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(54) **INSULATING LIQUID AND INDUCTIVE ARRANGEMENT COMPRISING A CONTAINER WITH INSULATING LIQUID**

(57) The present disclosure relates to an insulating liquid (26) for an enclosure (24) intended to enclose an inductive device comprising a winding (20) surrounded by solid insulation (22) as well as to an inductive arrangement comprising a container (24) with such an inductive device (12) and insulating liquid (26). The insulating liquid (26) comprises a first main component in the form of a

first oil having an equilibrium resistivity of at least 10^{13} ohm metres and at least one second auxiliary component in the form of a second oil or additive having a lower equilibrium resistivity causing the equilibrium resistivity of the insulating liquid to be at least 10^{11} ohm metres and at most half the value of the equilibrium resistivity of the first oil when in use in the enclosure.

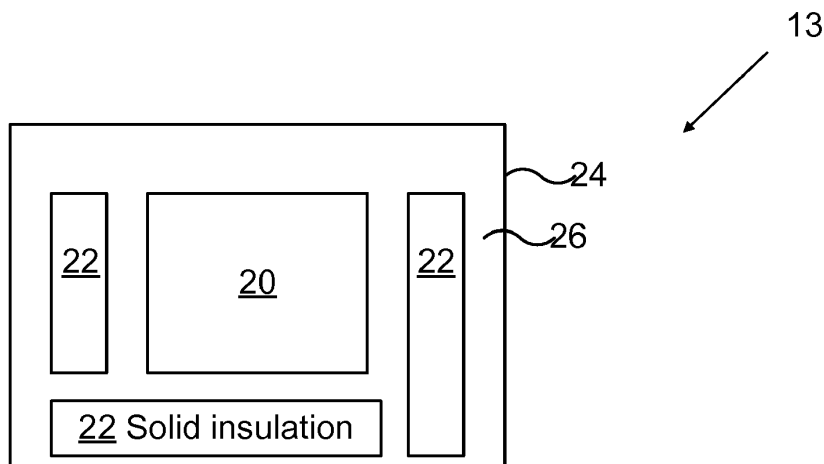


Fig. 2

Description

TECHNICAL FIELD

[0001] The present disclosure relates to an insulating liquid for an enclosure intended to enclose an inductive device as well as to an inductive arrangement comprising a container with an inductive device and insulating liquid.

BACKGROUND

[0002] Inductive devices, such as transformers, are important equipment in a wide variety of electrical environments. One such environment is the High Voltage Direct Current (HVDC) environment, where the transformer is subject to strong electrical DC potential fields.

[0003] The dielectric insulation in converter transformers usually comprises liquid insulation, such as in the form of mineral oil, and solid insulation, such as cellulose like paper and pressboard. Solutions with alternative liquids such as synthetic esters are also considered. The solid insulation is then typically impregnated by the liquid as well as surrounded by it.

[0004] Because of the strong electrical DC potential fields that the transformer and its insulation is subjected to, the resistivity of the oil is an important factor.

[0005] GB 611254 discusses the resistivity of a mineral oil to which additives have been added. The document is more particularly concerned with electric capacitors, which contain mineral oil impregnated spacers as a dielectric material. According to the document capacitors containing mineral oil exhibit marked improvement in high temperature operating stability and in life duration when the mineral oil contains a small amount of beta naphthol. An addition of beta naphthol is described as resulting in a marked decrease in the resistivity of the oil. The stabilizing effect of the beta naphthol appears to be related to the effect of electric stress on the mineral oil at elevated temperatures.

[0006] When using a mineral or ester oil as liquid insulation together with solid insulation of cellulose such as pressboard and paper, the resistivity of the oil is much lower than the impregnated cellulose material.

[0007] Recently a new type of liquid insulation has emerged, the so-called Gas-to-Liquid (GTL) oil. This liquid has a high degree of purity. It is essentially sulphur-free. This type of oil is of interest to use in transformers for a variety of reasons. However, due to its purity, the resistivity of the oil is high. The resistivity is significantly higher than the resistivity of mineral oil. This changes the ratio between the resistivities of the oil and the cellulose.

[0008] Transformers that experience strong electrical DC potential fields are subjected to DC stress. After the DC voltage has been applied for some time, this DC stress is typically higher in the impregnated cellulose insulation compared to the liquid. This is advantageous since the impregnated cellulose has a higher dielectric withstand capability. The impregnated cellulose gets

more stressed since it usually has a higher effective resistivity than the liquid. For GTL and GTL impregnated cellulose the effective resistivity of the liquid is larger than the impregnated cellulose. This means that DC electric field is shifted to the liquid instead which is dielectrically weaker than impregnated cellulose and this has adverse effects on the insulation system.

[0009] There is thus a need for reducing the stress of such insulating liquid.

SUMMARY

[0010] A first aspect of the invention is directed towards an insulating liquid for an enclosure intended to enclose an inductive device comprising a winding surrounded by solid insulation, the insulating liquid comprising:

- a first main component in the form of a first oil having an equilibrium resistivity of at least 10^{13} ohm metres and at least one second auxiliary component in the form of a second oil or additive having a lower equilibrium resistivity causing the equilibrium resistivity of the insulating liquid when in use in the enclosure to be at least 10^{11} ohm metres and at most half the value of the equilibrium resistivity of the first oil.

[0011] The equilibrium resistivity of the first oil may additionally be higher than $8 \cdot 10^{13}$ ohm meter and the equilibrium resistivity of the liquid insulation may be in the range $10^{11} - 4 \cdot 10^{13}$ ohm meter. The equilibrium resistivity of the insulating liquid may additionally be lowered so that it is in the range $10^{11} - 2.5 \cdot 10^{13}$ ohm metres.

[0012] The equilibrium resistivity of the second component is thus lower than the equilibrium resistivity of the first main component.

[0013] The first oil may be a gas to liquid oil. It may more particularly be a hydrocarbon oil having an equilibrium resistivity above $1 \cdot 10^{14}$ ohm metres. As an alternative it may be a hydrocracked isoparaffinic oil.

[0014] The additive may be an additive in the group of organic acids, metal and ammonium salts of organic acids, a mixture of organic acids and metal and ammonium salts of organic acids, carbon black and alcohols like phenols or naphthols, such as beta naphthol. The additive may be added in an amount in the range of 0.001 - 1 percent by weight, with advantage in an amount in the range of 0.01 - 1 percent by weight and preferably in an amount in the range of 0.1 - 1 percent by weight. The rest of the liquid insulation may be the first oil.

[0015] The second oil may be a mineral oil. It may also be a synthetic or natural ester oil. When the second oil is mineral oil, it may be added in an amount in the range of 5 - 49 percent by weight. The mineral oil may with advantage be added in an amount in the range of 10 - 49 percent by weight. In case the second oil is a natural or synthetic ester, the second component may be present in an amount in the range of 1 - 40 percent by weight and more preferably in an amount in the range of 2 - 20 per-

cent by weight. In both cases the rest of the liquid insulation may be the first oil.

[0016] A second aspect of the invention is directed towards an inductive arrangement comprising a container with a winding of an inductive device surrounded by solid insulation, where the container is filled with an insulating liquid comprising a first main component in the form of a first oil having an effective resistivity that is higher than the effective resistivity of the solid insulation and at least one second auxiliary component in the form of a second oil or additive having a lower equilibrium resistivity causing the effective resistivity of the insulating liquid to be lower than the effective resistivity of the solid insulation.

[0017] The effective resistivity of the at least one second auxiliary component is thus lower than the equilibrium resistivity of the first main component. The effective resistivity of the solid insulation may be 1 - 10 times higher than the effective resistivity of the insulating liquid during steady state operation. Steady state operation may in this case be operation that has lasted at least in the range between 10 and 90 minutes and as an example for at least 60 minutes.

[0018] The equilibrium resistivity may be the resistivity when the insulating liquid is subjected to an electrical field strength of below 0.01 kV/mm in an electrical direct or slowly varying alternating current potential field. The variation is typically a variation with a frequency below 10 mHz. The equilibrium resistivity may additionally be obtained at room temperature, such as at a temperature in an interval of 20 - 25 °C.

[0019] The effective resistivity may be the resistivity when the enclosure is subjected to an electrical field strength in the range 1 - 10 kV/mm in an electrical direct current potential field during steady state operation. Additionally, the electrical field strength may be the field strength obtained during steady state operation of the inductive arrangement.

[0020] The invention has a number of advantages. It lowers the oil stress that may be experienced by the insulating liquid in strong electrical direct current potential fields. The invention also improves the reliability and safety of an inductor arrangement having an insulating liquid that is based on the first oil. It also allows the insulating liquid to be tailored after the environment in which it is to be used.

[0021] 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, step, etc." are to be interpreted openly as referring to at least one instance of the element, apparatus, component, means, step, etc., unless explicitly stated otherwise. The steps of any method disclosed herein do not have to be performed in the exact order disclosed, unless explicitly stated. The use of "first", "second" etc. for different features/components of the present disclosure are only intended to distinguish the features/components from other similar features/compo-

nents and not to impart any order or hierarchy to the features/components.

BRIEF DESCRIPTION OF THE DRAWINGS

[0022] Embodiments will be described, by way of example, with reference to the accompanying drawings, in which:

Fig 1 schematically illustrates two transformers connected to two converters of an HVDC converter station, and

Fig. 2 schematically shows a liquid-filled transformer, in accordance with an embodiment of the present invention.

DETAILED DESCRIPTION

[0023] Embodiments will now be described more fully hereinafter with reference to the accompanying drawings, in which certain embodiments are shown. However, other embodiments in many different forms are possible within the scope of the present disclosure. Rather, the following embodiments are provided by way of example so that this disclosure will be thorough and complete, and will fully convey the scope of the disclosure to those skilled in the art. Like numbers refer to like elements throughout the description.

[0024] The invention is concerned with insulation used for inductive devices such as transformers and more particularly with liquid insulation provided for such inductive devices. However, before this is discussed in more detail, the environment of such an inductive device will first be described with reference being made to fig. 1.

[0025] Figure 1 illustrates an inductive device 12 in a converter station 10. The inductive device 12 is a first transformer and this first transformer is connected to the Alternating Current (AC) side of a first converter 14. The first converter 14 has a direct current (DC) side connected to a first pole P1 of a high Voltage Direct Current (HVDC) system. Thereby the first converter 14 is also an AC/DC converter. There is also a second transformer 16 connected to an AC side of a second AC/DC converter 18, which converter has a DC side connected to a second pole P2 of the HVDC system. Both converters 14 and 18 are also connected to a neutral line which is grounded. The first pole P1 may here have a high positive electric potential, while the second pole P2 may have a second low electric potential. A potential may be in the range 100 - 1100 kV, 300 - 1100 kV or 500 - 1100 kV. As an example, the first potential P1 may be +800 kV and the second potential -800kV. In the system it is also possible that there is polarity reversal. That is in the given example, the first pole P1 may change from having a potential of +800 kV to having a potential of -800 kV, while the second pole P2 may change from having a potential of -800 kV to having a potential of +800 kV.

[0026] The system in fig. 1 is merely an example. It should be realized that the present invention is in no way limited to the shown HVDC system or in fact any DC systems. The inductive device is also not limited to being a transformer. It may for instance be a reactor. However, what the figure shows is that an inductive device such as a transformer may experience high electric DC field strengths because of the environment in which it is provided even though it functions to transform between different AC levels.

[0027] Fig. 2 shows one realization of an inductive arrangement 13 comprising the inductive device in the form of the first transformer 12. The inductive arrangement 13 comprises an enclosure, for instance realized as a transformer tank 24, which enclosure comprises transformer windings 20 of the transformer and solid insulation 22, typically cellulose-based such as pressboard and/or paper. The solid insulation typically surrounds the windings 20. The cellulose is furthermore impregnated in an insulating liquid, which may be the liquid insulation described below or another liquid insulation, such as mineral oil or an ester. Impregnated cellulose typically has a resistivity that is above 10^{14} ohm meters and sometimes also above 10^{15} ohm meters. In the tank 24 there is also liquid insulation 26.

[0028] The liquid insulation 26 is based on a first oil, which in various embodiments is a hydrocarbon oil such as a gas-to-liquid (GTL) oil. This oil may be an isoparaffinic oil with uniform molecular structure and low impurity levels and may additionally be essentially sulphur-free. The oil may as an example be Diala S4 ZX-I from Shell. As an alternative, the first oil may be a hydrocracked isoparaffinic oil. This type of oil may have a high dc field resistivity than the solid insulation. The equilibrium resistivity of the first oil is typically at least 10^{13} ohm metres. It may be higher than $8 \cdot 10^{13}$ ohm meter and with advantage above 10^{14} ohm metres. The equilibrium resistivity of the first oil is the resistivity when it is subjected to an electrical field strength of below 0.01 kV/mm in an electrical direct or slowly varying alternating current potential field. The variation is typically a variation with a frequency below 10 mHz. The equilibrium resistivity may additionally be obtained at room temperature, such as at a temperature in an interval of 20 - 25 C°.

[0029] It is in many cases desirable to use such an oil as liquid insulation in an inductive device. One reason may be that the oil is biodegradable. The use of such an oil may thus be environmentally friendlier than conventional oils.

[0030] Moreover, through the transformer being placed in the vicinity of a high electrical potential, such as the potential of the first pole P1 shown in fig. 1, the transformer 12 with solid and liquid insulation 22 and 26 will experience high electrical DC field strengths.

[0031] It is advantageous if the electrical stress caused by such high electrical DC field strengths is experienced by the solid insulation.

[0032] However, this will typically not be the case if the

GTL oil is used as liquid insulation, due to it having a higher resistivity than the solid insulation.

[0033] Thereby it is possible that there occurs electric field shifting to the oil, which has a substantially lower withstand capability compared to the solid insulation. Through the oil having a higher resistivity than the solid insulation, the oil is stressed and this may lead to breakdown.

[0034] Also, when performing DC withstand tests it is important that almost all the stress is accommodated over the solid insulation.

[0035] For polarity reversal it is desirable to have an oil resistivity which is less than but close to that of the impregnated cellulose. This ensures that some stress remains in the oil prior to the polarity reversal limiting the stress in the oil directly after polarity reversal, while making sure most of the stress is over the cellulose after some time

[0036] In order to address this the first oil used in the enclosure is a first main component of the insulating liquid, which insulating liquid has also received at least one second auxiliary component in the form of a second oil and/or an additive having a lower equilibrium resistivity than the first oil. The addition of the second auxiliary component thereby causes the equilibrium resistivity of the insulating liquid to be lowered when in use in the enclosure. According to an aspect of the invention the second component is added in an amount that causes the equilibrium resistivity of the insulating liquid to be at least 10^{11} ohm metres and at most half the value of the equilibrium resistivity of the first oil. When the equilibrium resistivity of the first oil is higher than $8 \cdot 10^{13}$ ohm meter, the equilibrium resistivity of the liquid insulation may be in the range $10^{11} - 4 \cdot 10^{13}$ ohm meter. The equilibrium resistivity of the liquid insulation may furthermore be in the range $10^{11} - 2.5 \cdot 10^{13}$ ohm metres.

[0037] When the second component is mineral oil, this second component may be added in an amount in the range of 5 - 49 percent by weight or more preferably in an amount in the range of 10 - 49 percent by weight, with the rest being the first oil. In case the second component is a natural or synthetic ester, the second component may be present in an amount in the range of 1 - 40 percent by weight or more preferably in an amount in the range of 2 - 20 percent by weight, with the rest being the first oil. In case the second component is an additive, it may be added in an amount in the range of 0.001 - 1 percent by weight, more preferably in an amount in the range of 0.01 - 1 percent by weight and most preferably in an amount in the range of 0.1 - 1 percent by weight with the rest being the first oil.

[0038] Through the use of the second component, the resistivity is thus lowered and this may be used for improving the performance of a transformer that has liquid insulation based on the first oil.

[0039] The first liquid may thereby have received some additives or have been mixed with a second oil. Examples of a second oil are mineral oil or synthetic or natural ester

oils, where a mineral oil may have a paraffinic structure, a naphthenic structure and/or an aromatic structure. The mineral oil may additionally contain Nitrogen, Sulphur and/or Oxygen. One example of a natural oil is Nytro 10XN. A natural or synthetic ester may in turn be derived from an organic or inorganic acid and comprise at least one o-alkyl group in place of a hydroxyl group. One example of a synthetic ester is Midel 7131, while an example of a natural ester is FR3. When the second component is an additive it may be an additive in the group of organic acids, metal and ammonium salts of organic acids, a mixture of organic acids and metal and ammonium salts of organic acids. A salt of an organic acid may in this case be organoammonium, such as tetrabutyl ammonium. The additive may additionally be carbon based, such as carbon black, or comprise alcohols like phenols or naphthols, such as beta naphthol.

[0040] As was mentioned above, the equilibrium resistivity is the resistivity at equilibrium at low field strengths. However, as was also mentioned earlier the inductive device is typically to be used at high electrical field strengths.

[0041] The resistivity of insulating liquids is believed to have a heavy dependency on the field strength as well as the time during which it is subject to a certain DC field. The resistivity is dependent on the amount of molecules being ionized, (positive and negative ions). This amount is dependent on the electric field and consequently the resistivity of the liquid insulation will have a dependency on the electric field strength.

[0042] The resistivity may more particularly be considered to be inversely proportional to a sum of the ion mobilities of the positive and negative ions times the ion concentration times the elementary charge.

[0043] It may therefore be important that the added second components causes the liquid insulation to have a resistivity that has a certain relationship to the resistivity of the solid insulation when being operated in such strong fields. This type of resistivity is called an effective resistivity and is a resistivity when the inductive device is subjected to an electrical field strength in the range 1 - 10 kV/mm in an electrical direct current potential field. The effective resistivity may additionally be the resistivity obtained during steady state operation of the inductive arrangement for a set time. This time may range between 10 and 90 minutes and may as an example be 60 minutes.

[0044] The first oil may thereby have an effective resistivity that is higher than the effective resistivity of the solid insulation. The second component in this case also has a lower effective resistivity than the effective resistivity of the first main component. The second component may in this case be added in an amount causing the effective resistivity of the insulating liquid to be lower than the effective resistivity of the solid insulation. The second component may additionally be added in an amount causing the effective resistivity of the solid insulation to be 1 - 10 times higher than the effective resistivity of the insulating liquid.

[0045] It can in this way be seen that a resistivity ratio between solid and liquid insulation can be achieved where the liquid is less resistive than the solid. It is in this case possible that the liquid insulation still retains some electric stress. This removes the risks related to high resistive oils in inductive devices. It can be seen that the risk of excessive oil stress under DC may be eliminated and the stress under polarity reversal decreased. The resistivity of the liquid insulation can thus be adjusted such that the ratio between solid insulation resistivity and liquid insulation resistivity does not become as large as when mineral oil is used as liquid insulation. Since the amount of second component can be adjusted it will be possible to tailor the liquid insulation to the specific environment in which it is to be used. The insulation design may thereby be optimized.

[0046] The present disclosure has mainly been described above with reference to a few embodiments. 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 present disclosure, as defined by the appended claims.

Claims

1. An insulating liquid (26) for an enclosure (24) intended to enclose an inductive device comprising a winding (20) surrounded by solid insulation (22), the insulating liquid (26) comprising:
 - a first main component in the form of a first oil having an equilibrium resistivity of at least 10^{13} ohm metres and at least one second auxiliary component in the form of a second oil or additive having a lower equilibrium resistivity causing the equilibrium resistivity of the insulating liquid, when in use in the enclosure, to be at least 10^{11} ohm metres and at most half the value of the equilibrium resistivity of the first oil.
2. The insulating liquid according to claim 1, wherein the first oil is a gas to liquid oil or a hydrocracked isoparaffinic oil.
3. The insulating liquid according to claim 2, wherein the first oil is a hydrocarbon oil having an equilibrium resistivity above $1 \cdot 10^{14}$ ohm metres.
4. The insulating liquid according to previous claim, wherein the additive is an additive in the group of organic acids, metal and ammonium salts of organic acids, a mixture of organic acids and metal and ammonium salts of organic acids, carbon black and an alcohol like naphthol.
5. The insulating liquid according to any previous claim, wherein the second oil is a mineral oil.

6. The insulating liquid according to any of claims 1 - 4, wherein the second oil is a synthetic or natural ester oil.

7. A inductive arrangement (13) comprising a container (24) with a winding (20) of an inductive device (12) surrounded by solid insulation (22), the container (24) being filled with an insulating liquid (26) comprising a first main component in the form of a first oil having an effective resistivity that is higher than the effective resistivity of the solid insulation and at least one second auxiliary component in the form of a second oil or additive having a lower equilibrium resistivity causing the effective resistivity of the insulating liquid to be lower than the effective resistivity of the solid insulation.

8. The inductive arrangement according to claim 7, wherein the effective resistivity of the solid insulation is 1 - 10 times higher than the effective resistivity of the insulating liquid.

9. The inductive arrangement according to claim 7 or 8, wherein the first oil has an equilibrium resistivity of at least 10^{13} ohm metres and the insulating liquid has an equilibrium resistivity of at least 10^{11} ohm metres and at most half the value of the equilibrium resistivity of the first oil.

10. The inductive arrangement according to any of claims 7 - 9, wherein the first oil is a gas to liquid oil.

11. The inductive arrangement according to claim 10, wherein the first oil is a hydrocarbon oil having an equilibrium resistivity above $1 \cdot 10^{14}$ ohm metres.

12. The inductive arrangement according to any of claims 7 - 11, wherein the additive is an additive in the group of organic acids, metal and ammonium salts of organic acids, a mixture of organic acids and metal and ammonium salts of organic acids, carbon black and alcohols like phenols or naphthols.

13. The inductive arrangement according to any of claims 7 - 12, wherein the second oil is a mineral oil.

14. The inductive arrangement according to any of claims 7 - 12, wherein the second oil is a natural or synthetic ester oil.

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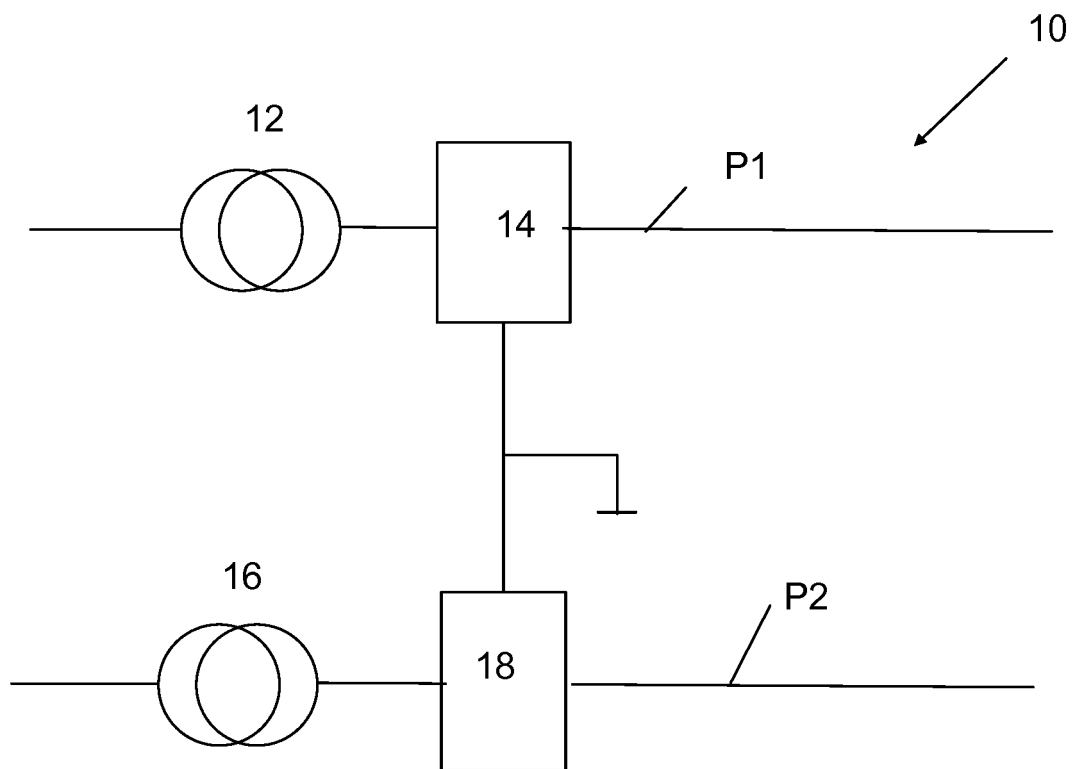


Fig. 1

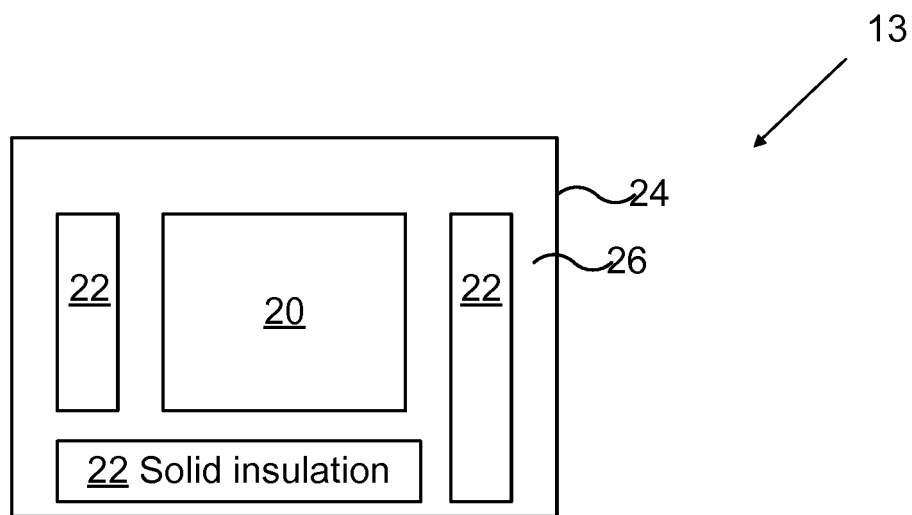


Fig. 2



EUROPEAN SEARCH REPORT

Application Number
EP 19 18 0578

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EPO FORM 1503 03.82 (P04C01)

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A		1-6, 8-11,13, 14	
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The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 20 November 2019	Examiner Greß, Tobias
CATEGORY OF CITED DOCUMENTS X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document		T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons & : member of the same patent family, corresponding document	

**ANNEX TO THE EUROPEAN SEARCH REPORT
ON EUROPEAN PATENT APPLICATION NO.**

EP 19 18 0578

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This annex lists the patent family members relating to the patent documents cited in the above-mentioned European search report.
The members are as contained in the European Patent Office EDP file on
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For more details about this annex : see Official Journal of the European Patent Office, No. 12/82

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