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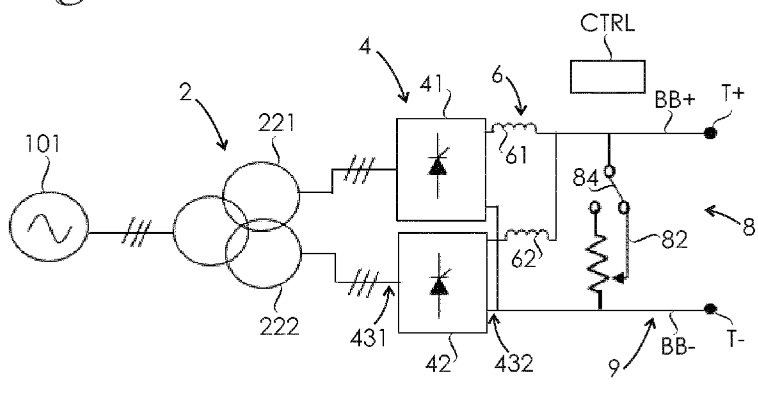
(54) Title: DIRECT CURRENT POWER SUPPLY ASSEMBLY

Fig. 1



(57) Abstract: A direct current power supply assembly comprising a transformer (2), a rectifier system (4), and a choke system (6). The transformer (2) has a primary winding system adapted to be connected to a three-phase alternating current network (101), and a secondary winding system comprising a first secondary winding (221) and a second secondary winding (222) such that there is 30° phase shift between the first secondary winding (221) and the second secondary winding (222). The rectifier system (4) comprises a first rectifier device (41) connected to the first secondary winding (221), and a second rectifier device (42) connected to the second secondary winding (222), and each of the rectifier devices comprises thyristors and/or diodes. The choke system (6) comprises a first choke (61) connected to an output of the first rectifier device (41), and a second choke (62) connected to an output of the second rectifier device (42).

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DIRECT CURRENT POWER SUPPLY ASSEMBLY

FIELD OF THE INVENTION

The present invention relates to a direct current power supply assembly.

Direct current power supply assemblies for charging electric vehicles from a three-phase alternating current network are known in the art. A known assembly comprises a half-controlled diode-thyristor bridge, a harmonic filter and a power factor correction circuit. In further known assemblies said half-controlled diode-thyristor bridge is replaced with a diode bridge, or with a fully controlled thyristor bridge.

One of the disadvantages associated with the known direct current power supply assembly is that it is expensive.

BRIEF DESCRIPTION OF THE INVENTION

An object of the present invention is to provide a direct current power supply assembly so as to alleviate the above disadvantage. The objects of the invention are achieved by a direct current power supply assembly which is characterized by what is stated in the independent claim. The preferred embodiments of the invention are disclosed in the dependent claims.

The invention is based on the realization that it is possible to meet the grid code with a direct current power supply assembly having a twelve pulse rectifier system comprising thyristors and/or diodes, without providing the direct current power supply assembly with a harmonic filter and a power factor correction circuit.

A direct current power supply assembly according to the invention comprises a transformer, a rectifier system, and a choke system. The transformer has a secondary winding system comprising a first secondary winding and a second secondary winding such that there is 30° phase shift between the first secondary winding and the second secondary winding. The rectifier system comprises a first rectifier device connected to the first secondary winding, and a second rectifier device connected to the second secondary winding, and each of the rectifier devices comprises thyristors and/or diodes. The choke system comprises a first choke connected to an output of the first rectifier device, and a second choke connected to an output of the second rectifier device. A leakage reactance of the transformer and inductance values of the first choke and the second choke are selected as a suitable combination such that the direct current power supply assembly meets the grid code for the entire operating range of the direct current power supply assembly. In an embodiment, a simulation software is utilized for finding said suitable combination. An advantage of the direct current power supply assembly of the invention is that it meets the grid code without using harmonic filter and power factor correction. The assembly of the invention is inexpensive and simple.

Further, the direct current power supply assembly of the invention has high efficiency, high power density and low electromagnetic disturbance. Compared to a known direct current power supply assembly whose rectifier system comprises IGBTs, the direct current power supply assembly of the invention has low commutation noise level, and high reliability.

BRIEF DESCRIPTION OF THE DRAWINGS

In the following the invention will be described in greater detail by means of preferred embodiments with reference to the attached drawings, in which

Figure 1 shows a simplified circuit diagram of a direct current power supply assembly according to an embodiment of the invention during a start-up of the assembly;

Figure 2 shows the circuit diagram of Figure 1 after a transient time from the start-up; and

Figure 3 shows a simplified circuit diagram of a direct current power supply assembly according to another embodiment of the invention after a transient time from the start-up.

DETAILED DESCRIPTION OF THE INVENTION

Figure 1 shows a simplified circuit diagram of a direct current power supply assembly comprising a transformer 2, a rectifier system 4, a controller CTRL, a choke system 6, a stabilization load system 8, and a bus bar system 9. The controller CTRL is adapted for controlling the rectifier system 4 and the stabilization load system 8.

The transformer 2 has a primary winding system connected to a three-phase alternating current network 101, and a secondary winding system connected to an alternating current input 431 of the rectifier system 4. The transformer 2 is a three-phase three winding transformer. The secondary winding system of the transformer 2 has a first secondary winding 221 and a second secondary winding 222.

Nominal primary voltage of the transformer 2 is 415 V, and nominal secondary voltage of the transformer 2 is 500 V. Nominal power of the transformer 2 is 500 kVA. In alternative embodiments, nominal primary voltage of the transformer is equal to or greater than 150 V, nominal secondary voltage of the transformer is equal to or greater than 150 V, and nominal power of the transformer is equal to or greater than 10 kVA.

The bus bar system 9 has a positive bus bar BB+ and a negative bus bar BB-. The direct current power supply assembly is adapted to be connected to a load thereof by means of a positive load terminal T+ connected to the positive bus bar BB+, and a negative load terminal T- connected to the negative bus bar BB-.

The rectifier system 4 is a twelve pulse rectifier system. The rectifier system 4 comprises a first rectifier device 41 whose three-phase input is connected to the first secondary winding 221 of the transformer 2, and a second rectifier device 42 whose three-phase input is connected to the second secondary winding 222 of the transformer 2. There is 30° phase shift between the first secondary winding 221 and the second secondary winding 222. The first rectifier device 41 and the second rectifier device 42 are six pulse fully controlled thyristor bridge rectifiers. The first rectifier device 41 and the second rectifier device 42 are identical with each other.

The primary winding of the transformer 2 is a star-connected winding, the first secondary winding 221 is a delta-connected winding, and the second secondary winding 222 is a star-connected winding. There are several alternative ways to provide the 30° phase shift between the first secondary winding and the second secondary winding. A number of said alternatives is disclosed in Table 1. Designing a phase shift between first and second secondary winding of a three winding transformer is known in the art.

Table 1. Winding arrangement alternatives for a three winding transformer.

Primary winding	First secondary winding	Second secondary winding
Y	Y	Δ
Y	Δ	Y
Δ	Δ	Y
Δ	Y	Δ
Y	Δ+15°	Δ-15°
Y	Δ-15°	Δ+15°

The transformer 2 is adapted to provide 30° phase shift between the inputs of the first rectifier device 41 and the second rectifier device 42. In alternative embodiments, said 30° phase shift is provided without a three winding transformer. An example of such an embodiment is discussed later.

The choke system 6 connects a direct current output 432 of the rectifier system 4 to the bus bar system 9. The choke system 6 comprises a first choke 61 connected between an output of the first rectifier device 41 and the bus bar system 9, and a second choke 62 connected between an output of the second rectifier device 42 and the bus bar system 9.

A first output terminal of the first rectifier device 41 is connected to the positive bus bar BB+ of the bus bar system 9 through the first choke 61. A first output terminal of the second rectifier device 42 is connected to the positive bus bar BB+ through the second choke 62. The second output terminals of the first rectifier device 41 and the second rectifier device 42 are connected to the negative bus bar BB- of the bus bar system 9. In alternative embodiments, the choke system alternatively or additionally comprises a choke connected between the second output terminal of the first rectifier device and the negative bus bar of the bus bar system, and/or between the second output terminal of the second rectifier device and the negative bus bar of the bus bar system.

A leakage reactance of the transformer 2 and inductance values of the first choke 61 and the second choke 62 are selected as combination such that the direct current power supply assembly meets the grid code relating to the three-phase alternating current network 101 for the entire operating range of the direct current power supply assembly, and currents at the output of the first rectifier device 41 and the output of the second rectifier device 42 are greater than zero for the entire operating range of the direct current power supply assembly. With the selected combination of the leakage reactance of the transformer 2 and the inductance values of the first choke 61 and the second choke 62, currents at the output of the first rectifier device 41 and the output of the second rectifier device 42 have sawtooth or triangular waveforms and a phase shift of 30° for the entire operating range of the direct current power supply assembly.

A leakage reactance of the transformer 2 is 10 %, and inductance values of the first choke 61 and the second choke 62 are 0.05 mH. With above mentioned selections, the direct current power supply assembly of Figure 1 meets the grid code according to standard EN50160.

For a specific direct current power supply assembly, a combination of a leakage reactance of the transformer and inductance values of the first choke and the second choke can be selected by means of a suitable simulation software.

Table 2 shows technical specifications of direct current power supply assemblies having different nominal values. The direct current power supply assemblies of Table 2 meet the grid code according to standard EN50160.

In Table 2 U_{rs_out} is nominal voltage of the direct current output of the rectifier system;

P_{as} is nominal active power of the direct current power supply assembly;

$U_{tr,nom}$ are nominal voltages of the transformer comprising nominal primary voltage / nominal voltage of the first secondary winding / nominal voltage of the second secondary winding;

%XL is a feasible range for percent leakage reactance of the transformer; and

L_{ch} is a feasible range for inductance value of the first choke and the second choke.

Table 2. Examples of direct current power supply assemblies according to the invention.

U_{rs_out} (Vdc)	**P_{as} (kW)**	**$U_{tr,nom}$ (Vac)**	**%XL**	**L_{ch} (mH)**
600	400	415/500/500	5%-15%	0.01-0.1
	800	415/530/530	5%-15%	0.01-0.1
700	400	415/560/560	5%-15%	0.01-0.1
	800	415/600/600	5%-15%	0.01-0.1
550-650	100	415/500/500	5%-15%	0.1-1
370	25	415/300/300	5%-15%	0.1-1

The stabilization load system 8 is connected between the positive bus bar BB+ and the negative bus bar BB- of the bus bar system 9, and adapted to provide a stabilization load for the rectifier system 4 in situations where there is no useful electric load connected between the positive load terminal T+ and the negative load terminal T-. In other words the stabilization load system 8 is adapted to stabilize an open circuit voltage of the bus bar system 9.

The stabilization load system 8 comprises a rheostat 82 and a single pole double throw changeover switch 84. The controller CTRL is adapted to control the rheostat 82 to provide a first load during a start-up of the assembly, and to decrease the load from the first load to a second load within a transient time from the start-up. The controller CTRL comprises a relay logic for controlling the rheostat 82.

The transient time is less than one second. In an alternative embodiment the transient time is less than five seconds. In a further alternative embodiment, the stabilization load system has a constant resistance, and the controller is not adapted for controlling the stabilization load system.

The first load provides an electric current of 2 A, and the second load provides an electric current of 0.2 A. The first load is adapted to provide a first current through the thyristors of the rectifier system 4, and the second load is adapted to provide a second current through the thyristors of the rectifier system 4. The first current is equal to or greater than a latching current of the thyristors, and the second current is equal to or greater than a holding current of the thyristors. In an alternative embodiment a ratio between the second load and the first load is in a range of 5 – 20 %.

The controller CTRL is adapted to control the rectifier system 4 such that triggering angles of the thyristors increase as a function of a voltage of the three-phase alternating current network 101. When said voltage is 90% of the nominal voltage thereof, the thyristors are triggered at 3°, when said voltage is equal to the nominal voltage thereof, the thyristors are triggered at 18°, and when said voltage is 110% of the nominal voltage thereof, the thyristors are triggered at 28°.

In alternative embodiments, the controller is adapted to control the rectifier system such that when the voltage of the three-phase alternating current network is 90% of the nominal voltage thereof, the triggering angles of the thyristors are in the range of 0-5°, when said voltage is equal to the nominal voltage thereof, the triggering angles of the thyristors are in the range of 15-20°, and when said voltage is 110% of the nominal voltage thereof, the triggering angles of the thyristors are in the range of 25-30°.

Figure 3 shows a simplified circuit diagram of a direct current power supply assembly which is a modification of the direct current power supply assembly of Figures 1 and 2. In the embodiment of Figure 3, the three winding transformer 2 has been replaced by a transformer 2′ comprising a first transformer unit 21′ and a second transformer unit 22′, each of which is a two winding transformer. In other respects the assembly of Figure 3 is identical to the assembly of Figures 1 and 2.

The transformer 2′ has a primary winding system connected to a three-phase alternating current network 101′, and a secondary winding system connected to an alternating current input 431′ of the rectifier system 4′. The primary winding system of the transformer 2′ comprises a primary winding of the first transformer unit 21′, and a primary winding of the second transformer unit 22′. The secondary winding system of the transformer 2′ comprises a first secondary winding 221′ and a second secondary winding 222′. The first secondary winding 221′ is a secondary winding of the first transformer unit 21′, and the second secondary winding 222′ is a secondary winding of the second transformer unit 22′. The input of the first rectifier device 41′ is connected to the first secondary winding 221′, and the input of the second rectifier device 42′ is connected to the second secondary winding 222′.

The primary winding of the first transformer unit 21′ is a star-connected winding, and the first secondary winding 221′ is a delta-connected winding. The primary winding of the second transformer unit 22′ is a star-connected winding, and the second secondary winding 222′ is a star-connected winding. There is 30° phase shift between the first secondary winding 221′ and the second secondary winding 222′. Designing a phase shift between secondary windings of parallel connected transformer units is known in the art.

In an alternative embodiment the rectifier system comprises a half-controlled diode-thyristor bridge. In a further alternative embodiment the rectifier system comprises a diode bridge. A rectifier system with a diode bridge is usable if fluctuations in a voltage of the three-phase alternating current network are small, for example within ±2%, and the load connected between the positive load terminal and the negative load terminal is substantially constant.

The direct current power supply assembly according to the invention can be designed for charging any type of rechargeable device. Typical embodiments include direct current power supply assemblies designed for charging electric vehicles such as cars, buses, trucks, trains or trams. In an embodiment, a direct current power supply assembly according to the invention is adapted to be coupled to a load or rechargeable device by means of a temporary coupling device such as a plug or a pantograph.

It will be obvious to a person skilled in the art that the inventive concept can be implemented in various ways. The invention and its embodiments are not limited to the examples described above but may vary within the scope of the claims.

CLAIMS

1. A direct current power supply assembly comprising:

a transformer (2) having a primary winding system adapted to be connected to a three-phase alternating current network (101), and a secondary winding system;

a bus bar system (9) having a positive bus bar (BB+) and a negative bus bar (BB-);

a rectifier system (4) comprising semiconductor switches, an alternating current input (431) connected to the secondary winding system of the transformer (2), and a direct current output (432);

a choke system (6) through which the direct current output (432) of the rectifier system (4) is connected to the bus bar system (9),

c h a r a c t e r i z e d in that

the semiconductor switches comprise thyristors and/or diodes,

the secondary winding system of the transformer (2) comprises a first secondary winding (221) and a second secondary winding (222) such that there is 30° phase shift between the first secondary winding (221) and the second secondary winding (222),

the rectifier system (4) is a twelve pulse rectifier system, and comprises a first rectifier device (41) whose input is connected to the first secondary winding (221) of the transformer (2), and a second rectifier device (42) whose input is connected to the second secondary winding (222) of the transformer (2), and the choke system (6) comprises a first choke (61) connected between an output of the first rectifier device (41) and the bus bar system (9), and a second choke (62) connected between an output of the second rectifier device (42) and the bus bar system (9), and

a leakage reactance of the transformer (2) and inductance values of the first choke (61) and the second choke (62) are selected as combination such that the direct current power supply assembly meets the grid code relating to the three-phase alternating current network (101) for the entire operating range of the direct current power supply assembly.

2. A direct current power supply assembly according to claim 1, **c h a r a c t e r i z e d** in that the semiconductor switches comprise thyristors, and the direct current power supply assembly comprises a controller (CTRL) and a stabilization load system (8), the controller (CTRL) being adapted for control-

ling the rectifier system (4), and the stabilization load system (8) being connected between the positive bus bar (BB+) and the negative bus bar (BB-) of the bus bar system (9), and adapted to provide a stabilization load for the rectifier system (4) in situations where there is no useful electric load connected to the bus bar system (9).

3. A direct current power supply assembly according to claim 2, **characterized** in that the stabilization load system (8) comprises a rheostat (82), and the controller (CTRL) is adapted to control the rheostat (82) to provide a first load during a start-up of the assembly, and to decrease the load from the first load to a second load within a transient time from the start-up, wherein the first load is adapted to provide a first current through the thyristors, and the second load is adapted to provide a second current through the thyristors, the first current being equal to or greater than a latching current of the thyristors, and the second current being equal to or greater than a holding current of the thyristors.

4. A direct current power supply assembly according to claim 3, **characterized** in that a ratio between the second load and the first load is in a range of 5 – 20 %.

5. A direct current power supply assembly according to claim 3 or 4, **characterized** in that the transient time is less than five seconds.

6. A direct current power supply assembly according to any one of preceding claims, **characterized** in that the transformer (2) is a three winding transformer.

7. A direct current power supply assembly according to any one of preceding claims, **characterized** in that a first output terminal of the first rectifier device (41) is connected to a bus bar of the bus bar system (9) through the first choke (61), and a first output terminal of the second rectifier device (42) is connected to the bus bar through the second choke (62), and the second output terminals of the first rectifier device (41) and the second rectifier device (42) are connected to the other bus bar of the bus bar system (9).

8. A direct current power supply assembly according to claim 2, **characterized** in that the controller (CTRL) is adapted to control the rectifier system (4) such that triggering angles of the thyristors increase as a function of a voltage of the three-phase alternating current network (101).

9. A direct current power supply assembly according to any one of preceding claims, **characterized** in that the assembly is adapted for charging

electric vehicles.

10. A direct current power supply assembly according to any one of preceding claims, **characterized** in that the leakage reactance of the transformer (2) is in a range of 5 to 15 %.

11. A direct current power supply assembly according to claim 10, **characterized** in that the first choke (61) and the second choke (62) have identical inductance values in a range of 0.05 to 1 mH.

12. A direct current power supply assembly according to claim 11, **characterized** in that inductance values for the first choke (61) and the second choke (62) are selected based on nominal values of the direct current power supply assembly such that when

a nominal primary voltage of the transformer (2) is in a range of 380 to 450 V,

nominal secondary voltage of the transformer (2) is in a range of 450 to 650 V

nominal voltage of the direct current output (432) of the rectifier system (4) is in a range of 550 to 750 V, and

nominal active power of the direct current power supply assembly is in a range of 350 to 850 kW,

the first choke (61) and the second choke (62) have inductance values in a range of 0.01 to 0.1 mH, and when

a nominal primary voltage of the transformer (2) is in a range of 380 to 450 V,

nominal secondary voltage of the transformer (2) is in a range of 250 to 550 V

nominal voltage of the direct current output (432) of the rectifier system (4) is in a range of 350 to 700 V, and

nominal active power of the direct current power supply assembly is in a range of 20 to 150 kW,

the first choke (61) and the second choke (62) have inductance values in a range of 0.1 to 1 mH.

Fig. 1

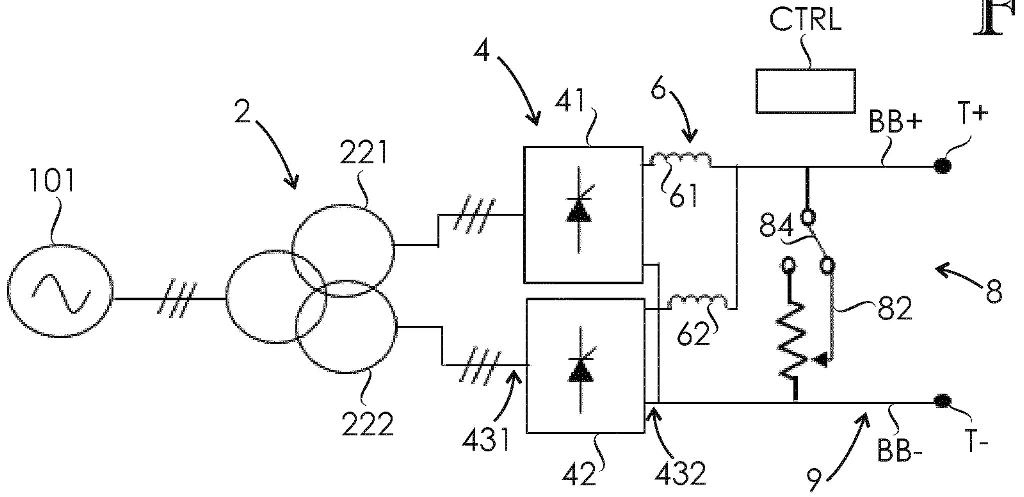


Fig. 2

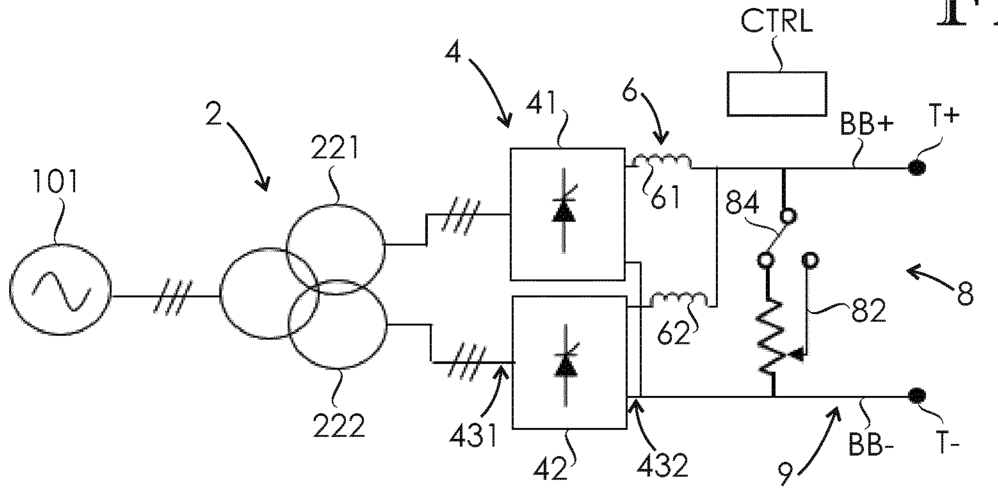
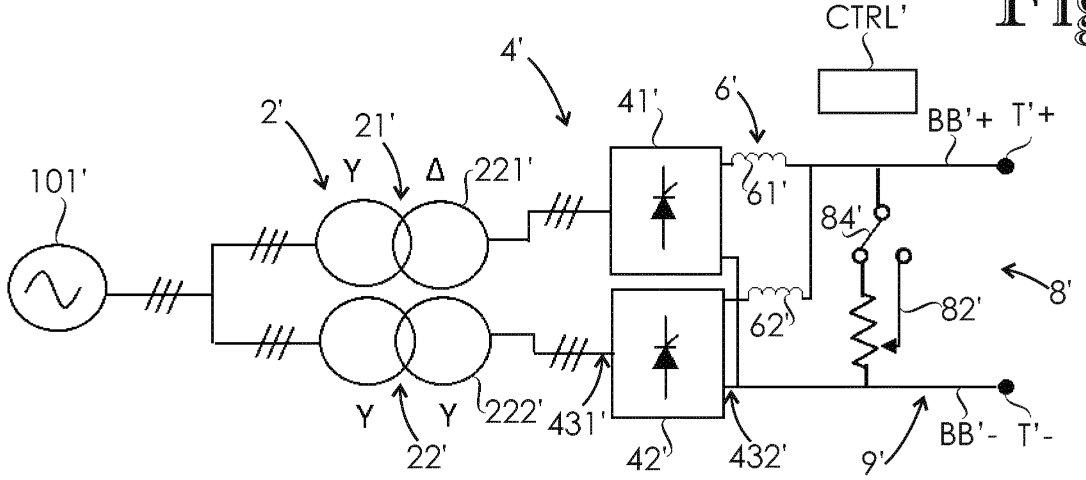


Fig. 3



INTERNATIONAL SEARCH REPORT

International application No
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A. CLASSIFICATION OF SUBJECT MATTER
INV. H02M7/08 H02M7/17 H02M1/36 B60L53/00
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B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)
H02M B60L H01F

Documentation searched other than minimum documentation to the extent that such documents are included in the fields searched

Electronic data base consulted during the international search (name of data base and, where practicable, search terms used)

EPO-Internal, WPI Data

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	US 8 737 097 B1 (YASKAWA AMERICA INC [US]) 27 May 2014 (2014-05-27) the whole document -----	1-12
A	GB 2 383 477 A (FARRER WALTER [GB]) 25 June 2003 (2003-06-25) abstract; figures 2,3 -----	1-12
A	JP S49 124523 A (.) 28 November 1974 (1974-11-28) abstract figure 4 figures 11(A),11(B),11(C),11(D) figures 11,12 -----	2,3
A	CN 105 656 261 A (NANTONG GUANYOUDA MAGNET CO LTD) 8 June 2016 (2016-06-08) abstract -----	2,3

☐ Further documents are listed in the continuation of Box C.

☒ See patent family annex.

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Date of the actual completion of the international search	Date of mailing of the international search report
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Name and mailing address of the ISA/	Authorized officer
European Patent Office, P.B. 5818 Patentlaan 2 NL - 2280 HV Rijswijk Tel. (+31-70) 340-2040, Fax: (+31-70) 340-3016	Standaert, Frans

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INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No
PCT/EP2019/071829

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