the desired 50% reduction.

Another feature of the present invention is the decrease in polarization of the transformer due to flow of stray railway currents or other direct currents effected by reason of the design and zig-zag winding of the transformer, which also provides better control of voltages across the coils in the transformer for a given exciting current.

We also provide a transformer having two cores instead of the double H magnetic cores previously employed, with the result that voltages induced on one side of the insulating sleeve do not carry over to the other side to cause the induced sheath potentials to ground on either
end of the next adjacent conductor to be larger than would otherwise be the case.

Our present invention also contemplates a sheath bonding system which is extremely flex-
ible in special circumstances, and can be employed as a continuation of other types of
bonding for special applications, such as exten-
sions of lines, or interposition of relatively long
cable lengths in a line where a greater spacing
between manholes is essential. Thus, with our
present system we are able to provide a bonding
arrangement wherein the sheath section has
identical units at opposite ends for tying the
section into a solid bonded adjacent sheath sec-
tion or to finish up a line which has other types of
sheath bonding therein. By the provision of a
sheath section wherein the ends are provided
with single bonding units at opposite ends we
have a section which can be interposed in a line
which has sheath bonding of some other type,
but where special considerations require a rela-
tively long distance between manholes at certain
points. Also, two adjacent sections having sub-
stantially identical units at their adjacent ends
can be readily bonded, and the single units can
be employed in place of double units at any in-
sulated gap. This renders our system extremely
valuable for use as an adjunct to systems already
installed where revisions or extensions are found
necessary.

In one modification, the use of sheet copper
as the conductor in the transformer winding,
instead of the previously employed rectangular

copper wire, we are able to obtain more uniform
distribution of surge potential through the wind-
ing incident to sheath voltage surges that occur
when switching unloaded lines, and also we in-
crease the capacity of the windings, with the
result that the magnitude of the surge poten-
tials on the sheaths is reduced below former
values.

The use of the zig-zag type of windings for
direct connection to the sheaths provides a re-
duction of 60% to 80% in the voltage drop across
the transformer when carrying single phase fault
currents as compared to previously designed bonding transformers, and also eliminates the
secondary windings with the exception of the
secondary action of a metal case, if such case is
provided. Incidental to a cable failure in our
present invention, the current from the cable
that fails goes through one coil at each end of the
cable length, and then divides over the common
neutral connection in the bonding transformers
to pass equally through the coils of other trans-
formers and back over the three sheaths of the
line and other ground connections to the stations.

Another feature of the zig-zag winding is that
the magnetic circuits are more nearly equal, so
that for a given exciting current there is more
uniformity in voltage across the coils than was
formerly possible.

Other objects and advantages of the present
invention such as the construction of the trans-
former itself and the manner of its connection
into the line, will appear more fully from the
following detailed description which, taken in
connection with the accompanying drawings, will
disclose to those skilled in the art the particular
construction and operation of a preferred form of
the present invention.

In the drawings:
Figure 1 is a diagrammatic illustration of the
application of the present invention to a three-
phase cable installation;

Figure 1A is a graph of the induced sheath voltages in the installation shown in Figure 1;
Figure 2 is a diagrammatic illustration of a
modification of our system;
Figure 3 is a perspective view of a sheath bonding transformer constructed in accord-
ance with the teachings of the present invention;
Figure 4 is an elevational view of the opposite end of the transformer shown in Figure 3;
Figure 5 shows diagrammatically the windings of
the sheath bonding transformer of the present
invention;
Figure 6 is a perspective view of a winding such as shown in Figures 3 and 4;
Figure 7 shows one manner of connecting the
transformer across the cable joint;
Figure 8 shows an optional manner of con-
nection;
Figure 9 illustrates another method of elimin-
ing sheath losses in a cable installation; and
Figure 9A indicates the induced sheath volt-
ages obtainable with the method shown in Fig-
ure 9.

Referring now in detail to Figure 1, we disclose
the sheaths of the three single conductor cables,
A, B and C, representing the three phases of an
alternating current transmission or distribution
line. The cables are provided at suitable inter-
vals with insulating sleeve connections or gaps
which mechanically connect adjacent lengths
of cable sheath together in a manhole or the like,
and which form electrically insulated gaps or
joints between the respective sheaths of the ad-
jacent cable lengths. It is to be understood that
the insulating gaps may be provided at cable
joints, or at intermediate points on long lengths
of cable, and generically include any form of in-
sulating gap which destroys the electrical con-
 tinuity of the sheath, regardless of whether
the conductor remains continuous or not.

Suitable connections 12 from the cable sheaths
A, B and C on one side of the sleeves or gaps 10
are led through transformer windings 11 to a
common neutral 14 which is grounded at 15. It is to be distinctly understood that
although grounding of neutrals to earth or other
cable sheaths is desirable, it is not necessary, for
the successful operation of our system. Simi-
larly, suitable connections from the opposite
or adjacent sheath of the next adjacent cable
length are led through the windings 17 to the
neutral 14, and thence to ground, or to the sheaths of other cables, if present in the same ducts or
manholes, which may be considered as grounds.
This construction is provided at each of the
cable joints, and as indicated by the dimension
Y in Figure 1A, the manholes or insulating sheath
joints may be placed apart a distance indicated
by the dimension Y.

Considering now the induced voltages from the
cables A, B and C to ground 15, as connected with the sheath bonding transformers as employed in the present
invention, reference is made particularly to
Figure 1A, in which the line C represents ground potential. The induced sheath voltage for any
one phase is represented by the line 17, and it will be noted that the induced voltage becomes zero at the points 19, which correspond to the neutral points 14 of the transformers. The max-
imum obtainable normal operating potential be-
tween ground and the sheath is indicated by the
dimension Z. It will also be noted that this
induced voltage is zero midway between the in-
sulating sleeve, or midway between the points
19. None of the induced voltage on one side
of the insulating sleeve is carried over to the other side of the sleeve by this bonding arrangement, using separate cores.

Attention is now directed to Figures 9 and 9A, which represent one type of a common form of sheath bonding, and which clearly show the advantages derived by a method of bonding such as shown in Figure 1.

In Figure 9, the three sheaths A', B' and C' correspond to the sheaths of Figure 1, and solid non-insulating sleeves are provided at 30, between adjacent lengths of the cable sheaths. The sheaths of all the insulated cables at the solid bond points 32 are interconnected by a common connection 22 and grounded to earth or other grounds in the manhole, if present. Intermediate the solid bond points 28 on the line, insulating sleeves 23 are provided at approximately the third points of the length of cable intermediate the bond points 33. Cross-bonding between the sheaths is employed at these points by means of the conductors 24, 25 and 27, similar cross-bonding being effected at each of the intermediate manhole connections.

The ground potential for a system such as shown in Figure 9 is indicated by the letter G' in Figure 9A, and the induced voltage for one complete sheath circuit between the solid bond points 22, is indicated by the line 23. This induced voltage, whose maximum may be 12 volts as indicated by the dimension V, averages considerably more throughout the length of the cable between the bond points 20 than for the corresponding induced voltage provided by the system shown in Figure 1.

The dimension indicated by the letter X is the distance between manholes. Other conditions of an installation being similar, it will be noted from a comparison of Figure 1A and Figure 9A, that the dimension Y, or the permissible distance between manholes with the bonding system shown in Figure 1, is substantially twice the distance X, for equal maximum normal sheath voltages V and Z, or the permissible distance between manholes with the bonding system shown in Figure 9 is only half as large as that allowable in the bonding system shown in Figure 1.

Thus it will be apparent that in the system shown in Figure 1, the sheath is at ground potential midway between the insulating sleeves, and also at the joints in the manhole, and for equal cable lengths the induced voltage between the sheath and ground is therefore approximately one-half of what it would be for the system shown in Figure 9, which is commonly known as the "Kirke-Searls" method. Therefore, for a given allowable maximum voltage between the sheath and ground, the use of bonding transformers, such as shown in Figure 1, allows the maximum distance between the insulating sleeves, that is, between the manholes, to be substantially doubled in comparison with former methods of bonding.

In the optional form of connection shown in Figure 2, which in some instances may be preferred, we have illustrated the application of our invention to a sheath bonding circuit similar to that shown in Figure 1, and illustrated substantially on the same scale.

This form of the invention contemplates the using in of an insulated sleeve section comprising the three sheaths A, B and C having insulated sheath section comprising the three sheaths A', B' and C' having the solid bond connection 22, corresponding to the bonded sections shown in Figure 9. This may be desirable when an extension of a previous installation is required, and series bonding is to be employed in the extension, or where a long stretch of sheath length such as under a viaduct or the like, is necessary and the distance between insulated gaps must be maintained as great as possible. The sheath section shown in Figure 2, with identical single transformer units at opposite ends, produces the same results as the bonding circuit shown in Figure 1, in which a double unit at each insulated gap is connected to the sheaths on both sides of the gap.

In the form shown in Figure 2, the sheath connection 16' from each of the sheaths A, B and C is connected through the transformer windings 17' to a common neutral 16", thus producing a single unit sheath bonding transformer for one end of the section. A corresponding single unit is provided at the opposite end of the section, comprising connections 12' connected through transformer winding 19' to the common neutral 19". As pointed out heretofore, like the grounds shown in Figure 2 are desirable but not necessary. The section lying adjacent to the right hand end of the section tied to the solid bonded section is provided with another single unit bonding transformer corresponding to that at the left hand end of the intermediate section shown in Figure 2 and similarly identified. Such a sheath bonding system, employing identical single units at opposite ends of the insulated sheath sections, has the same characteristics of operation as the system shown in Figure 1.

Considering now the structure shown in Figure 5, which is a diagrammatic layout of the transformer shown in Figure 1, the two transformer cores are indicated generally at 30 and 32, and comprise the three legs 33, 34 and 35, respectively, of the core 30, and the three legs 36, 37 and 38, respectively, of the core 32. The connections leading from the sheaths of the conductor are indicated at 39, 40, 42, 43, 44 and 45. The connections 33 and 43 may for example lead from the opposite sheaths of the A-phase of the conductor, the connections 35 and 45 from the B-phase, and the connections 42 and 44 from the C-phase. The connection 33 is provided with a portion of a winding 45 on the leg 33 of the core 30, and with the remaining portion of the winding indicated at 47 on the leg 33 of the winding, the other end of the winding being connected through the lead 45 to a common neutral 49 leading to ground at 50.

The connection 40 is provided with a winding 53 on the leg 35, and then jumps across to a winding 55 on the leg 33 before being led through the connection 56 to the neutral 49. Similarly, the connection 42 is provided with a winding 55 on the leg 34, and a winding 56 on the leg 35 before being led through the connection 57 to the neutral.

It will therefore be noted that each of the connections from a sheath to the transformer core is provided with a winding, one leg of which is connected to two of the legs of the core, either a middle and an outside leg, or the two outside legs, as in the case of the B-phase connection 40. Similarly, the connections 43, 44 and 45 are each wound about two legs of the transformer core 32, and then lead through the corresponding connections 55, 56 and 57 to the grounded neutral 49.

It will be noted that the B-phase of the two
sheath connections is wound about the two outside legs, but the connections leading away from the sheath will always be between the A and C phase connections, regardless of the disposition of the transformer cores 30 and 32. It is possible to insure that the middle or B-phase leads 39 and 45 will always be disposed between the phases 38—43 and 42—46. Since the A and C phase leads are each wound upon a middle leg and an outside leg, it is obvious that it is immaterial whether they are connected to the A and C phase sheaths or not, that is, the connection 39 could be connected to the sheath of an A phase, with the connection 45 being also connected to the opposite sheath of the A phase.

By the particular zig-zag winding thus provided, we insure that the winding which is wound about the two outside legs will at all times be so disposed that it will be connected to the proper phase, since the two outside leg windings may have a magnetic circuit which is slightly different from a winding which has a portion on the central leg and a second porti on on an outer leg. By this particular method of winding, as compared to sheath bonding transformers with electrically separate secondaries, we achieve a reduction of 60% to 80% in voltage drop across the transformer when carrying single phase fault currents, depending on the size of the copper conductor employed; and the elimination of the secondary bare copper windings or insulated delta windings, which were previously used, with consequent reduction in weight, size and cost of the transformers. This means that the cost of installation is also reduced. Also, polarity of the transformer due to flow of stray D.C. rail- way or other currents is reduced because the currents divide equally by resistance over symmetrically connected coils with mutually neutralizing magnetic effects. Reduced variation or better control of voltages across the coils is obtained in the various transformers in one lot for a given exciting current and consequent increase in maximum allowable distance between the manholes.

By the use of the two cores without a common magnetic neutral, but having an interconnected electrical neutral, the voltages induced on one side of the insulating sheave do not carry over to the other side to cause induced sheath potentials on that side of the sleeve. Thus, for randomly unequal successive cable lengths voltages divide equally at opposite ends of each sheath section, as desired, independently of connective lengths.

Reference should now be made to Figures 3 and 4, inclusive, which show in detail one manner of constructing a double unit transformer according to the present invention. The transformers are preferably formed in halves, and the halves are then joined by connecting a neutral jumper. Thus the transformers may be mounted either two in a single transformer case, or in separate cases, depending upon the particular installation which is necessary. Figure 7 shows one method of connecting single unit transformers, as described in connection with the Figure 2, in which the transformer core 30 or C3 is half a transformer, that is, each contains a transformer core such as the core 30 or C3 and the ground connection 37 leading thereto corresponds to the common ground connection 43 of Figure 2. The transformer case 55 is provided with three leads 88 leading to the sheaths of the three phase conductors A, B and C which are on one side of the insulating sleeve 10. Similarly, the transformer housed in the case 58 is provided with three leads 93 leading to the respective sheaths of the phase conductors upon the opposite side of the insulating sleeves 10. This construction is particularly desirable when the insulating sleeve connection is made in an octagonal shaped manhole, in which the conductors leading away from the sheave 19 are set an angle with respect thereto, and the insulating connection is of considerable length. In such case, the transformer connection would have to be fed back of the sleeves 10 if a single case were employed, and consequently a considerably longer lead would be necessary.

By the present arrangement, the two transformer cases can be separately mounted at opposite ends of the manhole on opposite sides of the sleeve by suitable wall brackets or the like, and individual connections can be led thereto without requiring crossing over of the feed-in wires for the transformers from the sheave on one side of the sleeve to a transformer case disposed on the opposite side. In Figure 8 we show a transformer case 70, in which both of the cores 30 and 32 may be mounted when it is desired that the sheath bonding transformer be entirely enclosed in a single case, as in the circuit shown in Figure 1. In this case, the neutral 39 is led out through a suitable lead 72 to ground, and the case is provided with suitable outlet connections 73 and 74 leading to the sheaths of the phase conductors A, B and C on opposite sides of the insulating sleeves 10. In other respects, the connections and the windings for the transformers are the same as described in connection with Figure 2.

Referring now in detail to one form of construction of the transformer, as shown in Figures 3 and 4, the transformer core, such as the core 30 disclosed in Figure 5, is clamped in a suitable framework comprising supporting angle members 75 held together by suitable securing means 76 which form a framework for holding the laminated plates comprising the transformer core in fixed position. A perspective showing of one manner of providing the windings about one of the transformer legs is shown in Figure 6. While the transformer leg 38 is shown in Figure 6 as having the width of the copper sheet being such as to fit within the opening between the legs of the transformer core and to provide a clearance with respect to the end walls of the opening. Thus, if the opening or core window were four inches in length, the width of the sheet copper strip would be approximately 3 inches.

By the use of sheet copper, a more uniform distribution of surge potential through the winding incident to certain sheath voltage surges that occur when switching unloaded lines is obtained, and the number of turns of the windings is increased, with the result that the magnitude of the surge potential on the sheath is reduced below former values.

Inasmuch as each of the legs of a transformer core is provided with two windings, which means that for each core the copper must be provided, that is, a tap at each end of each of the two windings, the manner of placing the sheet copper upon the core is of importance.

As shown in Figure 6, we first form a press board rectangle, indicated at 30, which engages closely about the leg of the transformer to be wound. About this insulating rectangular form, the copper conductor in sheet form is wound.
Simultaneously with the winding of the sheet copper, a sheet of asbestos or other suitable insulating material is wound about the former at its end before being cut and bent in the form shown at 33 in Figure 6, that is, extending at right angles to the length of the sheet, and being projected outwardly beyond the end of the winding. The inner end of the winding is cut and bent to project outwardly through the end of the coil in a similar manner before starting the winding. The copper sheet, with the layer of insulation therewith, is wound about the form 30, and may be wound either in a clockwise or counter-clockwise direction. We have found that for zig-zag connections of the coils, an odd number of half turns may be used without any appreciable unbalance. This brings the end of this particular winding out at the opposite side of the form 33 from that at which the winding was started, and the ends are folded over as indicated at 33.

Suitable sheets of mica are then wound around the first coil, and tape is applied adre to hold the same in position. Then about the end of this coil the inner end of the outer coil is begun. It may be wound in a reverse direction, that is, reverse with respect to the direction of winding of the coil 33, or the winding may be started from the opposite end. Properly positioned connections of the end leads according to design convenience and control of the internal surge distribution. The outer coil is preferably lapped for an odd number of half turns. The ends of the outer coil are turned at right angles to the length of the sheet, and extend from the ends of the coil, as shown at 33.

Suitable mica 39 is imposed about the outer end of the outer coil, and the coil is then bound in position by means of adhesive tape 36. The inner coil described in connection with Figure 6 may be a coil used previously as illustrated at 52 in Figure 5, with the outer coil being the coil corresponding to that indicated at 45 in Figure 5, both coils being wound, or else connected, in opposite directions, about the same leg of the transformer core. The use of half turns permits all phase and neutral coil endings to terminate at one side of the transformer, as shown in Figure 3, while all other zig-zag terminals to be cross-connected terminate on the other side, as shown in Figure 4. This is of great convenience in design whether flat copper sheet or wire is used and is of great advantage in the assembly of the transformer on which we have found by theory and test to be unobjectionable, contrary to general belief.

The extending ends of each of the inner and outer coils is bent in the form shown at 33 in Figure 6, and is reversed outwardly to the side of the coil and then inwardly toward the center of the coil as indicated at 90, terminating in a substantially cylindrical passage adapted to receive the jumper connecting the same to the next coil, or to a lead-in connection. At the upper and lower ends of the completed coil indicated in its entirety at 92 in Figure 6, we provide alternate sheets of cardboard 57 and mica 53, which close the ends of the coil, and against which are clamped the supporting angle members 75.

Considering now that Figures 3 and 4 show a transformer made entirely of the type shown at 30 in Figure 2, each of the legs is provided with two coils, which therefore have four terminal points, the one end of one of the coils being connected to a conductor leading to the sheath of the corresponding cable, the other end of this coil leading to a zig-zag jumper to which is connected the second portion of the winding about a different leg of the transformer, and the other of the coils having a connector leading to a jumper leading to the first portion of its winding about a different leg of the transformer, and having its other end connected to a conductor leading to the neutral. Thus, considering the end elevation shown in Figure 3, the three transformer legs are indicated generally at 33, 34, and 35. The leg 33 is provided with a jumper connection 39 which leads to a tap 103 formed by the extending end of the sheet copper being rolled over to receive the end of the conductor 33. This tap 103 leads to an outer coil winding 34 (see Figure 5) which upon being secured in a similar manner is provided with the extending end 102 as shown in Figure 4, which is rolled as indicated at 103 to receive one end of a jumper 104 which extends the inner end of the outer coil 46 across to the winding on the transformer leg 34.

The coil on the leg 33 is also provided with the rolled junction 105 which receives the jumper 106 leading from the coil 52 on the leg 35 over to the coil 53 on the leg 33. The inner end of this coil, which has its outer end connected at 159, is provided with the extending rolled end 167 which leads to the zig-zag jumper 22 forming the common grounded neutral for the transformer. Corresponding reference numerals of the conductors, connections, and jumpers shown in Figures 3 and 4 are applied to the same relative parts in Figure 5, and are believed to therefore indicate the manner in which the coils are interconnected between the respective legs of the transformer to provide the zig-zag winding shown diagrammatically in Figure 5. It is believed that the details of the transformer connections will thus be apparent from a consideration of these figures without further description.

If the two halves of the sheath bonding transformer are to be mounted in a single case, they will be the same in construction except that the ground neutral will be provided with common connection for the end points of the conductors 156, 159, and 53. Then the three connections of each of the three sheaths will lead from opposite sides of the transformer casing, while the common ground connection can lead from either one of the sides, or from a different side to ground. The particular details of construction and assembly of the case, and the manner of mounting the transformer cores therein, may be varied in practice, but it is pointed out that the cores can be inserted into the case with insulating compound for completely enclosing the same against the effects of moisture or the like, and for sealing the same within the case.

It will therefore be apparent that we have provided a sheath bonding transformer and a sheath bonding system whereby, with the use of zig-zag winding with two separate three-legged core type magnetic circuits in the transformers, we obtain improved operation with smaller cost than has prevailed for previous types of such transformers. We are also able, with this particular system, to effect a reduction of about 50% in the normal operating voltage between the sheath and ground, while still providing for certain features of operation which are not possible in previous types of bonding systems, such as the provision for the operation of a half-transformer on one side of the insulating sleeve completely independently of the operation of the other half-transformer. Thus, both the cores, enclosed in compound, may be put into one case.
or into separate cases, as practical considerations may dictate.

We also have provided for the use of sheet copper for bonding transformers, in that it increases the capacitance of the transformer winding and also provides for more uniform distribution of surge potential through the winding incident to sheet voltage surges, and maximum separation of coil ends subjected to greatest differences of sheath potentials.

In field practice cables may be irregularly wet along the sheath length or entirely submerged portions in water in the ducts. This introduces leakage currents between cable sheaths which may be uniquely shared between the half transformer at each end of a cable sheath or between the several phases in any one transformer, this partially upsetting the desired voltage relations.

We have found that by designing the transformers to have exciting currents considerably larger than the leakage currents, the latter may be made unimportant and yet exciting currents will be small enough to prevent appreciable sheath losses. Thus, for example, we have found that transformers designed to have 10 to 20 amperes normal full voltage excitation currents adequately control voltages in wet ducts, and have no material effect on the 50% voltage of the maximum sheath potential relative to ground.

In practice we have found that these increased excitation currents can be produced by introducing air gaps in the core, employing iron requiring greater excitation currents, by the use of comparatively high flux densities, or by intentionally introducing spacings at the edge joints of the laminations in the cores. Any one or combination of these schemes might be employed.

With a three-legged core transformer, the exciting currents in the coils on the legs are different due to the unavoidable inequalities in the magnetic circuits. However, by the use of the particular zig-zag arrangement which we have provided, the variations in currents are reduced in magnitude, since a zig and zag of each half-transformer phase winding is on different coil legs, tending to average out the inequalities. This characteristic, the minimizing of the effect of stray direct currents, and the use of separate cores and of proper excitation currents results in an unusually close approximation to the desired 50% reduction in sheath potential to ground.

We are aware that various changes, both in details and design or construction are possible, and we do not intend to limit ourselves to the exact construction and details of connection of the transformer as shown and described, but only as far as defined by the scope and spirit of the appended claims.

We claim:

1. A sheath bonding system for the sheaths of a three phase alternating current line comprising a transformer core having three legs, each of said legs having windings thereon, one winding on each leg being connected at one end to conductors leading from the sheaths of a three phase line and at the opposite end being jumpered across to one end of a winding on a different leg, the other end of another winding on said first leg being connected to a neutral common to all said legs.

2. A sheath bonding system for the sheaths of a three phase alternating current line comprising a transformer core having three legs, each of said windings on each leg, one end of one of said windings being connected to a neutral common to a winding on each of the other legs, the other end of said winding being jumpered across to one end of a winding on another leg, the second winding of said pair of windings having one end connected to a sheath of a phase conductor.

3. A sheath bonding system for the sheaths of a three phase alternating current line comprising a transformer core having three legs, each of said legs having inner and outer windings thereon, the outer windings of each leg being connected at one end to conductors leading from the sheaths of a three-phase line and at the opposite end being jumpered across to one end of an inner winding on a different leg, the other end of the inner windings being connected to a common neutral.

4. A sheath bonding system for a three-phase line comprising a pair of transformer cores, each leg of each of said cores having two windings thereon, one of each of said windings being connected to a winding on an adjacent leg, so that one of each of said windings is connected to the sheath of a phase conductor, and one of each of said windings being connected to a common grounded neutral.

5. A sheath bonding system for a three-phase line having insulating gaps separating the sheaths of adjacent lengths of conductors, comprising a pair of transformer cores, each of the legs of each core having a pair of windings thereon in insulated relation, each of said windings consisting of an odd number of half turns and provided with extending integral taps projecting axially of said windings at the ends thereof, said taps being bent to lie flat on the external periphery of said windings on opposite sides thereof and rolled to provide sockets for jumper connections.

6. In a sheath bonding transformer of the class described, a transformer core having a plurality of legs, each of said legs having sheet copper windings thereon, the ends of each winding being folded over to extend at right angles to the length of the sheet and being rolled on the surface of said winding to provide terminal connecting cylinders disposed at an angle to a transverse plane through said winding.

7. A sheath bonding transformer for a three-phase line having insulated gaps separating the sheath lengths of said line, comprising a transformer core, each of the legs of said core having a pair of windings thereon in insulated relation, each of said windings consisting of an odd number of half-turns whereby the ends of each winding are disposed on opposite sides of said legs.

8. A sheath bonding transformer for a three-phase line having insulated sheath sections, comprising a transformer core having three legs, each of said legs having a pair of windings thereon, one end of each pair of windings being connected to an end of a winding on another leg of said transformer, and each of said windings consisting of an odd number of half-turns whereby the end connections between windings are all on the same side of said core.

9. A sheath bonding system for a three-phase line having electrically discontinuous sheath sections, comprising a transformer core having three legs, each of said legs having a pair of windings thereon, each of said windings consisting of an odd number of half-turns, the end of each winding terminating on opposite sides of the respective leg, and taps at the end of each winding, one tap of one winding on each of said legs being
10. A sheath bonding system for a three-phase line having electrically discontinuous sheath sections, comprising a transformer core having three legs, each of said legs having a pair of windings thereon, each of said windings consisting of an odd number of half-turns, the end of each winding terminating on opposite sides of the respective leg, taps at the end of each winding, one tap of one winding on each of said legs being connected to a sheath at one end of a sheath section, and one tap of one winding on each of said legs being connected to a common neutral.

11. In a sheath bonding transformer of the class described, a transformer case, a transformer core closely fitting in said case and having a plurality of legs, each of said legs having an inner and an outer winding of sheet copper, a sheet of insulating material wound with the sheet of copper in each winding, each of said windings consisting of an odd number of half turns to provide end connections at opposite sides of said legs, whereby jumpered connection between windings on different legs can be accommodated on one side of said core.

12. In a sheath bonding system of the class described, a transformer core leg, a sheet of copper of a width less than the length of said leg wound thereabout simultaneously with a wider sheet of insulation to form a substantially rectangular shaped winding, the inner end of said copper sheet being split longitudinally and folded over to form a tab extending normal to the length of said sheet and projecting out of said winding on one end thereof, the outer end of said sheet being similarly folded to extend in either direction on the opposite side of said winding, a second winding insulated from and corresponding to said first winding and having tabs extending parallel to said tabs of said first winding on opposite sides of said winding, all of said tabs having rolled portions for receiving jumper connectors.

13. A sheath bonding system for connection to the sheaths of phase conductors upon opposite sides of insulating sleeves in an alternating-current line, the transformer being characterized by zigzag connections between windings around at least two legs of the transformer, and connection from each sheath conductor winding to a common neutral disposed between the windings from opposite sides of said sleeves.

14. A sheath bonding system for a three-phase line having electrically discontinuous sheath sections, comprising a bonding transformer at the ends of each section, connections from the sheaths at each end of said section to transformer windings on said transformers, each of said transformers being characterized by zigzag connections between windings around at least two legs of the transformer, and connection from the ends of said windings to a common neutral.

15. A sheath bonding system for a three-phase line having insulated sheath sections, comprising a transformer core, connections from the sheaths at one end of any said sections to windings on said core, said windings being characterized by zigzag connections between coils on at least two of the legs of said core, and a common neutral terminating all of said windings.

16. A sheath bonding system for a three-phase line having electrically discontinuous sheath sections, comprising a transformer core, connecting means from the adjacent ends of each sheath in a sheath section to windings characterized by zigzag connections between coils on said core and terminating in a common neutral, and a metal transformer case receiving said transformer core and windings and acting as a secondary for said transformer.

17. A sheath bonding system for a three-phase line having electrically discontinuous sheath sections which are subjected to irregular submersion in water, comprising a transformer core, windings thereon, a common neutral, and connecting means from the sheath sections of the three phases through said windings on the core to said neutral, said core and windings being proportioned to have an electrical impedance considerably less than the leakage resistance between sheath sections caused by said submersion.

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