A bushing for a power system and system comprising such a bushing

It is presented a bushing (1) comprising a condenser core (3) arranged to house an electrical conductor (15) along a central axis (X) of the condenser core (3), wherein the condenser core (3) has a tapering end portion (3-2a) arranged to be in contact with a fluid dielectric having higher dielectric withstand strength than air, the tapering end portion (3-2a) presenting a surface having a first portion (4-1) with a first inclination (I-1) in the axial direction and a second portion (4-2) with a second inclination (I-2) in the axial direction, which second inclination (I-2) differs from the first inclination (I-1), wherein the first portion (4-1) and the second portion (4-2) define planes that intersect the central axis (X). A system comprising such a bushing is also presented herein.
The present disclosure generally relates to insulation in power systems and in particular to a bushing and a system comprising such a bushing.

In power transmission and power distribution networks, a bushing is an insulating structure used for leading an electrical conductor with a first electric potential through a surface or wall, such as a turret wall of a high voltage direct current (HVDC) transformer or an HVDC reactor, with a second electric potential.

In HVDC applications, a bushing should be designed taking both DC components and AC components into account. In such applications, the oil side of the bushing, where the electrical conductor in the bushing typically is interconnected with an electrical conductor of the electrical equipment, for instance the converter side windings of a transformer, is subjected to high electrical stress created by AC voltages, steady state DC voltages, and transient phenomenon. For this purpose, an insulation structure surrounding the oil side of the bushing is needed in the turret, the transformer tank or reactor tank. For some applications, the insulation structure may be large and complex.

A general object of the present disclosure is to provide a bushing with increased electrical withstand strength.

Another object is to provide a system comprising an inductive device and a bushing, for which inductive device the requirements on its insulation structure may be set lower than for a corresponding existing system.

Hence, according to a first aspect of the present disclosure there is provided a bushing comprising a condenser core arranged to house an electrical conductor along a central axis of the condenser core, wherein the condenser core has a tapering end portion arranged to be in contact with a fluid dielectric having higher dielectric withstand strength than air, the tapering end portion presenting a surface having a first portion with a first inclination in the axial direction and a second portion with a second inclination in the axial direction, in which second inclination differs from the first inclination, wherein the first portion and the second portion define planes that intersect the central axis.

By providing a bushing which has a tapering end portion having a first portion and a second portion, each with a different inclinations in the axial directions, the distance from the bushing boundary to interior components of the bushing is controlled along said end portion. Thereby the creep stress or tangential stress along the tapering end portion can be controlled. Controlling the creep stress along the tapering end portion is beneficial for the performance of the turret and bushing insulation of e.g. an inductive device such as a transformer which can be used with the bushing, and the shape of the end portion can increase the dielectric withstand strength and reduce the amount, complexity and cost of the turret insulation structure.

According to one embodiment, the first portion and the second portion form a concave region of the tapering dielectric fluid medium side end portion.

According to one embodiment, the concave region is at least 20% of the length of the tapering dielectric fluid medium side end portion.

According to one embodiment, tapering fluid medium side end portion of the condenser core comprises conductive layers concentrically arranged around the central axis, wherein the conductive layers are arranged in a stair-like formation axially, with an innermost conductive layer having an edge defining the first step and the outermost conductive layer having an edge defining the last step, and each conductive layer between the innermost conductive layer and the outermost conductive layer having an edge defining at least part of an intermediate step.

According to one embodiment, the tangent between the edge of the innermost conductive layer and the edge of the outermost conductive layer is not tangential to at least one edge of a conductive layer arranged between the innermost conductive layer and the outermost conductive layer.

Thereby two degrees of freedom can be used when designing the bushing, i.e. the curvature of the tapering end portion and the axial curvature provided by the edges of the conductive layers. The axial curvature of the conductive layers can be designed to provide an advantageous axial voltage distribution and the axial curvature of the tapering end portion provides the distance between the conductive layer and said end portion, whereby optimal bushing designs may be provided by combining the above mentioned design parameters.

According to one embodiment, the edges of at least some of the conductive layers define a locally concave profile of the conductive layers.

With a locally concave profile is herein meant that a curvature defined by the edges of at least some of the conductive layers is concave, wherein the profile of all of the conductive layers may have a more complex shape than concave.

According to one embodiment, the tapering end portion is an oil side end portion of the bushing.

According to one embodiment, the surface of the tapering end portion is an external surface of the bushing.

According to one embodiment, the surface of the tapering end portion comprises cellulose material.

According to one embodiment, the tapering end portion is rotationally symmetric.
[0019] According to one embodiment, the bushing is an HVDC bushing.

[0020] The bushing may advantageously be used with an inductive device. Thus according to a second aspect of the present disclosure there is provided a system comprising an inductive device and a bushing according to the first aspect presented herein, wherein the bushing may be arranged in an opening of the housing of the inductive device.

[0021] According to one embodiment, the inductive device is an HVDC transformer.

[0022] According to one embodiment, the inductive device is an HVDC reactor.

[0023] Generally, all terms used in the claims are to be interpreted according to their ordinary meaning in the technical field, unless explicitly defined otherwise herein. All references to "a/an/the element, apparatus, component, means, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, etc., unless explicitly stated otherwise.

BRIEF DESCRIPTION OF THE DRAWINGS

[0024] The specific embodiments of the inventive concept will now be described, by way of example, with reference to the accompanying drawings, in which:

- Fig. 1 is a schematic side view of an example of a bushing;
- Fig. 2 is a portion of the bushing in Fig. 1;
- Figs 3a-c are schematic views of variations of the bushing in Fig. 1; and
- Fig. 4 is a system comprising the bushing of Fig. 1 and an inductive device.

DETAILED DESCRIPTION

[0025] The inventive concept will now be described more fully hereinafter with reference to the accompanying drawings, in which exemplifying embodiments are shown. The inventive concept may, however, be embodied in many different forms and should not be construed as limited to the embodiments set forth herein; rather, these embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the inventive concept to those skilled in the art. Like numbers refer to like elements throughout the description.

[0026] Fig. 1 depicts a schematic side view of a bushing 1. The bushing 1 is an electrical insulator for insulating an electrical conductor which is to be lead through a surface, such as a wall, having a different electric potential than the electrical conductor.

[0027] The bushing 1 has a condenser core 3. The condenser core 3 is arranged to house an electrical conductor along a central axis X of the condenser core 3. Conductive layers C are arranged concentrically around the central axis X, and housed in the condenser core 3. The condenser core 3 has a surface 3a acting as an external surface or cover of the conductive layers 6.

[0028] The bushing 1 has a first portion 3-1, a second portion 3-2, and a mounting flange 3-3 separating the first portion 3-1 from the second portion 3-2 of the bushing 1. The first portion 3-1, the flange 3-2 and the second portion 3-2 defines the total axial length of the bushing 1.

[0029] The first portion 3-1 is arranged for extension in a first type of medium, and the second portion 3-2 is arranged to for extension in a second type of medium.

[0030] The first type of medium and the second type of medium may be the same medium or they may be different media. The first medium may for instance be oil, an insulating gas such as SF₆, or air, depending on the bushing type and application. The second medium may be any dielectric fluid having a dielectric withstand strength that is higher than the dielectric withstand strength of air. Such medium may for instance be transformer oil or SF₆.

[0031] At least one of the first portion 3-1 and the second portion 3-2 has a tapering end portion. Although in the following examples the tapering end portion 3-2a of the second portion 3-2 is described, it is to be noted that this design could be applied to the first end portion as well, if the external surface of the first end portion is arranged to be in contact with a dielectric fluid having higher dielectric withstand than air. Such dielectric fluids can for example be oil or an insulating gas such as SF₆.

[0032] Fig. 2a shows a portion of a schematic cross-sectional side view of the second portion 3-2. The second portion 3-2 is arranged to be in contact with a dielectric fluid with greater dielectric withstand strength than air. Since the second portion 3-2, and thus also the tapering end portion 3-2a, is arranged to be in contact with a dielectric fluid with greater dielectric withstand than air, the design of the second portion differs from the design of an air side bushing portion.

[0033] The tapering end portion 3-2a has a first portion 4-1 with a first inclination 1-1 in the axial direction and a second portion 4-2 with a second inclination 1-2 in the axial direction. The second inclination 1-2 differs from the first inclination 1-1. Thus, the tapering end portion 3-2a changes inclination in the axial direction. Moreover, the first portion 4-1 and the second portion 4-2 define planes that intersect the central axis X. Thus, the inclination of both the first portion 4-1 and the second portion 4-2 define planes that are non-parallel with the central
axis X. Hence, the tapering end portion 3-2a has a non-conical profile.

According to one embodiment, the first portion 4-1 is adjacent the second portion 4-2 in the axial direction. The region where the first portion 4-1 joins the second portion 4-2 is curved in towards the interior of the condenser core 3. Hence, the first portion 4-1 and the second portion 4-2 form a concave region 5-1. The concave region 5-1 is at least 20% of the length of the tapering end portion 3-2a.

As one alternative to the concave design of the tapering end portion 3-2a profile, the first inclination and the second inclination may define a convex profile of the dielectric fluid medium side end portion. It is to be noted that other profile shapes of the tapering dielectric fluid medium side end portion are also envisaged. Moreover, embodiments with more than one inclination change in the axial direction are also contemplated.

The axial location where the first portion 4-1 joins the second portion 4-2 may be selected depending on the particular application. Such selection may for instance by based on computer simulations of the resistive voltage distribution on the condenser core for that application for different inclinations and different axial locations of where the first portion 4-1 joins the second portion 4-2. The selection of inclination values and location where the first portion 4-1 joins the second portion 4-2 is determined based on the most advantageous resistive voltage distribution for that application.

The surface 3a of the condenser core 3 may be machined during manufacturing so as to provide the first portion 4-1 with the first inclination I-1 and the second portion 4-2 with the second inclination 1-2. To this end, the condenser core 3 may for instance comprise a cellulosic material such as paper.

Referring to Fig. 3a, the tapering end portion 3-2a of the condenser core 3 is shown. The condenser core 3 comprises conductive layers C-1, C-2, C-3, C-4 concentrically arranged around the central axis X. The conductive layers C-1, C-2, C-3, C-4 may for instance be metal foils.

The conductive layers are arranged in a stair-like formation axially, with an innermost conductive layer C-1 having an edge E-1 defining the first step and the outermost conductive layer C-4 having an edge E-4 defining the last step. Each conductive layer C-2, C-3 between the innermost conductive layer C-1 and the outermost conductive layer C-4 has an edge E-2, E-3 defining at least part of an intermediate step. Thus each intermediate conductive layer C-2, C-3 either defines an intermediate step by itself, or forms an intermediate step together with one or more adjacent conductive layers, if several adjacent conductive layers have edges at the same axial position.

In the example in Fig. 3a the radial distance \( \Delta r \) (x) between the edges of the conductive layers and the surface 3a of the condenser core 3 varies in the axial direction X in the tapering end portion 3-2a of the bushing 1. However, variations of the bushing where the radial distance is constant, i.e. when the edges of the conductive core follow the profile of the condenser core and thus are located at the same or essentially the same radial distance from the surface of the tapered end portion are also envisaged. By being able to select the profile of both the conductive layers and the profile of the condenser core, the distance between the edges and the surface of the condenser core can be controlled. Hence, two degrees of freedom can be obtained for the bushing design, increasing the possibility of creating a bushing design with good creep stress characteristics.

According to one example, as shown in Fig. 3b, the tangent T between the edge E-1 of the innermost conductive layer C-1 and the edge E-4 of the outermost conductive layer C-4 is not tangential to at least one edge of a conductive layer C-2, C-3 arranged between the innermost conductive layer C-1 and the outermost conductive layer C-4. Thereby, the edges of the conductive layers C-1, C-2, C-3, C-4 can define a concave profile P of the stair-like formation of the conductive layers C-1, C-2, C-3, C-4.

It is to be noted that the inclination change of the tapering dielectric fluid medium side end portion 3-2a relative the conductive layer 6 is exaggerated for illustrative purposes.

Fig. 3c shows an another example of a bushing 1 for which the tapering end portion 3-2a has a third portion 4-3 with a third inclination 1-3 which differs from the first inclination I-1. The third portion 4-3 defines a plane that intersects the central axis X. The first portion 4-1 and the third portion 4-3 form a convex region 5-2 of the tapering end portion 3-2a.

In this example, the first portion 4-1, the second portion 4-2 and the third portion 4-3 have a total length corresponding to at least 20% of the tapering end portion 3-2a.

Further variations of the shape of the tapering end portion include a continuous curve shape, i.e. a smooth curve, which locally may be concave or convex. In this context, a first and/or second portion of the tapering end portion can be an arbitrarily short portion for which its inclination is constant.

According to any example presented herein, the surface 3a of the tapering end portion 3-2a may either be an external surface of the bushing 1, or it may be covered by an insulating bushing cover, for instance made of porcelain or a composite material. In those cases when the tapering end portion is covered by an insulating bushing cover, dielectric fluid is provided between the surface of the condenser core and the insulating bushing cover.

According to any example presented herein the tapering end portion 3-2a may be rotationally symmetric with respect to the central axis X.

Fig. 4 shows a schematic view of a system 8 comprising an inductive device 10 and bushing 1. In the example the inductive device 10 has a turret with an
opening in which the bushing 1 is arranged. The bushing 1 has an electrical conductor 15 extending along the central axis X through the bushing 1. The electrical conductor is interconnected with an inductive arrangement, such as windings, in the interior 14 of the inductive device 10. The interior 14 may be filled with a dielectric medium such as insulating oil for protecting and cooling the inductive device 10.

0049 The inductive device 10 can for instance be an HVDC transformer, wherein the bushing 1 may be a converter side bushing or a line side bushing of the HVDC transformer, or an HVDC reactor.

0050 The bushing presented herein can beneficially be used for medium voltage and high voltage applications in power distribution or power transmission applications. The bushing may be used in direct current systems or alternating current systems.

0051 The inventive concept has mainly been described above with reference to a few examples. However, as is readily appreciated by a person skilled in the art, other embodiments than the ones disclosed above are equally possible within the scope of the inventive concept, as defined by the appended claims.

Claims

1. A bushing (1) comprising a condenser core arranged to house an electrical conductor (15) along a central axis (X) of the condenser core (3), wherein the condenser core (3) has a tapering end portion (3-2a) arranged to be in contact with a fluid dielectric having higher dielectric withstand strength than air, the tapering end portion (3-2a) presenting a surface having a first portion (4-1) with a first inclination (I-1) in the axial direction and a second portion (4-2) with a second inclination (I-2) in the axial direction, which second inclination (I-2) differs from the first inclination (I-1), wherein the first portion (4-1) and the second portion (4-2) define planes that intersect the central axis (X).

2. The bushing (1) as claimed in claim 1, wherein the first portion (4-1) and the second portion (4-2) form a concave region of the tapering end portion (3-2a).

3. The bushing (1) as claimed in claim 2, wherein the concave region is at least 20% of the length of the tapering end portion (3-2a).

4. The bushing as claimed in any of the preceding claims, wherein the tapering end portion (3-2a) of the condenser core comprises conductive layers (C-1, C-2, C-3, C4) concentrically arranged around the central axis (X), wherein the conductive layers (C-1, C-2, C-3, C4) are arranged in a stair-like formation axially, with an innermost conductive layer (C-1) having an edge (E-1) defining the first step and the outermost conductive layer (C-4) having an edge (E-4) defining the last step, and each conductive layer (C-2, C-3) between the innermost conductive layer (C-1) and the outermost conductive layer (C-4) having an edge (E-2, E-3) defining at least part of an intermediate step.

5. The bushing as claimed in claim 4, wherein the tangent between the edge (E-1) of the innermost conductive layer (C-1) and the edge (E-4) of the outermost conductive layer (C-4) is not tangential to at least one edge (E-2, E-3) of a conductive layer (C-2, C-3) arranged between the innermost conductive layer (C-1) and the outermost conductive layer (C-2).

6. The bushing (1) as claimed in claim 4 or 5, wherein the edges (E-1, E-2, E-3) of at least some of the conductive layers (C-2, C-3) define a locally concave profile of the conductive layers.

7. The bushing as claimed in any of the preceding claims, wherein the tapering end portion (3-2a) is an oil side end portion of the bushing.

8. The bushing (1) as claimed in any of the preceding claims, wherein the surface of the tapering end portion (3-2a) is an external surface of the bushing.

9. The bushing (1) as claimed in any of the preceding claims, wherein the condenser core (3) comprises cellulose material.

10. The bushing (1) as claimed in any of the preceding claims, wherein the tapering end portion (3-2a) is rotationally symmetric.

11. The bushing (1) as claimed in any of the preceding claims, wherein the bushing (1) is an HVDC bushing.

12. A system (8) comprising an inductive device (10) having an opening and a bushing (1) according to any of claims 1-11 for arrangement in the opening of the inductive device (10).

13. The system (8) as claimed in claim 12, wherein the inductive device (10) is an HVDC transformer.

14. The system (8) as claimed in claim 12, wherein the inductive device (10) is an HVDC reactor.
### DOCUMENTS CONSIDERED TO BE RELEVANT

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The present search report has been drawn up for all claims

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**Place of search**
The Hague

**Date of completion of the search**
24 May 2012

**Examiner**
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ANNEX TO THE EUROPEAN SEARCH REPORT
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