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(54) **TRANSFORMER FOR A MODULAR, POWER ELECTRONIC CONVERTER**

(57) A transformer for a modular converter comprises
a core (1) having a core window;
a first winding (20), in particular a high-voltage winding, surrounding a first section of the core, said first winding enclosed by an encapsulation (21) made from solid, electrically insulating material;
a second winding (30), in particular a low-voltage winding,

surrounding the first or a second section of the core; an electrically insulating supporting structure attached to the first winding, in particular to the encapsulation, for holding the first winding in a defined position relative to the core; wherein the supporting structure is not extending into the core window.

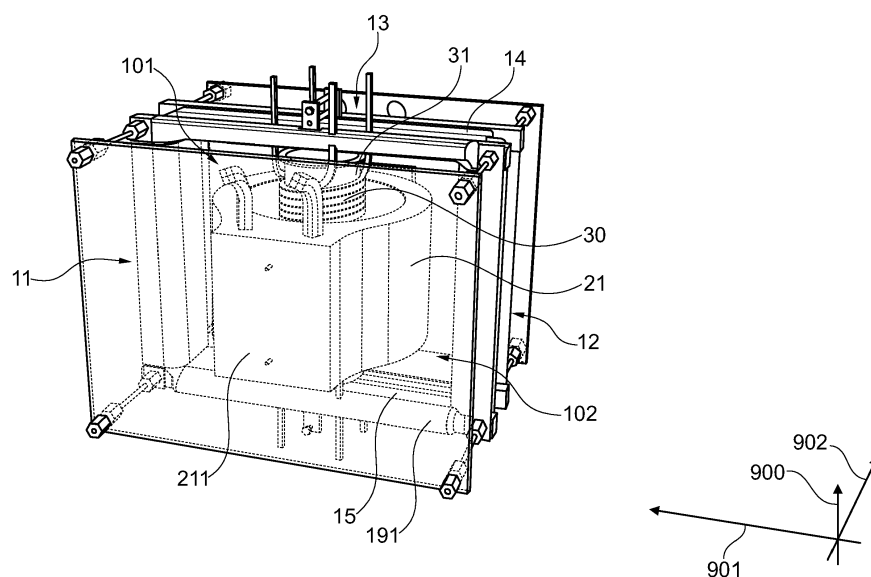


Fig. 3

Description

FIELD OF THE INVENTION

[0001] The invention pertains to the field of electrical power transformers. In particular, it relates to a transformer for a modular, power electronic converter, and to a method for assembling such a transformer, in accordance with the preamble of the independent patent claims.

BACKGROUND OF THE INVENTION

[0002] Electrical power transformers, also known as power-electronic transformers (PET), allow conversion of voltage and frequency with an additional benefit of providing galvanic insulation. In known, exemplary PETs, input DC is inverted to medium-frequency primary AC of e.g. 10 kHz and fed to a primary side of a medium-frequency transformer (MFT). A secondary AC from a secondary side of said MFT is rectified again to provide an output DC, generally having a lower voltage. Optionally, this output DC may be converted to AC again, which preferably has an output frequency of e.g. several 10 Hz. Likewise, the input DC may have been obtained from an AC source by means of a rectifier. A converter cell of a PET capable of performing this task is shown in Fig. 1.

[0003] PETs are, e.g. frequently used in modular converters for electric power supply of electric rail vehicles, e.g. trains or trams. Modular converters comprise a plurality of PET converter cells configured to produce from an AC input voltage a DC output voltage which -for traction applications - may be supplied to a drive unit or motor unit of the electric rail vehicle, but also to electrical installations on-board have recently received growing attention. Usually, the AC input voltage is supplied from a line, in particular an overhead line.

[0004] Exemplary modular converters are, e.g., described in WO 2014/037406 A1, DE 102010044322 A1, and EP 820893 A2, which are hereby included by reference in their entirety. The converters disclosed comprise a plurality of converter cells, connected in series on a primary side or line side of the modular converter, and in parallel on a secondary side or load side of the modular converter. Each converter cell comprises a resonant DC-to-DC converter as MFT, which is connected to the line via a primary AC-to-DC converter. In the resonant DC-to-DC converter, a DC-to-AC converter on the primary side is connected via a resonant transformer with a further AC-to-DC converter on the secondary side, in particular a motor side.

[0005] By connecting multiple converter cells in series on one side, and in parallel on the other side, it is possible to build galvanically insulated converters, e.g. from DC to DC, or from DC to AC. Due to the relatively high operating frequency of the MFT (e.g. 10 kHz as opposed to an output frequency of, say, 50 Hz) a size of the MFT can be kept small. The MFT is a central component in the converter cell. The size and cost of the MFT directly

influence the size and cost of the converter cell and thus of the PET. The requirements for an MFT are different from those for typical power transformers. Next to the voltage u_1 across a primary winding and the voltage u_2 across a secondary winding of the MFT, there is a voltage u_3 from secondary to primary winding. u_3 is either DC (if the converter cell is used in a DC converter, and without optional inverter), or low-frequency AC. In the second case, the frequency of u_3 is much lower than that of u_1 and u_2 , e.g. 50 Hz compared to 10 kHz. If many cells are connected in series on one side, then the magnitude of u_3 is much larger than that of u_1 and u_2 . For a modular converter with $N=24$ converter cells connected in series on the primary side and in parallel on the secondary side of said modular converter, when an input voltage of $U_1 = 24\text{kV}$ is applied to its primary side, for example, u_1 and u_2 may typically be about 1 kV, while u_3 may also be as high as 24kV. As a consequence, an electric insulation between the primary and secondary winding must be much significantly stronger than an insulation within a winding, generally referred to as inter-turn insulation. It is known that good insulation can be provided to transformers by submerging them into oil or by casting the transformer in a solid or jellylike insulation material like, e.g., silica gel. While oil transformers are well established and well known, so are their disadvantages. They need a tight containment and tight bushings. The quality of the oil needs to be monitored, and oil constitutes a risk with respect to fire. Casting a transformer fully in a solid or jellylike electric insulation material, on the other hand, generally generates a cooling problem, as heat can only be transferred by conduction, and thus not very efficiently. This is a concern in particular for MFTs, as their power density (and loss density) is typically relatively high, since their typical operating frequencies allow for a relatively small size.

[0006] While it is relatively straightforward to design a dry-type MFT relying on air only for insulation (and convective cooling) large clearances are required to provide sufficient electrical insulation, due to the magnitude of the voltage u_3 . In particular, these clearances need to be respected not only between high-voltage and low-voltage winding, but also between high-voltage winding and core, since the core is usually on ground potential. This leads to a generally unacceptable large size of a dry-type MFT. In particular, the high-voltage winding and the core will get uneconomically large and heavy. It is therefore advantageous to enclose, in particular to cast, both the low- and high-voltage winding in separate, solid insulations, with a first air gap in-between. Said first air gap enables efficient cooling similar to a purely air insulated system. However in contrast to the latter, the clearance distances can be kept significantly smaller. This is possible, since dielectric breakdown within the first air gap is generally acceptable in case of transient over-voltages such as, e.g., caused by a lightning impulse; while the solid insulation is dimensioned strong enough to withstand the transient overvoltage alone. It is, however, important that,

during normal operation, an electric field in the first air gap around the high-voltage winding is low enough to avoid partial discharges. In addition, the considerations as laid out above apply not only to the first air gap between the low- and high-voltage winding, but, in case of a grounded core, also to a second air gap between high-voltage winding and grounded core.

[0007] Exemplary dry-type transformers in accordance with the known art are built as illustrated in Fig. 2. The cast high-voltage windings 020 and low-voltage windings 030 are held in position with respect to an axial direction of said windings by means of insulating cushions 010 which are clamped between yokes of the core 1, or between a frame attached to the core, said frame being, in general, electrically conducting. The general function of the frame is to provide mechanical stability to the core, which may, in particular where the core has been assembled from a plurality of parts and/or sheets. In general, both core yokes and - if present - frame are electrically grounded. In this design, cushion interfaces 011 result between the cushion and the core yokes and, if present, between the cushion and the frame as indicated in Fig. 2. These cushion interfaces correspond - dielectrically - to microscopic air gaps in the solid insulation. The remainder of an insulating path between core (or frame) and high-voltage winding is formed by the cushion and the casting and lies within solid insulation material, which has a dielectric permittivity ϵ_r significantly larger than that of air. A typical value of filled epoxy resin as exemplary solid insulation material is $\epsilon_r = 4$ to 5, while $\epsilon_r = 1$ for air. This means that a capacitive electric field will concentrate in the microscopic air gaps, i.e. in the cushion interface, leading to partial discharge already at relatively low voltages. The dry-type transformer design based on cushions is therefore not suited for the high-voltage winding of a transformer with large voltage u_3 as described in the previous section. It is noted that it is very difficult - if not practically impossible - to completely avoid air inclusions - which effectively act as microscopic air gaps - at the cushion interfaces, even if the cushion is e.g. glued to the core, and/or the frame or the solid insulation around the winding.

[0008] It is an object of the invention to provide a transformer for a modular, power electronic converter and to a method for assembling such a transformer which overcome the disadvantages as described above, and that, in particular, satisfies the constraint with respect to the air gap as discussed above.

[0009] This object is achieved as described below, in particular by a transformer and by a method for assembling a transformer in accordance with the independent patent claims. Further exemplary embodiments are evident from the dependent claims and the following description.

SUMMARY OF THE INVENTION

[0010] Under one aspect of the present invention, a

transformer for a modular converter comprises

- a) a core having a core window;
- b) a first coil, said first coil comprising
 - i) a first winding, in particular a high-voltage winding, surrounding a first section of the core,
 - ii) an encapsulation made from solid, electrically insulating material and enclosing said first winding;
- c) a second winding, in particular a low-voltage winding, surrounding the first or a second section of the core;
- d) an electrically insulating supporting structure attached to the first winding, in particular to the encapsulation, for holding the first winding in a defined position relative to the core; wherein
- e) the supporting structure is not extending into the core window.

[0011] As the supporting structure does not extend into the core window, the use of cushions for supporting the first coil as known from the prior art becomes obsolete, and an occurrence of microscopic air gaps in solid insulation located within the core window, and preferably in a neighbourhood of the core window, may efficiently be avoided.

[0012] In accordance with another aspect of the invention, a method for assembling a transformer for a modular converter, the method comprising the steps of

- a) providing a core comprising a core window;
- b) providing a first coil, said first coil extending between a first termination and a second termination, and comprising
 - i) a first winding, in particular a high-voltage winding, extending in a axial direction,
 - ii) an encapsulation made from solid, electrically insulating material and enclosing said first winding

on the core with the first winding surrounding a first section of the core

- c) providing a second winding, in particular a low-voltage winding, on the core to surround the first section or a second section of the core;
- the method characterized by the step of

- d) attaching a supporting structure at a location distant from both the first and the second termination

of the first coil, said supporting structure adapted to holding the first coil in a defined position relative to the core.

[0013] In accordance with a variant of the invention as described above, the supporting structure is attached to the core at a distance $d_{\text{core},1}$ from the first termination, and at a distance $d_{\text{core},2}$ from the second termination, which distances are larger than a high voltage insulation distance d_{HV} for a rated voltage of the transformer, preferably with $d_{\text{core}} := \min\{d_{\text{core},1}, d_{\text{core},2}\} > d_{\text{HV}}$, most preferably $d_{\text{core}} \gg d_{\text{HV}}$. The high voltage insulation distance d_{HV} may be obtained according to $d_{\text{HV}} = V_{\text{rated}} / (\epsilon_r E_{\text{breakdown}})$, wherein $E_{\text{breakdown}}$ is an electric breakdown field strength of a gaseous insulation medium, in general air, surrounding the transformer in operation, and in particular provided between the first coil and the core, and/or the first coil and the second winding. In general, the gaseous insulation medium is air under at least approximately atmospheric pressure, preferably at ambient temperature. Thus, $2,5\text{kV/mm} < E_{\text{breakdown}} < 3,5\text{kV/mm}$ generally holds for the electric breakdown field strength in this case. V_{rated} is a rated voltage for normal operation of the modular converter, where, in particular, $V_{\text{rated}} > 10\text{kV}$ applies, preferably $V_{\text{rated}} \geq 50\text{kV}$. ϵ_r is a relative dielectric constant of a solid, electrically insulating material from which an encapsulation is provided around the first winding. Preferably, the high voltage insulation distance d_{HV} is obtained according to $d_{\text{HV}} = V_{\text{rated}} / E_{\text{breakdown}}$, most preferably according to $d_{\text{HV}} = S_{\text{safety}} V_{\text{rated}} / E_{\text{breakdown}}$, wherein S_{safety} is a safety parameter provided to accommodate for various imponderabilities, and may be required in the dimensioning of electric insulation according to various standard. $1.5 < S_{\text{safety}} < 5$ typically holds, in particular with $S_{\text{safety}} = 1.875$ or $S_{\text{safety}} = 3.75$.

[0014] In accordance with a variant of the invention as described above, the supporting structure is attached to the first coil 2 at a distance $d_{\text{coil},1}$ from the first termination, and at a distance $d_{\text{coil},2}$ from the second termination, which distances are larger than a high voltage insulation distance d_{HV} for a rated voltage of the transformer, preferably with $d_{\text{coil}} := \min\{d_{\text{coil},1}, d_{\text{coil},2}\} > d_{\text{HV}}$, most preferably $d_{\text{coil}} \gg d_{\text{HV}}$.

[0015] In accordance with another aspect of the invention, a transformer for a modular converter in accordance with the present invention comprises

- a core comprising a core window,
- a first coil, said first coil comprising
 - o a first winding, in particular a high-voltage winding,
 - o an encapsulation made from solid, electrically insulating material and enclosing said first winding;

- a second winding, in particular a low-voltage winding,
- an electrically insulating supporting structure for holding the first winding in a defined position relative to the core.

[0016] In accordance with the invention, at least a given fraction r of a shortest path p_1 between a conducting surface S_1 of the first winding and the core traverses gaseous insulation medium, where preferably $r > 0,1$, most preferably $r > 0,5$ is fulfilled.

[0017] Likewise, at least a given fraction r_2 of a shortest path p_2 between the conducting surface S_1 of the first winding and a conducting surface S_2 of the second winding traverses gaseous insulation medium, where preferably $r_2 > 0,1$, most preferably $r_2 > 0,5$ is fulfilled.

[0018] According to a variant of the invention as referred to under one or more of the aspects above, the first winding and/or the second winding are made from wire, in particular copper or aluminium wire, preferably with an insulation, in particular a cladding, formed on the conducting surface S_1 of a first wire forming the first winding, and/or the conducting surface S_2 of a second wire forming the second winding. Preferably, the insulation has a thickness $d_{\text{insulation}}$ which is smaller than a diameter d_{wire} of the respective wire, i.e. $d_{\text{insulation}} < d_{\text{wire}}$, preferably $d_{\text{insulation}} \ll d_{\text{wire}}$. The insulation provides, in particular, reliable inter-turn insulation for the respective winding, also for the first winding even when an encapsulation is present.

[0019] According to a variant of the invention as referred to under one or more of the aspects above, the supporting structure comprises a plurality of electrically insulating supporting elements, wherein none of the supporting elements is extending into the core window. Preferably, the supporting structure comprises all supporting elements which contribute to holding the first winding in a defined position relative to the core, in particular all electrically insulating elements attached to the first winding, in particular to the encapsulation enclosing the first winding; and is spatially restricted to an area outside the core window. In other words, none of the supporting elements, and none of any electrically insulating elements attached to the first winding, in particular to the encapsulation enclosing the first winding, extends into the core window.

[0020] According to a variant of the invention as referred to under one or more of the aspects and/or variants above, the core comprises

- a) a first limb, extending in a first longitudinal direction,
- b) a second limb, in particular extending in the first longitudinal direction,
- c) a first yoke extending in a second longitudinal direction, in particular perpendicular to the first longitudinal direction,

d) and a second yoke, in particular extending in the second longitudinal direction,

e) wherein the core window extends through the core in a lateral direction perpendicular to both the first and second longitudinal directions.

Preferably, dimensions D_1 and D_2 of the core in the first and/or second longitudinal directions are significantly larger than a dimension D_3 of the core in the lateral direction, i.e. $D_1 > D_3$ and/or $D_2 > D_3$, preferably with $D_1 \gg D_3$ and/or $D_2 \gg D_3$ so that the core may be regarded as essentially planar; albeit with a non-zero dimension l_3 of the core window in the lateral direction, in general with $l_3 \approx D_3$, and frequently with $l_3 = D_3$. Preferably, the supporting structure is attached to the first coil, in particular to the encapsulation, laterally with respect to the first lateral direction, i.e. at a distance d in lateral direction from the core, preferably with $d > D_3$, most preferably with $d \gg D_3$.

[0021] According to a variant of the invention as referred to under one or more of the aspects and/or variants above, and related to transformer designs generally referred to as core type, both the first and second limb extend from the first to the second yoke and vice versa, and surround the core window. The first coil extends between a first termination and a second termination of said first coil in an axial direction generally in parallel with the first longitudinal direction, with the first winding surrounding at least a section of the first limb representing a first section of the core.

[0022] Preferably, the second winding, which also extends between a first termination and a second termination of said second winding in an axial direction generally in parallel with the first longitudinal direction, also surrounds at least a portion of the same first section of the core as the first winding, with the first coil, and the first winding, surrounding the second winding. The first winding may then represent a primary winding of the transformer, and/or the second winding a secondary winding. In addition, the primary winding may comprise a third winding connected in series or in parallel with the first winding, which may in particular surround at least a section of the second limb, and/or the secondary winding may comprise a fourth winding connected in series or in parallel with the second winding, which may in particular also surround at least a section of the second limb; wherein the third winding may, in particular, surround the fourth winding. Alternatively, the first winding may represent a secondary winding of the transformer, and/or the second winding a primary winding. In addition, the primary winding may comprise a third winding connected in series or in parallel with the second winding, which may in particular surround at least a section of the second limb, and/or the secondary winding may comprise a fourth winding connected in series or in parallel with the first winding, which may in particular also surround at least a section of the second limb; wherein the third wind-

ing may, in particular, surround the fourth winding.

[0023] According to a variant of the invention as referred to under one or more of the aspects and/or variants above, and related to transformer designs generally referred to as shell type, the first and second limb extend between the first and second yoke and vice versa, and surround the core window. A third limb extends between the first and second yoke, in particular in the first longitudinal direction; and between the first and the second limb, so that the core window is divided into a first sub-window and a second sub-window, preferably with both sub-windows extending through the core in the lateral direction. The first coil extends between the first termination and the second termination of said first coil in the axial direction generally in parallel with the first longitudinal direction, with the first winding surrounding at least a section of the third limb representing a first section of the core of the shell type design transformer.

[0024] Preferably, the second winding, which also extends between a first termination and a second termination of said second winding in an axial direction generally in parallel with the first longitudinal direction, also surrounds at least a portion of the same first section of the core as the first winding, with the first winding surrounding the second winding. The first winding may then represent a primary winding of the transformer, and/or the second winding a secondary winding. Alternatively, the first winding may represent a secondary winding of the transformer, and/or the second winding a primary winding.

[0025] According to a variant of the invention as referred to under one or more of the aspects and/or variants above, the core is generally a closed core, i.e. no air gaps are present within any of the limbs or yokes, nor between any pair of limb and yoke, so that the magnetic flux linking the primary and secondary windings travels - at least essentially - entirely within a high-permeability material, in general a ferromagnetic or ferromagnetic, which constitutes the core, so that - at least essentially - no loss of magnetic flux through air occurs.

[0026] According to a variant of the invention as referred to under one or more of the aspects and/or variants above, the core - rather than being a closed core - may comprise a gap filled with a low-permeability material, in general air or synthetic material, in particular plastics.

[0027] These and other aspects of the invention will become apparent from and elucidated with reference to the embodiments described hereinafter.

BRIEF DESCRIPTION OF THE DRAWINGS

[0028] The subject matter of the invention will be explained in more detail in the following text with reference to exemplary embodiments which are illustrated in the attached drawings.

Fig. 1 shows circuit schematics for a converter cell of a modular, power electronic converter;

Fig. 2 schematically shows a sectional view of transformer in accordance with the prior art;

Fig. 3 schematically shows a perspective view of a transformer in accordance with the present invention;

Fig. 4 schematically shows a top view of the transformer from Fig. 3;

Fig. 5 schematically shows a sectional view of the transformer from Fig. 3 along line A-A' as indicated in Fig. 4.

[0029] In principle, identical reference symbols in the figures denote identical parts.

DETAILED DESCRIPTION OF EXEMPLARY EMBODIMENTS

[0030] Fig. 3 schematically shows a perspective view of a transformer in accordance with the present invention; Fig. 4 schematically shows a view from the top onto the transformer from Fig. 3; Fig. 5 schematically shows a sectional view of the transformer from Fig. 3. The transformer is of shell type design, and comprises a core 1 having a first limb 11, second limb 12 and a third limb 13 all extending in a first longitudinal direction 900. A first yoke 14 and a second yoke 15 extend in a second longitudinal direction 901 between and across the first limb 11, the second limb 12, and the third limb 13, so that first yoke 14, second yoke 15, first limb 11, and second limb 12 define and surround a core window, which is separated into a first sub-window 101 and a second sub-window 102 by the third limb 13.

[0031] A frame 19 is provided comprising two frame elements 191 arranged adjacent to the core in a lateral direction 902, said lateral direction 902 being perpendicular to both the first longitudinal direction 900 and second longitudinal direction 901, and also referred to as z-direction. The frame elements 191 are held together by two rods 192 which are, e.g., screwed to the frame elements 191 by means of dielectric screws 52.

[0032] A first winding 20 serving as a primary winding surrounds a central portion of the third limb 13. The first winding is cast into synthetic material having a relative dielectric constant $\epsilon_{r, \text{synth}} > 1$, preferably an epoxy resin, so that said epoxy resin forms an encapsulation 21 permanently enclosing said first winding 20. Encapsulation 21 and first winding 20 represent a first coil 2. A shape of the encapsulation 21 - and thus the first coil 2 - corresponds - at least essentially - to a hollow cylinder extending between a first termination 201 and a second termination 202 of the first coil 2. The encapsulation comprises two flattened regions 211 formed on opposite sides of its outer surface, so that the flattened regions 211 lie in two parallel planes, and each of the flattened regions 211 is located distant from the core 1. As is the case in the

exemplary transformer shown in Fig. 3, each of the flattened regions 211 is preferably formed on a thickening of the encapsulation.

[0033] A second winding 30 formed on a bobbin 31 and serving as a secondary winding also surrounds the same central portion of the third limb 13 as the first winding, and is itself surrounded by the first winding 20, with a cooling channel 40 being established between an inner surface of the encapsulation 21 and the second winding 30. Second winding 30 and bobbin 31 thus represent a second coil.

[0034] The second winding 30 is held in position relative to the third limb 13 by the bobbin 31, which rests on the second yoke 15 when the transformer is orientated as depicted in Fig. 2. The second winding 30 is tightly wound onto bobbin 31 between a first termination 301 and a second termination 302 of said second winding 30, and possibly glued or otherwise attached by means of an adhesive. Preferably, the bobbin 31 is clamped between the first yoke 14 and the second yoke 15 for improved mechanical stability.

[0035] Dielectric plates 50 are attached to the frame 19 by means of dielectric rods 51, with said rods extending away from the frame 19 in lateral direction 902. The dielectric plates 50 are held in position by dielectric nuts 52 threaded onto threads provided on the dielectric rods 51, which may also be used for attaching the dielectric rods 51 to the frame elements 191. This allows for a mechanically robust design, while avoiding high electric fields on surfaces of the dielectric plates 50, rods 51, and nuts 52.

[0036] The first coil 2 is attached to the dielectric plates 50 with each of the flattened regions 211 abutting against a surface of one of the dielectric plates 50, and is preferably fixed by means of dielectric screws and/or adhesive.

[0037] Dielectric plates 50 with attached dielectric rods 51 thus represent a supporting structure for the first winding 20, said supporting structure allowing to hold the first winding 20 in a defined position with respect to the core 1, in particular the third limb 13, while not extending into the core window, in particular not extending into a region between $z = -l_3/2$ and $z = +l_3/2$. In other words, the supporting structure is confined to a region outside of the core window. Likewise, the supporting structure does not extend into the cooling channel 40 provided between the first winding 30.

[0038] Fig. 5 schematically shows a sectional view of the transformer from Fig. 3 along line A-A' as indicated in Fig. 4. As may be seen, the use of the supporting structure as described above allows to respect a sufficient clearance distance d_{clear} between the encapsulation 21 enclosing the first winding 20 and the core 1, preferably with $d_{\text{clear}} > S_{\text{safety}} V_{\text{rated}} / E_{\text{breakdown}}$, wherein $E_{\text{breakdown}}$ is an electric breakdown field strength, V_{rated} a rated voltage for normal operation of the modular converter, and S_{safety} a safety parameter as detailed further above.

[0039] While the invention has been illustrated and de-

scribed in detail in the drawings and foregoing description, such illustration and description are to be considered illustrative or exemplary and not restrictive; the invention is not limited to the disclosed embodiments. Other variations to the disclosed embodiments can be understood and effected by those skilled in the art and practising the claimed invention, from a study of the drawings, the disclosure, and the appended claims. In the claims, the term "comprising" does not exclude other elements or steps, and the indefinite article "a" or "an" does not exclude a plurality. The mere fact that certain measures are recited in mutually different dependent claims does not indicate that a combination of these measures cannot be used to advantage. Any reference signs in the claims should not be construed as limiting the scope.

[0040] It is assumed that throughout this document, unless explicitly stated otherwise, a statement $a \approx b$ implies that $|a-b|/(|a|+|b|) < 1/10$, preferably $|a-b|/(|a|+|b|) < 1/100$, wherein a and b may represent any variables and/or physical or mathematical quantity described defined, and/or referred to anywhere in this this document, or as otherwise known to a person skilled in the art. Further, a statement that a is at least approximately equal or at least approximately identical to b implies that $a \approx b$, preferably $a = b$. Further, it is assumed that, unless stated otherwise, a statement $a >> b$ implies that $a > 5b$, preferably $a > 100b$; and statement $a << b$ implies that $5a < b$, preferably $100a < b$.

[0041] It should be noted that the term "comprising" does not exclude other features, in particular elements or steps, and that the indefinite article "a" or "an" does not exclude the plural. Also elements described in association with different embodiments may be combined.

[0042] It will be appreciated by those skilled in the art that the present invention can be embodied in other specific forms without departing from the spirit or essential characteristics thereof. The scope of the invention is indicated by the appended claims rather than the foregoing description and all changes that come within the meaning and range and equivalence thereof are intended to be embraced therein.

LIST OF REFERENCE SIGNS

010	insulating cushion
011	cushion interface
020	high-voltage winding
030	low-voltage winding
1	core
101	first sub-window
102	second sub-window
11	first limb
12	second limb
13	third limb

(continued)

14	first yoke
15	second yoke
19	frame
191	frame element
192	rod
2	first coil
20	first winding
201	first termination of the first coil
202	second termination of the first coil
21	encapsulation
211	flattened regions
30	second winding
301	first termination of the second winding
302	second termination of the second winding
31	bobbin
40	cooling channel
50	dielectric plate
51	dielectric rod
52	dielectric screw
900	first longitudinal direction
901	second longitudinal direction
902	lateral direction

Claims

1. A transformer for a modular converter comprising

- a) a core (1) having a core window;
- b) a first coil (2), said first coil comprising

- i) a first winding (20), in particular a high-voltage winding, surrounding a first section of the core,
- ii) an encapsulation (21) made from solid, electrically insulating material and enclosing said first winding;

- c) a second winding (30), in particular a low-voltage winding, surrounding the first or a second section of the core (1);
- d) an electrically insulating supporting structure attached to the first winding (20), in particular to the encapsulation, for holding the first coil (2) in a defined position relative to the core (1);

characterized in that

- e) the electrically insulating supporting structure does not extend into the core window.
2. The transformer according to claim 1, further **characterized in that** the supporting structure comprises a plurality of supporting elements, wherein none of the supporting elements extends into the core window.
 3. The transformer according to one of the previous claims, further **characterized in that** the first coil (2) surrounds the second winding (30), with a cooling channel (40) provided between the first coil (2) and the second winding (30), said cooling channel (40) preferably completely surrounding the first winding (20) in a radial direction.
 4. The transformer according to one of the previous claims, further **characterized in that** the core (1) comprises
 - a) a first limb (11), extending in a first longitudinal direction (900),
 - b) a second limb (12), in particular extending in the first longitudinal direction,
 - c) a first yoke (14) extending in a second longitudinal direction (901), in particular perpendicular to the first longitudinal direction (900),
 - d) and a second yoke (15), in particular extending in the second longitudinal direction (901),
 - e) wherein the core window extends through the core (1) in a lateral direction (902) perpendicular to the first and second longitudinal direction (901), and wherein the supporting structure is attached to the first coil (2) laterally with respect to the the lateral direction (902).
 5. The transformer according to one of the previous claims, further **characterized in that** the supporting element comprises a dielectric plate (50) attached to the first coil (2), in particular to the encapsulation enclosing the first winding (20).
 6. The transformer according to the previous claim, further **characterized in that** the dielectric plate (50) is attached to the core (1) by means a plurality of dielectric rods and/or screws.
 7. The transformer according to claim 4 and one of claims 5 or 6, further **characterized in that** the dielectric plate (50) is separated from the core (1) by a distance d_{plate} in the lateral direction (902), wherein the distance d_{plate} is larger than a high voltage insulation distance d_{HV} for a rated voltage of the transformer, preferably with $d_{\text{plate}} > 2 d_{\text{HV}}$.
 8. The transformer according to one of the previous claims, **characterized in that** the core (1) is conductively connected to a ground potential.
 9. A method for assembling a transformer for a modular converter, the method comprising the steps of
 - a) providing a core (1) comprising a core window;
 - b) providing a first coil, said first coil extending between a first termination (201) and a second termination (202), and comprising
 - i) a first winding (20), in particular a high-voltage winding, extending in a axial direction,
 - ii) an encapsulation made from solid, electrically insulating material and enclosing said first winding (20)
 - c) providing a second winding (30), in particular a low-voltage winding, on the core (1) to surround the first section or a second section of the core (1); the method **characterized by** the step of
 - d) attaching a supporting structure at a location distant from both the first and the second termination (201, 202) of the first coil (2), said supporting structure adapted to holding the first coil (2) in a defined position relative to the core (1).
 10. The method for assembling a transformer according to the previous claim, wherein the supporting structure is attached to the core (1).
 11. The method for assembling a transformer according to claim 9 or 10, further **characterized in that** in step d) of claim 9, the supporting structure is attached to the core (1) at a distance $d_{\text{core},1}$ from the first termination (201), and at a distance $d_{\text{core},2}$ from the second termination (202), which distances are larger than a high voltage insulation distance d_{HV} for a rated voltage of the transformer, preferably with $d_{\text{core}} := \min\{d_{\text{core},1}, d_{\text{core},2}\} > 2 d_{\text{HV}}$, most preferably $d_{\text{core}} \gg d_{\text{HV}}$.
 12. The method for assembling a transformer according to claim 9, 10 or 11, further **characterized by** the step of attaching the supporting structure to the first coil (2) at a location distant from the core (1).
 13. The method for assembling a transformer according to claim 12, further **characterized in that** the supporting element is attached to the first coil (2) at a distance d from the core (1) which is larger than a high voltage insulation distance d_{HV} for a rated voltage of the transformer, preferably with $d > 2 d_{\text{HV}}$.

14. The method for assembling a transformer according to one of claims 9 to 13, further **characterized by** the step of attaching the supporting structure to the first coil (2) at a location distant from both the first and the second termination (201, 202) of the first winding (20). 5

15. A modular, power electronic converter comprising,

a) a plurality of converter cells with 10

i) a first subset of, preferably all, said converter cells being electrically connectable in series on a first side of said modular power electronic converter, 15

ii) a second subset of, preferably all, said converter cells being electrically connectable in parallel on a second side of said modular converter; 20

characterized in that

b) at least each converter cell from any of the first or second subsets comprise a transformer according to one of claims 1 to 8, or a transformer manufactured according to one of claims 9 to 14. 25

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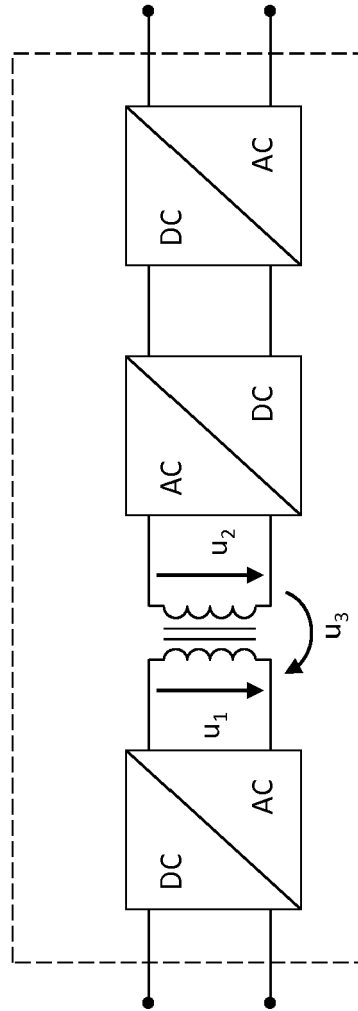


Fig. 1

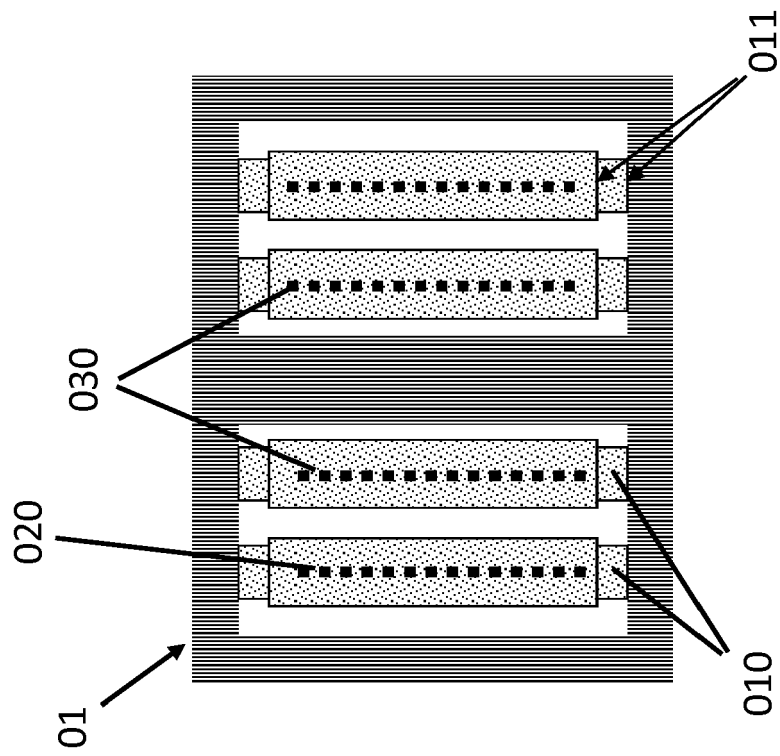


Fig. 2

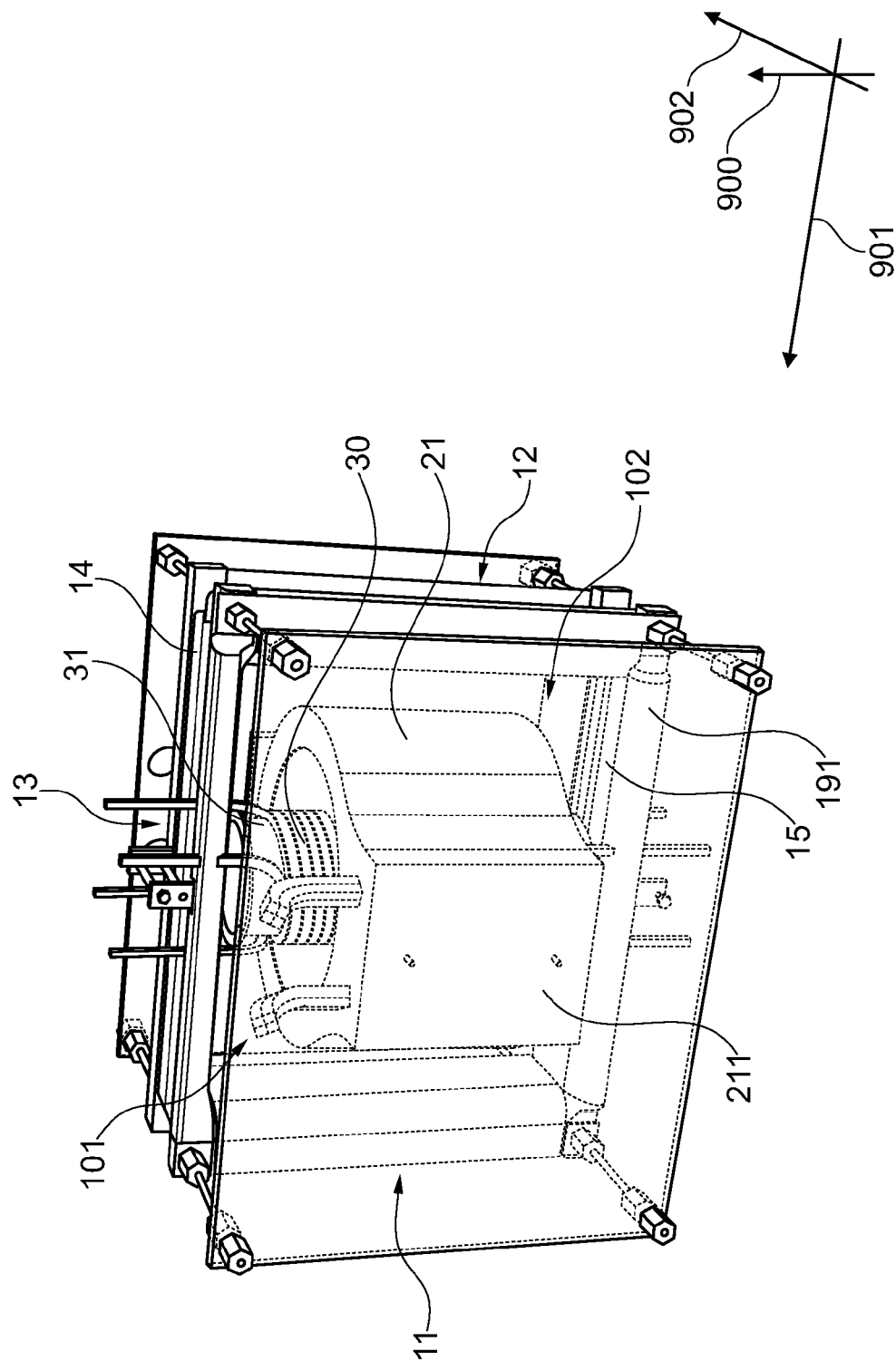


Fig. 3

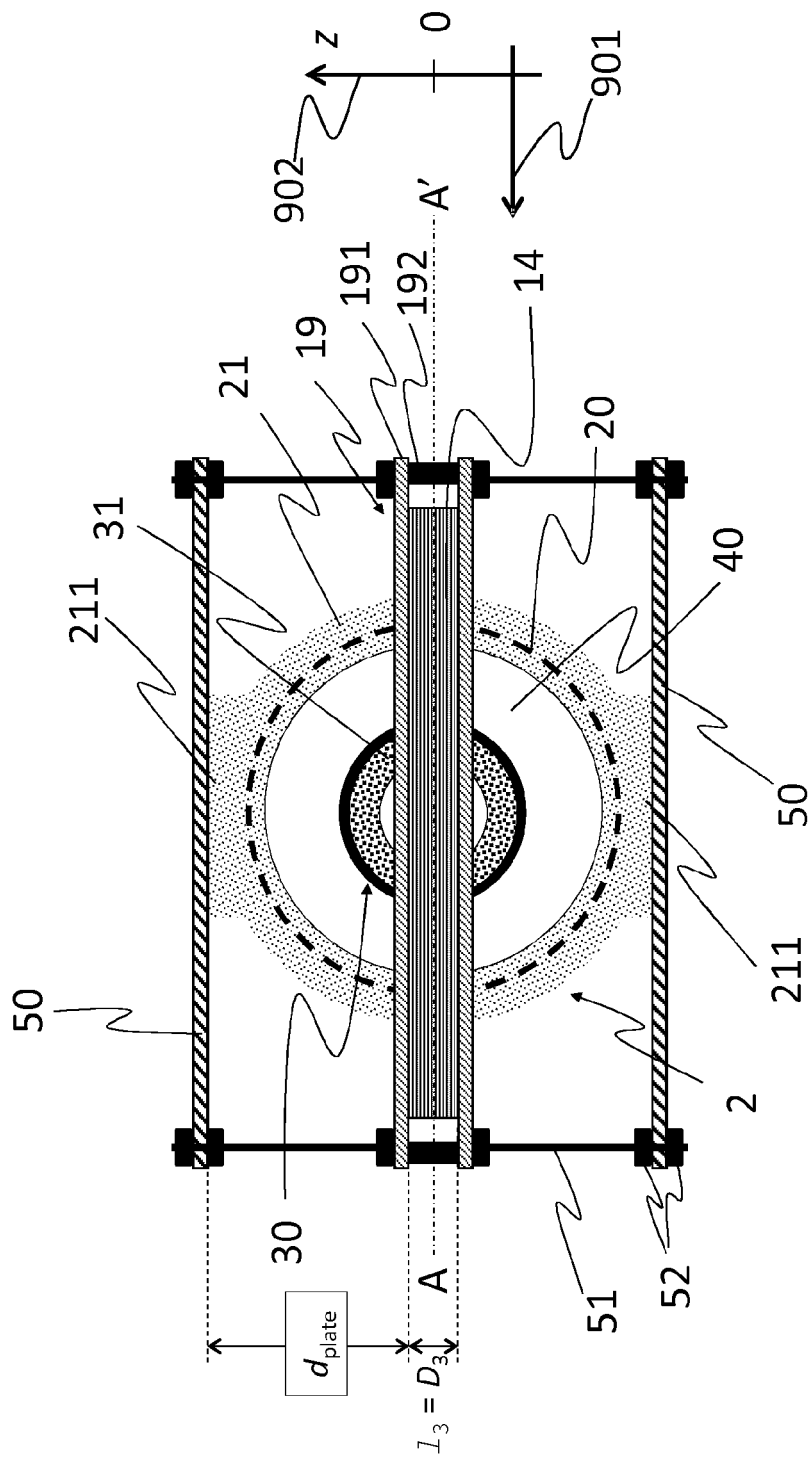
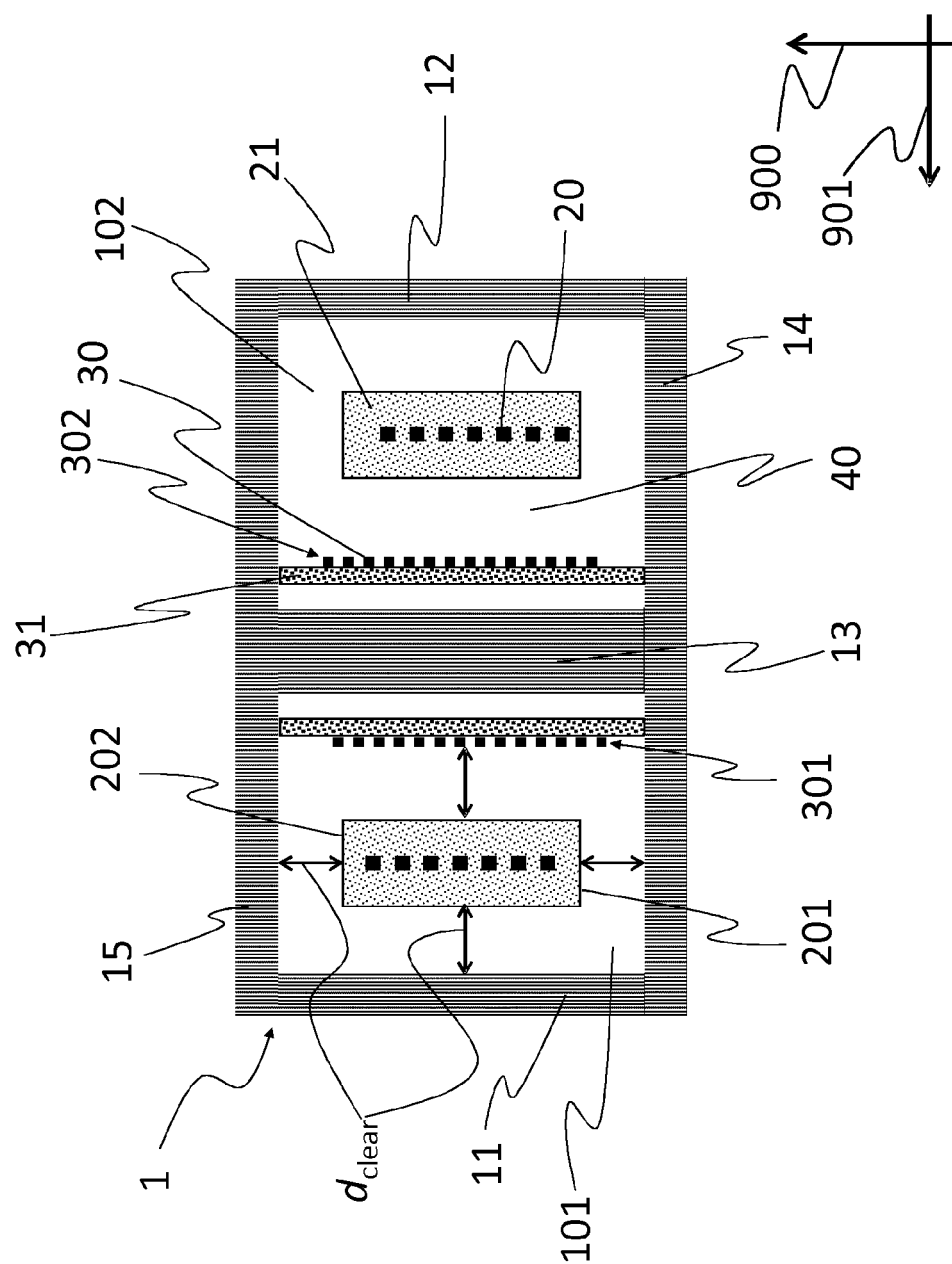


Fig. 4



Fi. 5



EUROPEAN SEARCH REPORT

 Application Number
 EP 15 16 6445

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DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	US 2015/109081 A1 (PATEL DHIRU S [CA]) 23 April 2015 (2015-04-23)	1-4,8,9,12,14	INV. H01F27/08
Y	* paragraphs [0006], [0009], [0026] * * figure 1 *	15	
X	DE 10 2005 058119 A1 (SIEMENS AG [DE]) 31 May 2007 (2007-05-31)	1-3,8	
Y	* paragraphs [0003], [0024], [0025], [0027] * * figures 1a, 1b, 2 *	15	
Y	EP 2 703 208 A1 (ABB TECHNOLOGY AG [CH]) 5 March 2014 (2014-03-05)	15	
A	* paragraphs [0001], [0033], [0046] *	1-14	TECHNICAL FIELDS SEARCHED (IPC)
A	EP 2 790 195 A1 (ABB TECHNOLOGY AG [CH]) 15 October 2014 (2014-10-15)	1-15	
	* paragraphs [0001], [0009], [0011], [0012], [0017], [0018] * * figures 1, 2 *		H01F
The present search report has been drawn up for all claims			
Place of search Munich		Date of completion of the search 5 November 2015	Examiner Van den Berg, G
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			

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

EP 15 16 6445

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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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Patent document cited in search report	Publication date	Patent family member(s)	Publication date
US 2015109081 A1	23-04-2015	US 2015109081 A1	23-04-2015
		WO 2015058299 A1	30-04-2015
DE 102005058119 A1	31-05-2007	BR PI0619185 A2	13-09-2011
		CN 101336460 A	31-12-2008
		DE 102005058119 A1	31-05-2007
		JP 2009517873 A	30-04-2009
		US 2008290981 A1	27-11-2008
		WO 2007063002 A1	07-06-2007
EP 2703208 A1	05-03-2014	CN 104768793 A	08-07-2015
		EP 2703208 A1	05-03-2014
		EP 2892752 A1	15-07-2015
		US 2015180352 A1	25-06-2015
		WO 2014037406 A1	13-03-2014
EP 2790195 A1	15-10-2014	NONE	

REFERENCES CITED IN THE DESCRIPTION

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Patent documents cited in the description

- WO 2014037406 A1 [0004]
- DE 102010044322 A1 [0004]
- EP 820893 A2 [0004]