(19) Europäisches Patentamt
European Patent Office
Office européen des brevets

(11) EP 2 117 020 A1

(12) EUROPEAN PATENT APPLICATION

(43) Date of publication:
11.11.2009 Bulletin 2009/46

(51) Int Cl.:
H01F 37/00 *(2006.01)* ***H01F 3/10*** *(2006.01)*

(21) Application number: **08155638.3**

(22) Date of filing: **05.05.2008**

(84) Designated Contracting States:
AT BE BG CH CY CZ DE DK EE ES FI FR GB GR HR HU IE IS IT LI LT LU LV MC MT NL NO PL PT RO SE SI SK TR
Designated Extension States:
AL BA MK RS

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(54) A reactor arrangement for alternating electrical current

(57) The invention relates to a reactor arrangement that comprises a magnetic core structure (101), a winding (102), and a permanent magnet (103, 103a). The permanent magnet generates a biasing magnetic flux component into a first part (104) and into a second part (105) of the magnetic core structure. The winding magnetizes the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component when electrical current is positive and the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component when the electrical current is negative. Hence, the biasing magnetic flux component can be utilized for locally relieving magnetic saturation of the magnetic core structure during both negative and positive temporal portions of the electrical current. Therefore, the size and the weight of the magnetic core structure can be reduced.

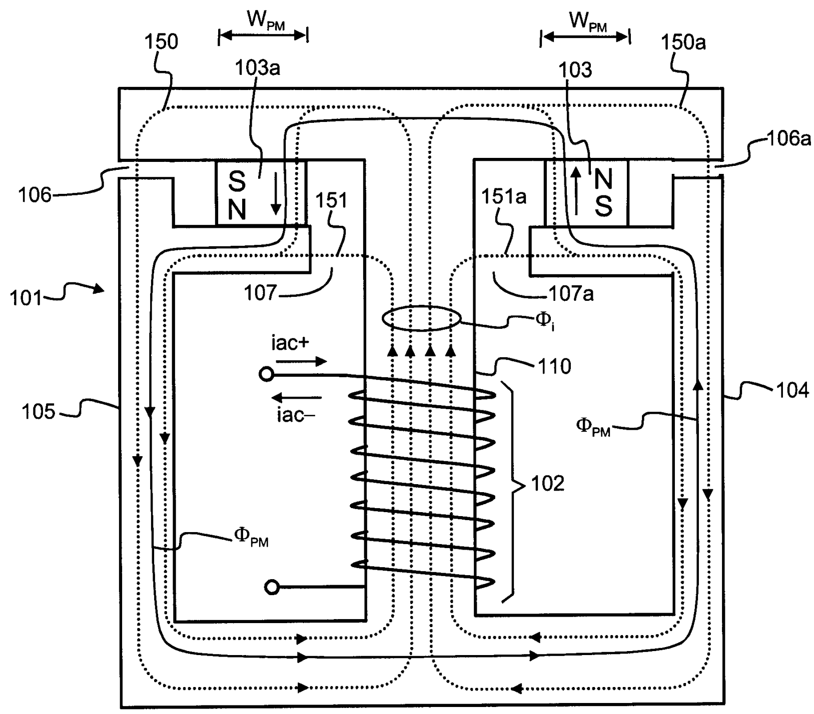

Figure 1

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Description

Field of the invention

[0001] The invention relates to a reactor arrangement suitable for alternating electrical current and to a method for providing inductive reactance for alternating electrical current. Furthermore, the invention relates to an electrical converter device having a reactor arrangement.

Background

[0002] In conjunction with many electrical converter devices, e.g. a frequency converter, an inductive electrical component is needed between an inverter bridge arranged to produce e.g. multiphase alternating voltage and an electrical system connected to it, and/or between a rectifier bridge and an alternating voltage network. The inductive electrical component can be needed, for example, for reducing slew rate of output voltage of an inverter, for over-current protection, for reducing radio frequency emissions, for suppressing common-mode electrical current, and/or for suppressing harmonics of voltage and/or of electrical current. The physical size of an inductive electrical component can be reduced by providing the inductive electrical component with a magnetic core structure that is made of magnetically amplifying material, i.e. material having the relative permeability greater than unity ($\mu_r > 1$). The magnetically amplifying material can be ferromagnetic or paramagnetic material. The magnetic core structure is preferably made of soft magnetic material that provides low hysteresis losses, e.g. electrical steel sheets, soft magnetic powder, ferrites, etc. In many applications, the magnetic saturation of magnetically amplifying material causes problems in conjunction with inductive electrical components, e.g. non-linear phenomena that may be harmful in operation of an inductive electrical component. For example, dynamical inductance (a change of magnetic flux / a change of electrical current) may drastically diminish as a response to a situation in which a magnetic core structure of an inductive electrical component gets magnetically saturated. Because of the above-mentioned facts, a magnetic core structure of an inductive electrical component is traditionally dimensioned with respect to a pre-determined value of electrical current in such a way that the magnetic core structure does not get too deeply saturated during operation. The requirement that the magnetic core structure must not get too deeply saturated sets lower limits to the size and the weight of the inductive electrical component.

[0003] In a solution according to the prior art, an inductive electrical component that is used for limiting fluctuations of direct electrical current, i.e. dc-current, is provided with a permanent magnet. In this document dc-current means electrical current the value of which may fluctuate over time but the flowing direction of which does not change. The permanent magnet is arranged to generate into a ferromagnetic core of the inductive electrical component a biasing magnetic flux component that has an opposite direction with respect to a magnetic flux component generated by dc-current flowing in windings of the inductive electrical component. With the aid of the biasing magnetic flux component the maximum value of the dc-current that can be used without causing a too deep saturation of the ferromagnetic core can be e.g. doubled compared with a situation in which no biasing magnetic flux component is being used. An inductive electrical component of the kind described above is disclosed e.g. in publication US3968465. The above-described solution according to the prior art is, however, suitable for only inductive electrical components that are used for limiting fluctuations of dc-current. In conjunction with an electrical converter device, e.g. a frequency converter, many inductive electrical components are, however, used as reactors for alternating electrical currents.

Summary

[0004] In accordance with a first aspect of the invention, there is provided a new reactor arrangement that is suitable for alternating electrical current. The reactor arrangement comprises:

- a magnetic core structure made of magnetically amplifying material,
- a winding arranged to magnetize the magnetic core structure as a response to a situation in which electrical current is directed to the winding, and
- at least one permanent magnet arranged to generate a biasing magnetic flux component into a first part of the magnetic core structure and into a second part of the magnetic core structure,

wherein the winding is arranged to magnetize the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current is positive and to magnetize the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current is negative.

[0005] The first part and the second part of the magnetic core structure are preferably driven into (or near to) magnetic saturation with the at least one permanent magnet when there is no electrical current in the winding. When there is positive electrical current in the winding, i.e. the electrical current is flowing in a first direction in the winding, the magnetic saturation of the first part of the magnetic core structure is relieved and the magnetic saturation of the second part of the magnetic core structure is, depending on the level of initial magnetic saturation caused by the at least one permanent magnet alone, increased or remained substantially unchanged. Correspondingly, when there is negative electrical current in the winding, i.e. the electrical current is flowing in a second direction in the winding, the magnetic saturation of the second part of the magnetic core structure is relieved and the magnetic saturation of the first part of the magnetic core structure is, depending on the level of initial magnetic saturation caused by the at least one permanent magnet alone, increased or remained substantially unchanged. Hence, the biasing magnetic flux component generated with the at least one permanent magnet can be utilized for locally relieving the magnetic saturation of the magnetic core structure during both negative and positive temporal portions of alternating electrical current and a part of the magnetic core structure in which the magnetic saturation is relieved at each time provides a low-reluctance path for the magnetic flux generated by the alternating electrical current.

[0006] The inductance of the reactor arrangement as a function of electrical current, i.e. the inductance curve, can be designed by adjusting levels of the magnetic saturation caused with the at least one permanent magnet into the first part and into the second part of the magnetic core structure and by adjusting physical dimensions of the magnetic core structure.

[0007] The magnetic core structure may comprise more than one (first) part that is arranged to conduct the biasing magnetic flux component generated with the at least one permanent magnet and that is magnetized with the winding in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current in the winding is positive. Correspondingly, the magnetic core structure may comprise more than one (second) part that is arranged to conduct the biasing magnetic flux component and that is magnetized with the winding in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current in the winding is negative.

[0008] In accordance with a second aspect of the invention, there is provided a new electrical converter device that comprises at least one reactor arrangement according to the invention. The electrical converter device can be, e.g. an inverter, a rectifier, and/or a frequency converter.

[0009] In accordance with a third aspect of the invention, there is provided a new method for providing inductive reactance for alternating electrical current. The method comprises:

- generating, with at least one permanent magnet, a biasing magnetic flux component into a first part of a magnetic core structure made of magnetically amplifying material and into a second part of the magnetic core structure, and

- directing the alternating electrical current to a winding arranged to magnetize the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is positive and to magnetize the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is negative.

[0010] A number of exemplifying embodiments of the invention are described in accompanied dependent claims.

[0011] Various exemplifying embodiments of the invention both as to constructions and to methods of operation, together with additional objects and advantages thereof, will be best understood from the following description of specific exemplifying embodiments when read in connection with the accompanying drawings.

[0012] The exemplifying embodiments of the invention presented in this document are not to be interpreted to pose limitations to the applicability of the appended claims. The verb "to comprise" is used in this document as an open limitation that does not exclude the existence of also unrecited features. The features recited in depending claims are mutually freely combinable unless otherwise explicitly stated.

Brief description of the figures

[0013] The exemplifying embodiments of the invention and their advantages are explained in greater detail below in the sense of examples and with reference to the accompanying drawings, in which:

figure 1 shows a reactor arrangement according to an embodiment of the invention,

figure 2 shows a reactor arrangement according to an embodiment of the invention,

figure 3 shows a reactor arrangement according to an embodiment of the invention,

figure 4 shows a reactor arrangement according to an embodiment of the invention,

figure 5 shows a reactor arrangement according to an embodiment of the invention,

figure 6 shows a block diagram of an electrical converter device according to an embodiment of the invention,

figure 7 shows a block diagram of an electrical converter device according to an embodiment of the invention,

figure 8 is a flow chart of a method according to an embodiment of the invention for providing inductive reactance for alternating electrical current, and figure 9 shows a reactor arrangement according to an embodiment of the invention.

Description of the embodiments

[0014] Figure 1 shows a reactor arrangement according to an embodiment of the invention. The reactor arrangement comprises a magnetic core structure 101 made of magnetically amplifying material, i.e. material having the relative permeability greater than unity (μ_r > 1). The magnetic core structure can be made of ferromagnetic or paramagnetic material. The magnetic core structure is preferably made of soft magnetic material that provides low hysteresis losses, e.g. electrical steel sheets, soft magnetic powder, ferrites, etc. The reactor arrangement comprises a winding 102 arranged to magnetize the magnetic core structure as a response to a situation in which electrical current i_{ac} is directed to the winding. Without limiting generality, the electrical current i_{ac} can be defined to be positive when it flows in a direction of an arrow i_{ac}+ and negative when it flows in a direction of an arrow i_{ac}-. The reactor arrangement comprises a first permanent magnet 103 and a second permanent magnet 103a that are arranged to generate a biasing magnetic flux component Φ_{PM} into a first part 104 of the magnetic core structure 101 and into a second part 105 of the magnetic core structure. In this embodiment of the invention, the magnetic core structure 101 is a three-leg magnetic core element. The first part 104 of the magnetic core structure is a first side leg of the magnetic core element and the second part 105 of the magnetic core structure is a second side leg of the magnetic core element. The winding 102 is located around a centre leg 110 of the magnetic core element. The permanent magnets 103 and 103a can be made of, for example, rare earth-metal permanent magnet material such as e.g. Sm-Co-permanent magnet material (Samarium Cobalt) and NbFeB-permanent magnet material (Neodymium-Iron-Boron). Each of the permanent magnets 103 and 103a can be a single block of permanent magnet material or be composed of many pieces of permanent magnet material. The winding 102 is arranged to magnetize the leg 104 of the magnetic core element in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current i_{ac} is positive and to magnetize the leg 105 of the magnetic core element in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current is negative. The magnetic flux component generated with the winding 102 is denoted with Φ_i in figure 1. The arrowheads of the Φ_i correspond to a situation in which the electrical current i_{ac} is positive.

[0015] The legs 104 and 105 of the magnetic core element 101 are preferably driven into (or near to) magnetic saturation with the permanent magnets 103 and 103a in a situation in which there is no electrical current in the winding 102. When there is positive electrical current (i_{ac}+) in the winding 102, the magnetic flux component Φ_i flows in the leg 104 in a direction opposite to the biasing magnetic flux component Φ_{PM} and in the leg 105 in a same direction as the biasing magnetic flux component Φ_{PM}. Therefore, when there is positive electrical current (i_{ac}+) in the winding 102, the magnetic saturation of the leg 104 is relieved and the magnetic saturation of the leg 105 is, depending on the level of initial magnetic saturation caused by the permanent magnets 103 and 103a alone, increased or remained substantially unchanged. Correspondingly, when there is negative electrical current in the winding, the magnetic saturation of the leg 105 is relieved and the magnetic saturation of the leg 104 is, depending on the level of initial magnetic saturation caused by the permanent magnets 103 and 103a alone, increased or remained substantially unchanged. Hence, the biasing magnetic flux component Φ_{PM} generated with the permanent magnets can be utilized for locally relieving the magnetic saturation of the magnetic core element 101 during both negative and positive temporal portions of alternating electrical current, i.e. the magnetic saturation of the leg 104 is relieved when the electrical current is positive and the magnetic saturation of the leg 105 is relieved when the electrical current is negative. Thanks to the above-described phenomenon, the legs 104 and 105 can be made thinner than those of a corresponding reactor arrangement in which there is/are no permanent magnet(s), i.e. no biasing magnetic flux component is present. Therefore, the size and weight of the magnetic core element 101 can be made smaller than in conjunction with a corresponding reactor arrangement having no permanent magnet(s).

[0016] The magnetic core element 101 is arranged to form, in addition to magnetic flux paths through the permanent magnets 103 and 103a, first additional magnetic flux paths (dashed curves 150 and 150a) arranged to by-pass the permanent magnets via first magnetic-gaps 106 and 106a and second additional magnetic flux paths (dashed curves 151 and 151 a) arranged to by-pass the permanent magnets via second magnetic-gaps 107 and 107a. The magnetic-gaps can contain for example air, plastic, or some other material that has a smaller relative permeability (μ_r) than that of the magnetically amplifying material of the magnetic core element 101.

[0017] Electrical current that flows in the winding 102 may get exceptionally high values during short circuits and other faults and anomalies. The lengths of the magnetic-gaps 107 and 107a in flowing directions of respective magnetic fluxes are preferably (but not necessarily) smaller than thicknesses of the permanents magnets 103 and 103a in flowing directions of respective magnetic fluxes. Therefore, the reluctances of the second additional magnetic flux paths 151 and 151 a are smaller than those of the magnetic flux paths via the permanent magnets 103 and 103a. Thus, in a situation in which there is exceptionally high electrical current in the winding 102, the magnetic-gaps 107 and 107a provide by-pass routes for strong magnetic flux components that could otherwise be directed to the permanent magnets and irreversibly demagnetize the permanent magnets. Furthermore, the magnetic flux components that flow via the first and second additional magnetic flux paths saturate the magnetic core element 101 in the vicinity of the permanent magnets 103 and 103a when exceptionally strong electrical current flows in the winding. Due to the magnetic saturation in the vicinity of the permanent magnets, the ability of the magnetic core element to direct demagnetizing magnetic field into the permanent magnets is decreased. Hence, the permanent magnets are protected against irreversible demagnetization during short circuits and other situations in which exceptionally strong electrical current flows in the winding.

[0018] The physical dimensions of the magnetic-gaps 106, 106a, 107 and 107a and the other physical dimensions of the magnetic core element 101 are preferably designed such that reluctance for the biasing magnetic flux component Φ_{PM} is smallest along the magnetically amplifying material of the magnetic core element. In other words, the design of the magnetic-gaps and the magnetic core element are arranged to force the biasing magnetic flux to flow mainly through the magnetically amplifying material instead of being shorted through the magnetic-gaps. Suitable shapes and dimensions for the magnetic core element, for the permanent magnets, and for the magnetic-gaps can be found with simulations and prototype testing. For example, numerical field calculation based on a finite element method (FEM) can be used in simulations.

[0019] The inductance of the reactor arrangement as a function of the electrical current i_{ac}, i.e. the inductance curve $L = f(i_{ac})$, can be designed by adjusting levels of the magnetic saturation caused with the permanent magnets 103 and 103a into the legs 104 and 105. The inductance curve can also be designed by adjusting physical dimensions of the magnetic core element, e.g. by adjusting physical dimensions of the centre leg 110 of the magnetic core element. The levels of the above-mentioned magnetic saturation can be adjusted by designing physical dimensions of the permanent magnets. For example, the same magnetic core element 101 can be used for different ratings of electrical current i_{ac} by choosing a suitable width of the permanent magnets W_{PM} for each value of the electrical current. The permanent magnets can be composed of several parallel pieces and different values of the width W_{PM} can be realized by varying a number of parallel pieces in each of the permanent magnets 103 and 103a.

[0020] In a reactor arrangement according to an embodiment of the invention the permanent magnets 103 and 103a are arranged to drive magnetic saturation of the legs 104 and 105 into the vicinity of a point of a magnetization curve in which the radius of curvature of the magnetization curve has its smallest value. In other words, the biasing magnetic flux component Φ_{PM} corresponds to the vicinity of the "knee"-point of the magnetization curve. The magnetization curve is the magnetic flux density (T) vs. magnetic field strength (A/m) -curve (B-H-curve) of the magnetically amplifying material of the magnetic core element 101.

[0021] In the reactor arrangement shown in figure 1, the winding 102 is located around the centre leg 110 of the magnetic core element. This is not, however, the only alternative as illustrated in figure 2.

[0022] Figure 3 shows a reactor arrangement according to an embodiment of the invention. The reactor arrangement according to this embodiment of the invention is composed of two permanent magnet biased reactors 350 and 351 that are electrically connected in series in such a way that the inductance of the reactor arrangement is mainly provided with the permanent magnet biased reactor 350 when electrical current i_{ac} is positive and with the permanent magnet biased reactor 351 when the electrical current i_{ac} is negative. Without limiting generality, the electrical current i_{ac} can be defined to be positive when it flows in a direction of an arrow i_{ac}+ and negative when it flows in a direction of an arrow i_{ac}-.

[0023] The reactor arrangement comprises a magnetic core structure 301 that has two separate magnetic core elements 301 a and 301 b. The magnetic core elements are made of magnetically amplifying material, i.e. material having the relative permeability greater than unity ($\mu_r > 1$). The reactor arrangement comprises a winding 302 that has a first coil arranged to magnetize the magnetic core element 301 a and a second coil arranged to magnetize the magnetic core element 301 b as a response to a situation in which the electrical current i_{ac} is directed to the winding. The reactor arrangement comprises a first permanent magnet 303 that is arranged to generate a biasing magnetic flux component Φ_{PM1} into parts (legs) 304 and 304a of the magnetic core structure 301. The reactor arrangement comprises a second permanent magnet 303a that is arranged to generate a biasing magnetic flux component Φ_{PM2} into parts (legs) 305 and 305a of the magnetic core structure 301. The winding 302 is arranged to magnetize the legs 304 and 304a of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM1} as a response to a situation in which the electrical current i_{ac} is positive and to magnetize the legs 305 and 305a of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM2} as a response to a situation in which the electrical current is negative. In figure 3, the magnetic flux component generated with the winding 302 into the magnetic core element 301 a is denoted with Φ_{i1} and the magnetic flux component generated with the winding 302 into the magnetic core element 301 b is denoted with Φ_{i2}. The arrowheads of the Φ_{i1} and Φ_{i2} correspond to a situation in which the electrical current i_{ac} is positive.

[0024] As came out in the above description of the reactor arrangement shown in figure 3, the term "magnetic core structure" covers in this document also situations in which the magnetic core structure comprises more than one magnetic core element, e.g. the magnetic core structure 301 comprises the magnetic core elements 301 a and 301 b.

[0025] Figure 4 shows a reactor arrangement according to an embodiment of the invention. The reactor arrangement comprises a magnetic core structure 401 made of magnetically amplifying material, i.e. material having the relative permeability greater than unity (μ_r > 1). The reactor arrangement comprises a winding 402 arranged to magnetize the magnetic core structure as a response to a situation in which electrical current i_{ac} is directed to the winding. Without limiting generality, the electrical current i_{ac} can be defined to be positive when it flows in a direction of an arrow i_{ac}+ and negative when it flows in a direction of an arrow i_{ac}-. The reactor arrangement comprises a permanent magnet 403 that is arranged to generate a biasing magnetic flux component Φ_{PM} into a first part (leg) 404 of the magnetic core structure 101 and into a second part (leg) 405 of the magnetic core structure. The permanent magnets 403 can be a single block of permanent magnet material or be composed of many pieces of permanent magnet material. The winding 402 is arranged to magnetize the leg 404 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current i_{ac} is positive and to magnetize the leg 405 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current is negative. The magnetic flux component generated with the winding 402 is denoted with Φ_i in figure 4. The arrowheads of the Φ_i correspond to a situation in which the electrical current i_{ac} is positive.

[0026] Figure 5 shows a reactor arrangement according to an embodiment of the invention. The reactor arrangement comprises a magnetic core structure 501 made of magnetically amplifying material, i.e. material having the relative permeability greater than unity (μ_r > 1). The reactor arrangement comprises permanent magnets 503 and 503a that are arranged to generate a biasing magnetic flux component Φ_{PM} into a first part (leg) 504 of the magnetic core structure 501 and into a second part (leg) 505 of the magnetic core structure. The reactor arrangement comprises windings 502, 502a, and 502b located around a centre leg 510 of the magnetic core structure 501. The winding 502 is arranged to magnetize the leg 504 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which electrical current i_{ac1} is positive and to magnetize the leg 505 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current i_{ac1} is negative. The winding 502a is arranged to magnetize the leg 504 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which electrical current i_{ac2} is positive and to magnetize the leg 505 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current i_{ac2} is negative. The winding 502b is arranged to magnetize the leg 504 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which electrical current i_{ac3} is positive and to magnetize the leg 505 of the magnetic core structure in a direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which the electrical current i_{ac3} is negative. The magnetic flux component generated with one or more of the windings 502, 502a, and 502b is denoted with Φ_i in figure 5.

[0027] The reactor arrangement shown in figure 5 can be used, for example, as a common-mode choke that is arranged to suppress fluctuations of a sum of the electrical currents i_{ac1}, i_{ac2}, and i_{ac3} ($i_{ac1} + i_{ac2} + i_{ac3}$).

[0028] The reactor arrangements according to the embodiments of the invention described above and shown in figures 1-5 are, however, just illustrative examples and possible shapes for magnetic core structures and the numbers of permanent magnets, windings, and magnetic gaps are not restricted to those presented in this document.

[0029] An electrical converter device according to an embodiment of the invention comprises at least one reactor arrangement according to an embodiment of the invention. The electrical converter device can be, for example, an inverter, a rectifier, and/or a frequency converter.

[0030] Figure 6 shows a block diagram of an electrical converter device 600 according to an embodiment of the invention. The electrical converter device comprises phase-specific reactor arrangements 611-613 for alternating electrical currents received from an alternating voltage network 623. The electrical converter device may further comprise phase-specific reactor arrangements 614-616 for alternating electrical currents supplied to a load 622 of the electrical converter device. Each of the reactor arrangements 611-616 is a reactor arrangement according to an embodiment of the invention. For example, each of the reactor arrangements 611-616 could be according to what is depicted in figure 1 or 2 or 3 or 4. In the exemplifying situation shown in figure 6, the load 622 is a three phase alternating current motor. The load can be as well some other electrical device, e.g. an induction heater. The electrical converter device comprises a converter unit 620 that is arranged to transfer energy from the alternating voltage network 623 to an intermediate circuit 624. The converter unit 620 can be e.g. a rectifier. The converter unit 620 can be as well a device that is capable of transferring energy, not only from the alternating voltage network 623 to the intermediate circuit 624, but also from the intermediate circuit back to the alternating voltage network. The electrical converter device comprises a converter unit 621 that is able to transfer energy from the intermediate circuit 624 to the load 622 and, preferably but not necessarily, also to transfer energy from the load to the intermediate circuit.

[0031] Figure 7 shows a block diagram of an electrical converter device 700 according to an embodiment of the invention. The electrical converter device comprises a reactor arrangement 717 that has phase-specific windings for alternating electrical currents received from an alternating voltage network 723. The reactor arrangement 717 is adapted to operate as a common-mode choke for the said alternating electrical currents. The electrical converter device may further comprise a reactor arrangement 718 having phase-specific windings for alternating electrical currents supplied to a load 722 and being adapted to operate as a common-mode choke. Each of the reactor arrangements 717 and 718 is a reactor arrangement according to an embodiment of the invention. For example, each of the reactor arrangements 717 and 718 could be according to what is depicted in figure 5.

[0032] Figure 8 is a flow chart of a method according to an embodiment of the invention for providing inductive reactance for alternating electrical current i_{ac}. A phase 801 comprises generating, with at least one permanent magnet (e.g. 403 in figure 4), a biasing magnetic flux component Φ_{PM} into a first part (e.g. 404 in figure 4) of a magnetic core structure (e.g. 401 in figure 4) and into a second part (e.g. 405 in figure 4) of the magnetic core structure. The magnetic core structure is made of magnetically amplifying material. The first part and the second part of the magnetic core structure can be e.g. legs of the magnetic core structure. A phase 802 comprises directing the alternating electrical current i_{ac} to a winding (e.g. 402 in figure 4) arranged to magnetize the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is positive ($i_{ac} > 0$) and to magnetize the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is negative ($i_{ac} < 0$).

[0033] A method according to an embodiment of the invention comprises directing at least two alternating electrical currents (e.g. i_{ac1}, i_{ac3}, and i_{ac3} in figure 5) to different windings (e.g. 502, 502a, and 502b in figure 5). Each of the windings is arranged to magnetize the first part of the magnetic core structure in the direction opposite to the biasing magnetic flux component Φ_{PM} as a response to a situation in which electrical current of that winding is positive and to magnetize the second part of the magnetic core structure in the direction opposite to the biasing magnetic flux component as a response to a situation in which the said electrical current is negative. The method according to this embodiment of the invention can be used for providing common-mode inductance for the at least two alternating electrical currents.

[0034] In a method according to an embodiment of the invention, the magnetic core structure (e.g. 101 in figure 1) is a three-leg magnetic core element, the first part of the magnetic core structure is a first side leg (e.g. 104 in figure 1) of the magnetic core element, the second part of the magnetic core structure is a second side leg (e.g. 105 in figure 1) of the magnetic core element, and the winding (e.g. 102 in figure 1) is located around a centre leg (e.g. 110 in figure 1) of the magnetic core element.

[0035] In a method according to an embodiment of the invention, the at least one permanent magnet is used for driving magnetic saturation of the first part and the second part of the magnetic core structure into the vicinity of a point of a magnetization curve in which the radius of curvature of the magnetization curve has its smallest value. In other words, the biasing magnetic flux component Φ_{PM} corresponds to the vicinity of the "knee"-point of the magnetization curve. The magnetization curve is the magnetic flux density (T) vs. magnetic field strength (A/m) -curve (B-H-curve) of the magnetically amplifying material of the magnetic core structure.

Example cases

[0036] Figure 9 shows a reactor arrangement according to an embodiment of the invention. The advantage that can be achieved with permanent magnets 903 and 903a is illustrated below with different physical dimensions W, W1, and W2 of a magnetic core element 901. The other dimensions of the magnetic core element 901 are: H = 60 mm, H1 = 10 mm, H2 = 10 mm, H3 = 4 mm, H4 = 8 mm, G1 = 2 mm, G2 = 4 mm, W_{PM} = 13mm, and the thicknesses of the magnetic core element and the permanent magnets in the direction perpendicular to the plane of figure 9 are 30 mm. The magnetic core element is made of electrical steel sheets. The magnetic flux density caused by the permanent magnets into legs 904 and 905 of the magnetic core element is about 1.7 T. The number of turns of the winding 902 is 90.

[0037] In the first example case W = 67 mm, W1= 6 mm, and W2 = 15 mm.

Values of the following quantity:

[0038]

$$100\ \% \times (L_{PM} - L_{noPM}) / L_{noPM},$$

that indicates the effect of the permanent magnets 903 and 903a are presented in Table 1 for different values of electrical current I. L_{PM} is the inductance of the reactor arrangement shown in figure 9 and L_{noPM} is the inductance of an otherwise similar reactor arrangement but without permanent magnets. The inductances are defined as Ψ/I, where Ψ is the flux linkage of the windings 902, i.e. not as dΨ/dI.

Table 1.

I [A]	$(L_{PM} - L_{noPM}) / L_{noPM}$ [%]
10	8.6 %

(continued)

I [A]	$(L_{PM} - L_{noPM})/ L_{noPM}$ [%]
15	19 %
20	17 %
25	13 %

[0039] In the second example case W = 63 mm, W1= 4 mm, and W2 = 15 mm. Values of the quantity that indicates the effect of the permanent magnets 903 and 903a are presented in Table 2 for different values of the electrical current I.

Table 2.

I [A]	$(L_{PM} - L_{noPM})/ L_{noPM}$ [%]
10	18 %
15	27 %
20	14 %
25	10 %

[0040] In the third example case W = 67 mm, W1= 6 mm, and W2 = 20 mm. Values of the quantity that indicates the effect of the permanent magnets 903 and 903a are presented in Table 3 for different values of the electrical current I.

Table 3.

I [A]	$(L_{PM} - L_{noPM})/ L_{noPM}$ [%]
10	- 0.2 %
15	21 %
20	13 %
25	8.5 %

[0041] In the fourth example case W = 63 mm, W1= 4 mm, and W2 = 20 mm. Values of the quantity that indicates the effect of the permanent magnets 903 and 903a are presented in Table 4 for different values of the electrical current I.

Table 4.

I [A]	$(L_{PM} - L_{noPM})/ L_{noPM}$ [%]
10	12 %
15	27 %
20	13 %
25	7.6 %

[0042] While there have been shown and described and pointed out fundamental novel features of the invention as applied to embodiments thereof, it will be understood that various omissions and substitutions and changes in the form and details of the devices and methods described may be made by those skilled in the art without departing from the scope of the inventive idea defined in the independent claims. For example, it is expressly intended that all combinations of those elements and/or method steps which perform substantially the same function in substantially the same way to achieve the same results are within the scope of the invention. Moreover, it should be recognized that structures and/or elements and/or method steps shown and/or described in connection with any disclosed form or embodiment of the invention may be incorporated in any other disclosed or described or suggested form or embodiment as a general matter of design choice. The specific examples provided in the description given above should not be construed as limiting. Therefore, the invention is not limited merely to the embodiments described above, many variants being possible without departing from the scope of the inventive idea defined in the independent claims.

Claims

1. A reactor arrangement comprising:

- a magnetic core structure (101, 301, 401, 501) made of magnetically amplifying material,
- a winding (102, 302, 402, 502) arranged to magnetize the magnetic core structure as a response to a situation in which electrical current is directed to the winding, and
- at least one permanent magnet (103, 103a, 303, 303a, 403, 503, 503a) arranged to generate a biasing magnetic flux component into a first part (104, 304, 304a, 404, 504) of the magnetic core structure and into a second part (105, 305, 305a, 405, 505) of the magnetic core structure,

characterized in that the winding is arranged to magnetize the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current is positive and to magnetize the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current is negative.

2. A reactor arrangement according to claim 1, wherein the reactor arrangement comprises at least one other winding (502a, 502b) and each of the at least one other winding is arranged to magnetize the first part (504) of the magnetic core structure (501) in the direction opposite to the biasing magnetic flux component as a response to a situation in which electrical current of that winding is positive, and to magnetize the second part (505) of the magnetic core structure in the direction opposite to the biasing magnetic flux component as a response to a situation in which the electrical current of that winding is negative.

3. A reactor arrangement according to claim 1, wherein the magnetic core structure (101, 501) is a three-leg magnetic core element, the first part of the magnetic core structure is a first side leg (104, 504) of the three-leg magnetic core element, the second part of the magnetic core structure is a second side leg (105, 505) of the three-leg magnetic core element, and the winding (102, 502, 502a, 502b) is located around a centre leg (110, 510) of the three-leg magnetic core element.

4. A reactor arrangement according to claim 1, wherein the at least one permanent magnet is arranged to drive magnetic saturation of the first part of the magnetic core structure and magnetic saturation of the second part of the magnetic core structure substantially to a point of a magnetization curve of the magnetically amplifying material in which a radius of curvature of the magnetization curve has its smallest value.

5. An electrical converter device, **characterized in that** the electrical converter device comprises at least one reactor arrangement (611-616, 717, 718) according to claim 1.

6. An electrical converter device according to claim 5, wherein the at least one reactor arrangement comprises phase-specific reactor arrangements (611-613) for alternating electrical currents received from an alternating voltage network (623).

7. An electrical converter device according to claim 5, wherein the at least one reactor arrangement comprises phase-specific reactor arrangements (614-616) for alternating electrical currents supplied to a load (622) of the electrical converter device.

8. An electrical converter device according to claim 5, wherein the at least one reactor arrangement comprises a reactor arrangement (717) having phase-specific windings for alternating electrical currents received from an alternating voltage network (723) and being arranged to operate as a common-mode choke for those alternating electrical currents.

9. An electrical converter device according to claim 5, wherein the at least one reactor arrangement comprises a reactor arrangement (718) having phase-specific windings for alternating electrical currents supplied to a load (722) of the electrical converter device and being arranged to operate as a common-mode choke for those alternating electrical currents.

10. A method for providing inductive reactance for alternating electrical current, the method comprising:

- generating (801), with at least one permanent magnet (103, 103a), a biasing magnetic flux component into a first part (104) of a magnetic core structure (101) made of magnetically amplifying material and into a second part (105) of the magnetic core structure,

characterized in that the method further comprises:

- directing (802) the alternating electrical current to a winding (102) arranged to magnetize the first part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is positive and to magnetize the second part of the magnetic core structure in a direction opposite to the biasing magnetic flux component as a response to a situation in which the alternating electrical current is negative.

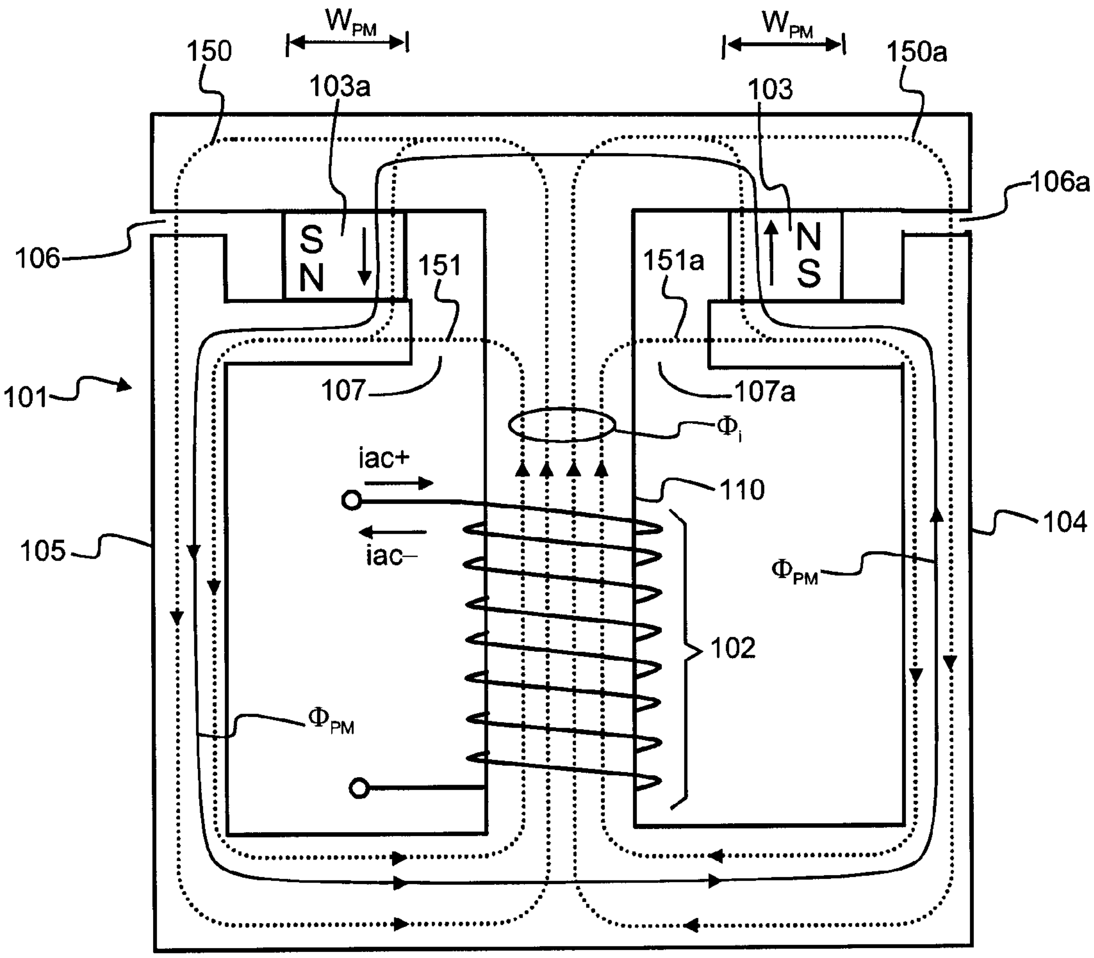


Figure 1

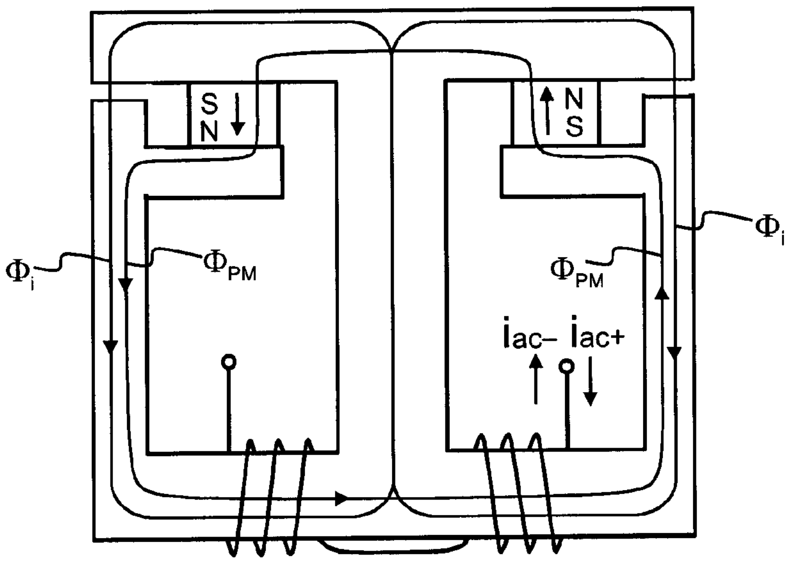


Figure 2

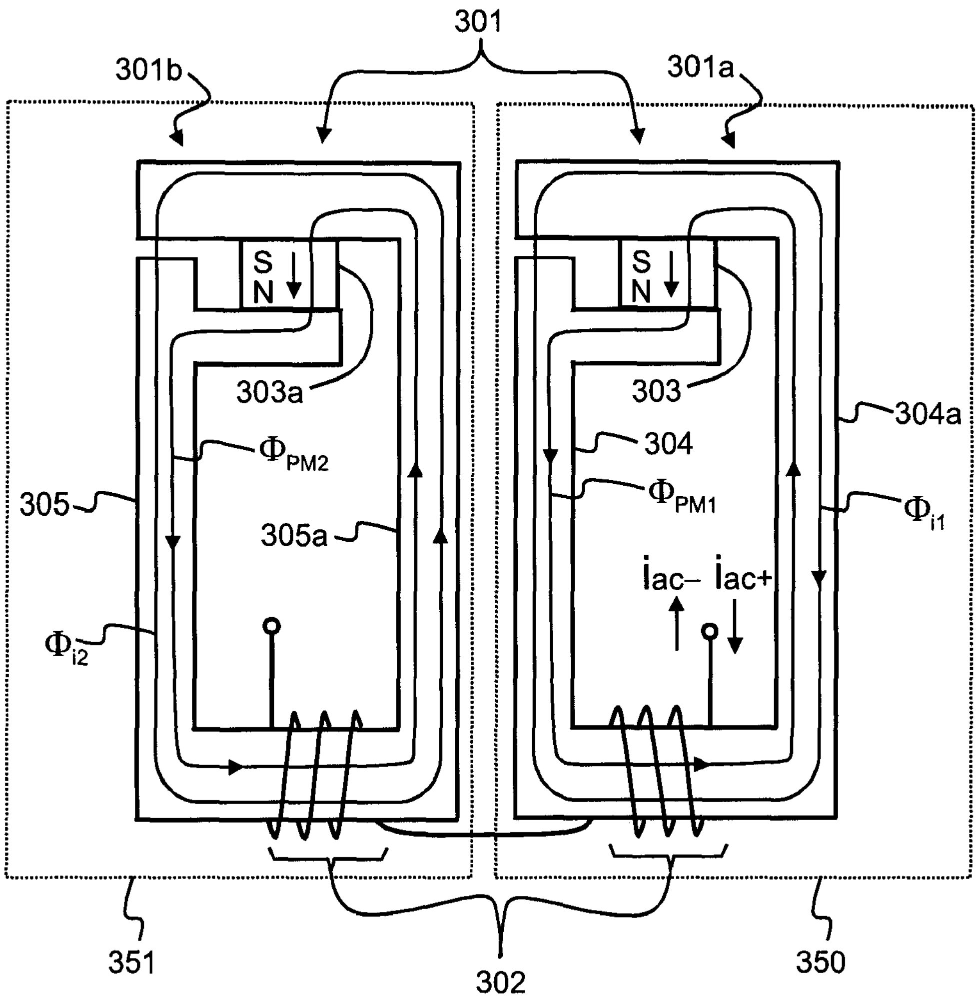

301
301b
301a
S
N
S
N
303a
303
304a
304
Φ_{PM2}
Φ_{PM1}
305
305a
Φ_{i1}
i_{ac-} i_{ac+}
Φ_{i2}
351
302
350

Figure 3

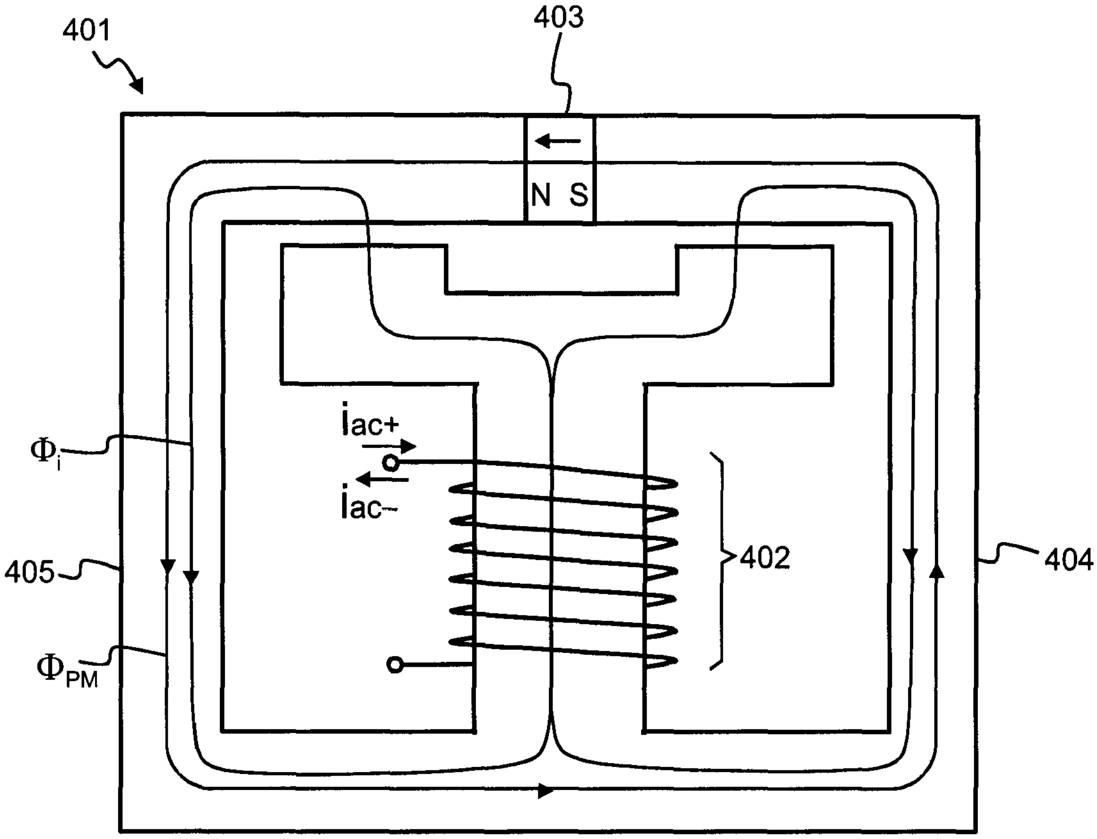
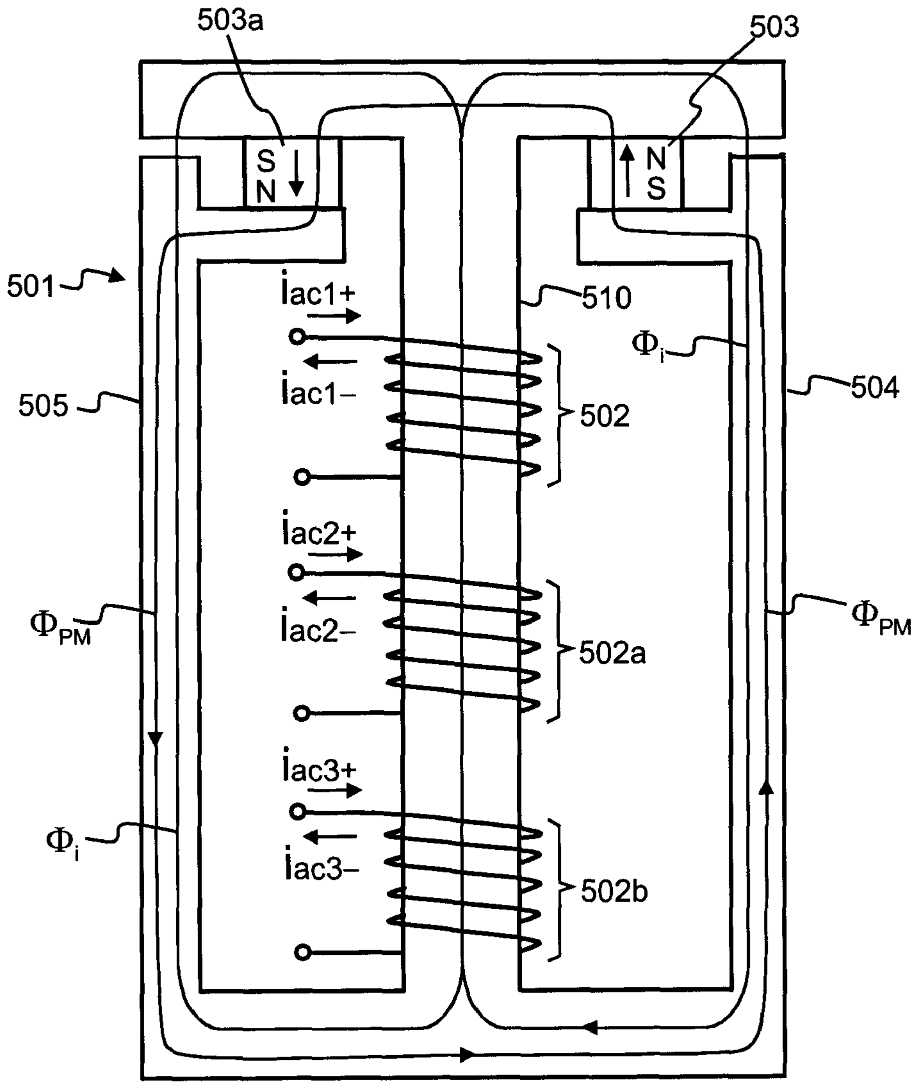


Figure 4



503a
503
S
N
N
S
501
510
i_{ac1+}
i_{ac1-}
Φ_i
505
502
504
i_{ac2+}
i_{ac2-}
Φ_{PM}
502a
Φ_{PM}
i_{ac3+}
Φ_i
i_{ac3-}
502b

Figure 5

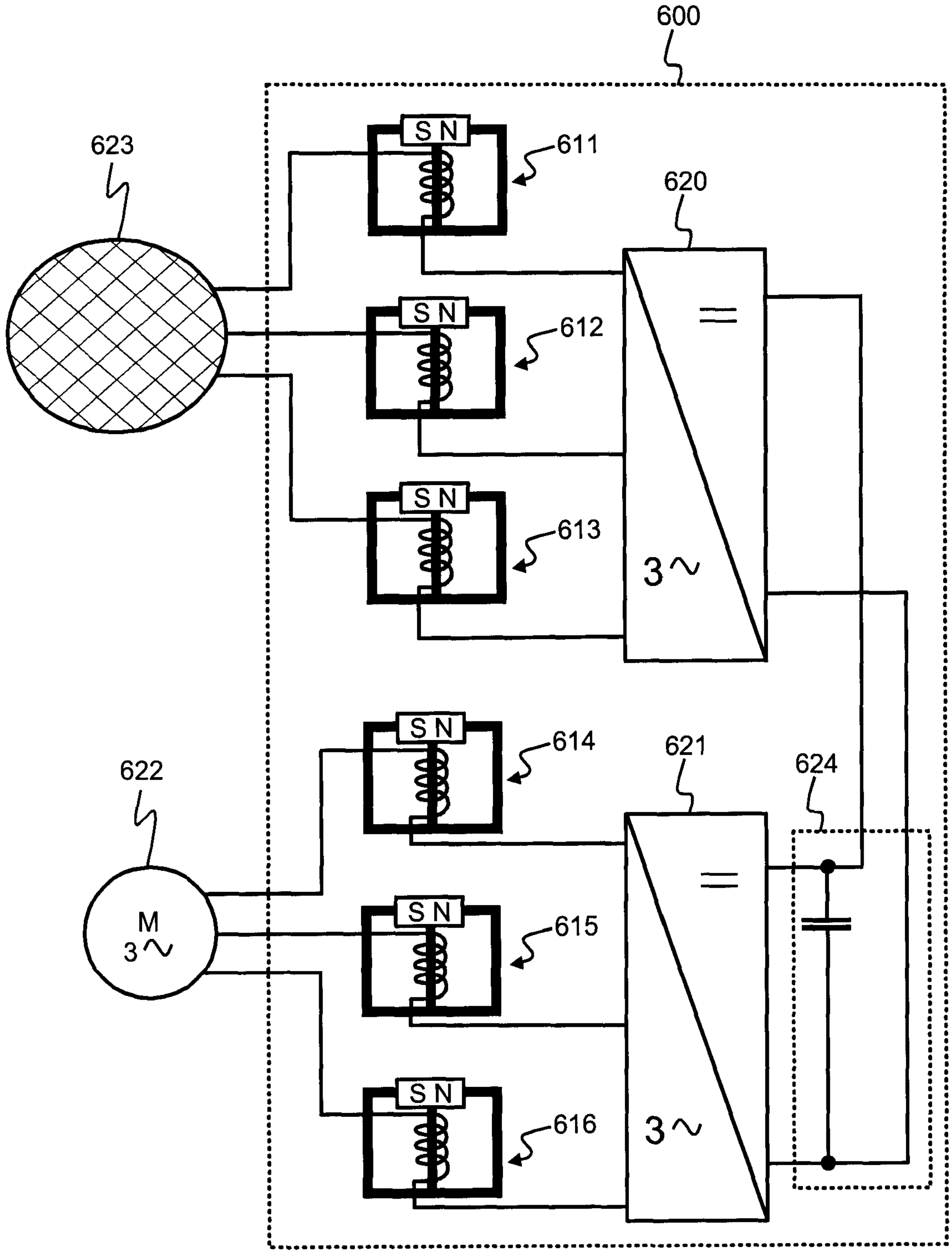

600
623
S N
611
620
S N
612
=
S N
613
3~
S N
614
621
624
622
M
3~
S N
615
=
S N
616
3~

Figure 6

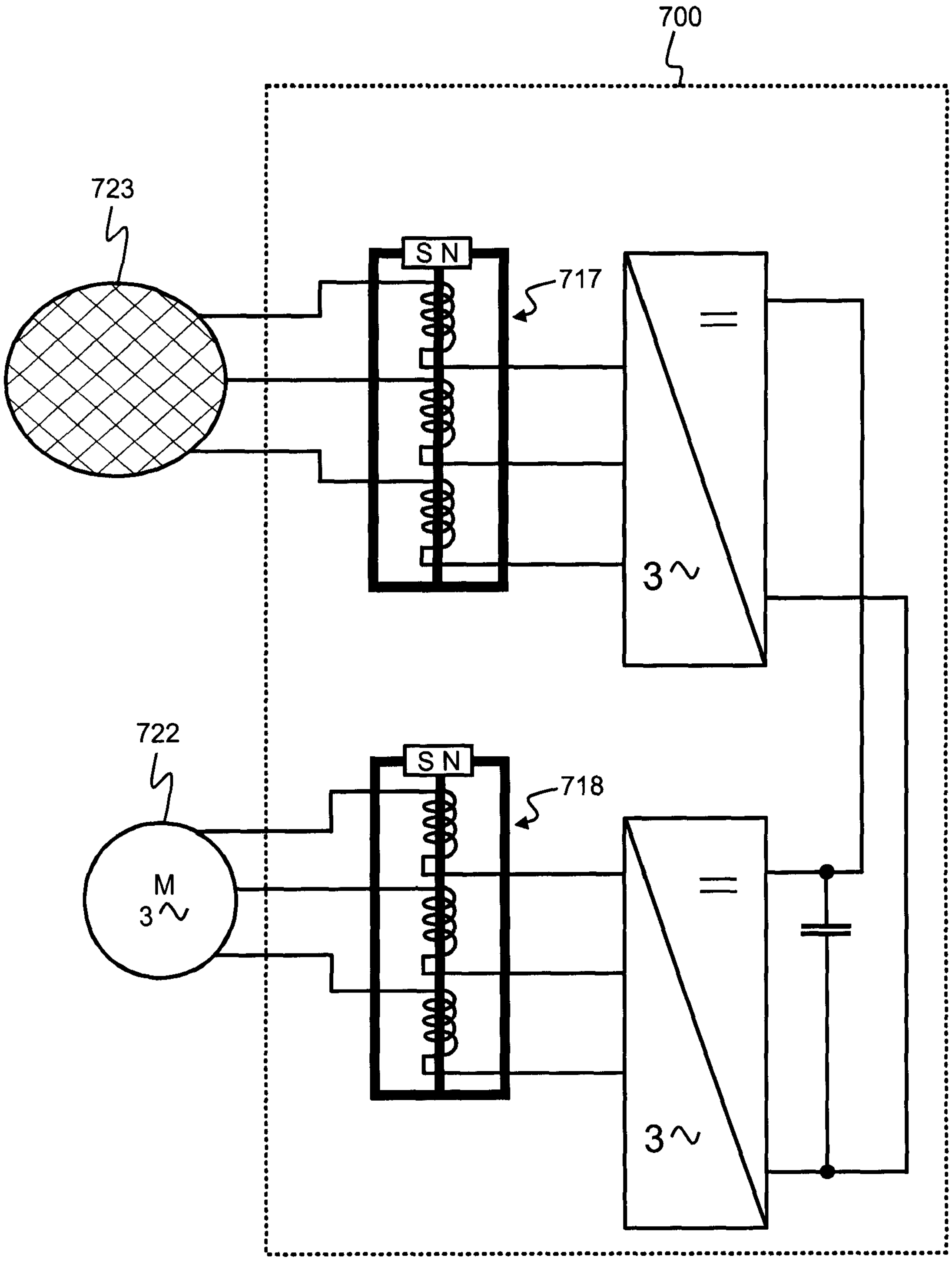


Figure 7

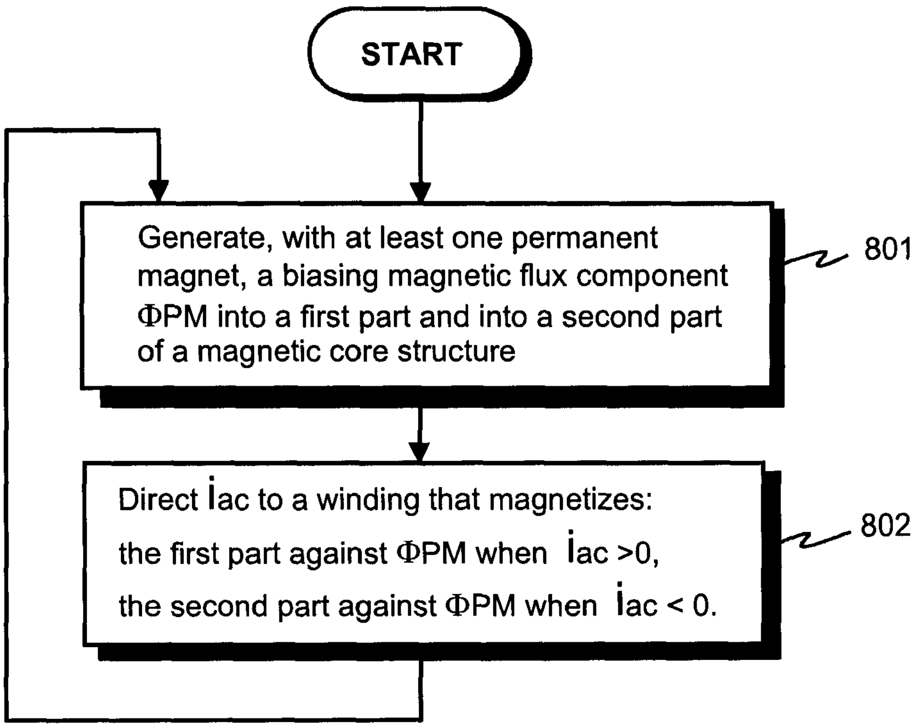

START
Generate, with at least one permanent magnet, a biasing magnetic flux component ΦPM into a first part and into a second part of a magnetic core structure
801
Direct $\dot{i}ac$ to a winding that magnetizes:
the first part against ΦPM when $\dot{i}ac$ >0,
the second part against ΦPM when $\dot{i}ac$ < 0.
802

Figure 8

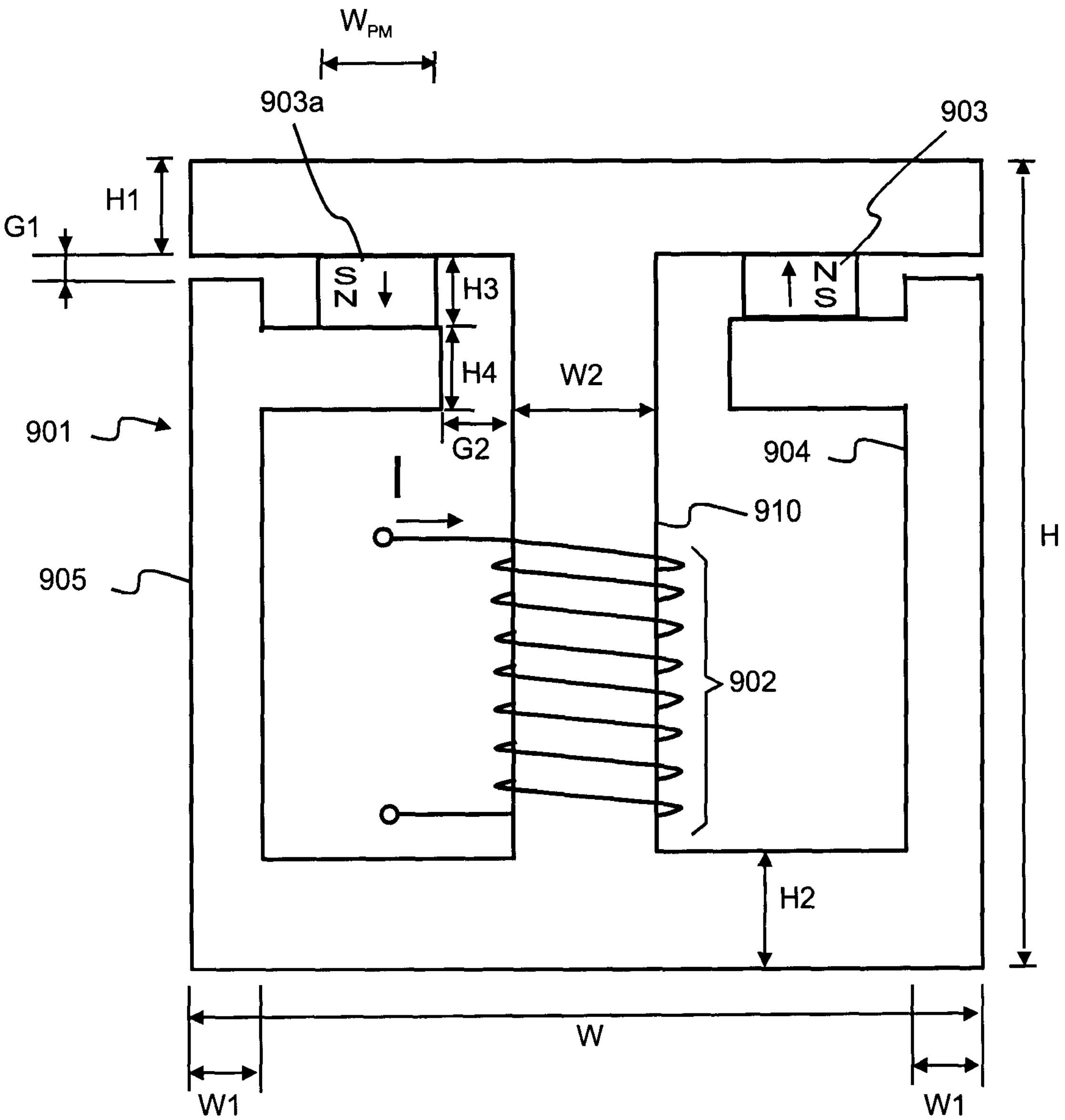

W_PM
903a
903
H1
G1
S
N
H3
N
S
H4
W2
901
G2
904
I
910
905
902
H
H2
W
W1
W1

Figure 9

European Patent Office

EUROPEAN SEARCH REPORT

Application Number
EP 08 15 5638

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Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (IPC)
X	JP 2001 358025 A (MITSUBISHI ELECTRIC CORP) 26 December 2001 (2001-12-26) * abstract; figures 1,11 * -----	1-10	INV. H01F37/00 H01F3/10
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X	DE 32 02 600 A1 (ZUMTOBEL AG [AT]) 9 September 1982 (1982-09-09) * pages 9,10; figures 1,6,7,9,10 * -----	1-10	
A	US 6 191 676 B1 (GABOR GEORGE [US]) 20 February 2001 (2001-02-20) * column 1, lines 16-25 * * column 23, lines 1-43; figure 16 * * column 25, lines 19-39; figures 20,22 * -----	2,5-9	
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			H01F H01M

The present search report has been drawn up for all claims

1

Place of search	Date of completion of the search	Examiner
The Hague	12 September 2008	Teske, Ekkehard

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12-09-2008

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