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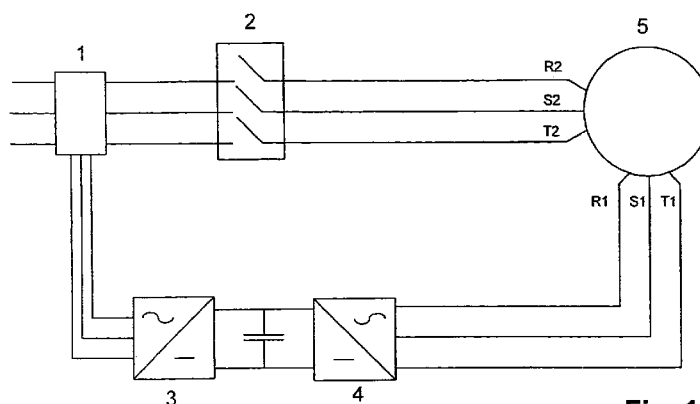
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(54) **Title:** METHOD FOR OPERATION OF A PERMANENT MAGNET SYNCHRONOUS MACHINE, AND A DEVICE IN AN ELECTRIC SYSTEM COMPRISING SUCH A MACHINE

**Fig. 1**

(57) **Abstract:** Device for systems with a permanent magnet synchronous machine (5), such as a motor or generator, with a converter (4) for feeding or withdrawal of power. The converter (4) is connected to the stator and provided for feeding or withdrawal of substantially less power than the maximum power, to combine direct connection and converter connection to a grid.

Method for operation of a permanent magnet synchronous machine, and a device in an electric system comprising such a machine.

5 The invention comprises a method for operation of a permanent magnet synchronous machine as stated in the introductory part of claim 1, and a device as stated in the introductory part of claim 6, in an electric system comprising one or more such machines.

Background

10 Current proposals for feeding and control of electric machines are dominated by three-phase feeding. The connection may be direct or over a converter. In some cases the rotor is fed by collector rings and converter.

 Usual prior art systems with field fed synchronous machines (*Electric Machines, Theory, Operation, Applications, Adjustment, and Control*, Charles I Hubert. ISBN 0-675-21136-0, page 305
15 – 308) has a fixed net frequency. In such systems the active power and the reactive power may be controlled. In generator systems, the power is controlled by controlling the energy supplied (wind, water, gas, steam, etc.) The reactive power is controlled by controlling the current of the field winding. At over magnetizing reactive power is fed into the system, which is normally increasing the voltage (provided inductive load angle). At too low magnetizing, reactive power from the net,
20 with inductive load angle the voltage will decrease. In usual synchronous machines, a magnetizing machine and an auxiliary motor (same source). The magnetizing machine provides collector less transfer of the magnetizing current. The auxiliary motor is running the machine to synchronous rotation. It is possible to combine the magnetizing machine and the starting machine as described in PCT application WO 85/02886.

25 In current PMSM systems converters is normally used for connecting the machine to the net. The converter provides a decoupling between net and machine which allows operation at variable rotation. The converter allows control toward the net. This “active front end” may use switches instead for diodes toward the net. This configuration provides a currently satisfactory net connection. The drawback is the increased costs by the converter. In some cases the costs for the
30 converter equal the machine costs.

 During the last decades, systems have been proposed with partly converter feeding to provide increased functionality. An example is the double fed asynchronous machine shown in *Electric Machines, Theory, Operation, Applications, Adjustment, and Control*, Charles I Hubert. ISBN 0-675-21136-0, Chapter 8. There the stator is fed directly from the net, while the rotor is fed via a
35 converter and collector rings. This configuration provides increased functionality with only 1/3

converter rating. It is known multi phase asynchronous machines and reluctance machines connected to the net through a double feed of the stator. Another example of prior art technology is the synchronous machine with a stator connected directly to the net, while the field circuit has a converter. This transformer has a power rating substantially less than the nominal rating of the generator. On slow rotating machines, normal synchronous machines will require unsuitable large diameter to accommodate the magnetizing windings. In such cases a permanent magnet synchronous machine is a favorable alternative. The drawback of PMSM machines is that the field cannot be controlled with a field winding, the control needs converters.

In some applications PMSM machines are connected directly to the net and are operated as motor or generator. This configuration may be used in a system with a stable speed. Due to the fixed voltage/speed curve of the PM machine, the flow of reactive power flow cannot be controlled in such systems. An alternative control for such systems is to install a parallel source of reactive power. Such sources can be established with staged static condensers or switched condenser assemblies (STATCOM). The drawback of such systems is the high costs.

“Soft Starter” is a notion used for systems with devices for providing a better start in regard of start current and transient torque (*Design of Intelligent Soft-Start Controller for Induction Motor*, Wen-Xiong Li, Jian-Guo Lv, Ming-Sheng Lu. JIE zm03, Proceedings of the Third International Conference on Machine learning and Cybernetics, Shanghai, 26-29 August 2004). Typical to such systems is the use of thyristors serially to the stator winding. The thyristors are ramping up the voltage to the stator, to provide a softer start than at direct starting. This type of equipment cannot give the functionality as a full bridge converter regarding torque/speed control at starting. The full bridge configuration can control the machine with advanced vector control, while the thyristor-serial connection provides less control. The use of vector control allows control of all kinds of machines optimally. Serial connection of thyristors has also been proposed to control active and reactive power.

Objects

The main object of the invention is to reduce costs and size, with a machine occupying less space than a corresponding permanent magnet synchronous machine.

It is also an object to provide a system with a higher efficiency compared with system with full converter.

Further objects will appear from the following description of the invention and its embodiments.

The Invention

The method according to the invention is described in claim 1. It is based on double feeding of the stator of a permanent magnet synchronous machine. The double feeding is achieved by using the combination of a direct feeding and a converter feeding of a stator. This provides more advantages compared to prior art technology. The advantages of different machine types are stated more specifically in the following examples. The invention may be called "double fed permanent magnet synchronous machine" (DFPMPS).

The invention also comprises a device in an electric system including a permanent magnet synchronous machine, as stated in claim 6. It comprises a device in a system with a permanent magnet synchronous machine, such as a motor or a generator, with a converter for feeding or withdrawal of power, the novelty being the converter being provided to feed or withdraw a power substantially under the maximum power, to combine direct feeding and converter feeding (or withdrawal).

This system has corresponding advantages as the method described.

Further features of the invention are described in the remaining claims.

The converter may be rated for less than approximately 50% of the total power (nominal power).

The invention may be used at different permanent magnet machines, both rotational and linear, motors as well as generators.

Permanent magnet synchronous machines today are thus connected direct to the grid or connected over a full converter (with the nominal power of the machine). By combining both kinds of connection of the stator, it is possible to have a solution operating on constant velocity with control of the reactive power flowing. The difference between the prior art and the novel solution is the double feeding of the prior art systems, feeding stator direct and the rotor via converter, while the novel invention has a feeding with both methods (direct and converter) to the stator. The rotor of a PMSM system has permanent magnets.

The novel system has reduced costs compared to a full converter solution, but will provide a substantial part of the functionality. Additionally to controlling the reactive power feeding, the converter may be used for controlling the torque. This novel solution has no brushes or collector rings and will thus need substantially less maintenance than prior art systems (Double Fed Induction Generator – DFIG).

The size of the converter fed part will vary according to the requirements for control of the system. The requirements for coupling varies from country to country. In Norway, the proprietor of the grid is placing the requirements. In the advice for grid connection, systems larger than 10 MW have particular connection requirements. These requirements imply that novel systems

should be designed to contribute to control the active and reactive power during different conditions of operation in the grid.

For such systems the requirement for the converter fed part of the system reach 50%. For smaller systems (< 10 MW), the invention will make the system more resistant to malfunction of the system. On voltage changes, the system may deliver reactive power to the grid. For smaller system (< 10 MW) the requirements of the grid proprietor will not guide the system design. In such systems the requirement for stable voltage will be most important. If one or more generator systems provide a voltage changes or frequency changes exceeding the limits for the output quality, the power supplier will be responsible for possible damage to the electric system. At the consumer side, damage occurs to equipment normally when the voltage is too high or too low. When using DFPMSG (Direct fed permanent magnet synchronous generators), the terminal voltage of the generator system is controlled, to avoid damages at the consume side.

The converter to be used according to the invention may be a standard converter. There is no limitation to the type of switches or topologies to be used. One example may be a full bridge converter. This converter may be based on IGBT (Insulated Gate Bipolar Transistor) technology and be designed with a part for the grid side (Active Front End) and a part connected to the motor. Said two converter parts are typically connected with a DC connection.

Example

The invention is now described with reference to the drawing.

Description to Figure 1

An integrated solution is shown in Figure 1. R1, R2, S1, S2, T1, and T2 denotes windings connected to two separate zero points. The windings are grouped to make each group a three phase system. Group 1 consists of R1, S1, T1. Group 2 consists of R2, S2, T2. The group 1 is connected to the grid through a converter 3. Group 2 is connected direct to the grid through a grid connector 2. When the machine is started the rotor is accelerated with the converter 3. It is possible to use the converter controlled part for operating at changing speeds. This may be useful in a wind power system when withdrawing a reduced power at low speeds. Or in a propeller system with pitch control.

1 denotes the connector between the direct connection and the converter. It may contain grid filters and/or transformers.

2 denotes a connector for making a direct connection. It may be physical (a contactor) or electronically (power electronics)

3 denotes a converter connected to the grid

4 denotes a converter connected to the electric machine,
5 denotes the electric machine.

Description to Figure 2

- 5 In Figure 2 a system is shown with two machines on the same shaft. This principle can also be used in systems without a common shaft for starting an engine with an alternative admission (e.g. water or steam).

Description to Figure 3

- 10 1 denotes the connector between the direct connection and the converter. It may contain grid filters and/or transformers.
- 2 denotes a connector for making a direct connection. It may be physical (a contactor) or electronically (power electronics)
- 3 denotes a converter connected to the grid
- 15 4 denotes a converter connected to the electric machine,
5 denotes the electric machine.
- 6 denotes a filter or a transformer (may also be operated without)
- 7 denotes a filter or a transformer (may also be operated without)
- 20 The converter of Figure 3 may be a common full bridge converter or another converter concept, e.g. a multi level converter. Converters with switches to be independently disconnected are favorable, e.g. IGBT switches.
- In Figure 3 the converter is connected over the direct connection via a filter or grid transformer. The filter may be L or LCL for this kind of system. The rating of the filter together with the
- 25 converter will govern the part of the power to be controlled.
- By using the converter, the reactive and the active power may be controlled. The system may also be controlled without disturbance of the grid. If only the direct connection is used, maximum efficiency may be achieved for some operations.
- The last solution is optimal in regard of efficiency, as the system may deliver full power without
- 30 using the converter. The converter mode of operation may be changed between passive, synchronizing, starting, stopping, reactive compensator and more.
- The operation with optimum efficiency is particularly important when generating power, but also important in systems with high cooling requirements. This may be the case in down hole operation with high surface temperatures. With the system of Figure 3, a system may be provided
- 35 using power electronics during start and operation to reduce the losses.

Description to Figure 4

Figure 4 shows an alternative to the electric system of Figure 1.

1 denotes the stator of the electric machine (6 phase)

5 2 denotes the device for connection to a grid

3 denotes the direct connection

4 denotes the converter

5 denotes the grid

10 Figure 4 is a schematically illustration of a double fed stator. The stator 1 has 6 phases. Three of the phases are connected to the direct connection 3, while three of the phases are connected to the converter 4. Both supplies are connected to the grid 5 to have the stator double fed.

Additionally the system may also have filters and transformers. Contactors may be arranged to allow by pass and/or parallel connection of the converter.

15 **Description to Figures 5 and 6**

Figure 5 is showing an alternative connection of the double fed system. In this case, the converter is connected between the two separate sets of windings. Figure 6 is showing a possible connection for the converter in Figure 5. The configuration in Figures 5 and 6 will allow all advantages of a double feeding (start, braking, reactive power control, damping of transients etc.)

20

Configurations

The system may be structured differently:

Integrated solution

25 In the integrated solutions, a machine may be split in different groups of windings. Each group is representing a three phase connection. One or more groups may be direct fed, while one or more may have a converter connection. An electric machine may be arranged with multiple three phase systems, e.g. a 9 phase system, with 3 phases connected via a converter and 6 phases connected direct.

30 **Systems solutions**

In one system one may use a physically decoupled system, where some parts are connected direct to the grid, while one or more parts are connected over a converter. The system control may be provided to control the power flow through the converter and the physical admission.

Examples of use

The invention may be used at a generator system powered by water or other kinds of energy. For one generator system, there may be multiple possibilities for dividing the system in a direct connected part and a converter connected part.

5 In electrical motors it is possible to use the converter part to bring the machine to a synchronous speed. When the speed is synchronous, the part for direct connection is connected. The system is operating like prior art synchronous machines with an auxiliary machine to achieve synchronous speed. The difference is the use of double fed windings of a stator of a PM machine. An example of this kind of system may be the propulsion system of a ship. In some systems the
10 propellers are having a constant speed and adjustment of the deflection of the propeller blade. This type of system may be started with propellers of zero deflection with the converter and some of the windings. When the machine has a synchronous speed, then the part to be direct connected is engaged. In this way less expensive and more efficient propulsion is achieved.

A further version of this invention is used for double fed linear PSM machines. Generally this
15 may provide the same advantages as described for rotating PMSM machines. This is further described with an example.

Linear machines are used in different markets and applications. One example is linear systems with a spring in each end, wherein resonance is involved. Such resonance systems are used for multiple applications. Common to some of these applications is the need for accelerating the
20 system to the resonance velocity. When this velocity is achieved, the work or operation is conducted at this velocity. The invention with double fed stator may e.g. be used at linear machines with a frequency converter for starting. At the resonance frequency, the double fed windings are connected. The converter fed windings may provide control to the machine, together with control of the reactive power against the grid.

25

Double feeding with full direct connection

A further alternative of a double fed PMSM may use the system of Figure 3, showing an alternative double feeding of the stator. In this case the stator is also fed by a converter and a direct connection.

30

Summary of the advantages of the invention

- When lines are down, the novel system may operate independently
- The active power can be controlled at substantially lower costs
- The reactive power can be controlled at substantially lower costs
- 35 - It is possible to change between direct and converter feeding (Figure 3)

- The invention may be used with multiple stators on a common shaft
- The invention may be used in systems with multiple machines, where one machine is converter fed and the remaining direct fed
- Double feeding may be used for lowering the losses.

5

The invention allows the replacing of a normal synchronous machine with a double fed permanent magnet synchronous machine.

Claims

1. Method for operating a permanent magnet synchronous machine, utilizing a converter for connection to a grid, **characterized** in that the feeding is made both direct and over a converter with a power substantially less than the total power.
- 5 2. Method according to claim 1, **characterized** in that the power of the converter less than about 50% of the total power.
3. Method according to claim 1 or 2, **characterized** in that the converter is used alone or for
10 starting the system.
4. Method according to one of the claims 1 to 3, **characterized** in that the converter is used to control the active and reactive flow of power and for frequency control.
- 15 5. Method according to one of the claims 1 to 3, **characterized** in that the converter is used for damping transients corresponding to the damping windings in prior art synchronous machines.
6. Device for systems with a permanent magnet synchronous machine (5), as a motor or generator, with a converter (4) for feeding or withdrawal of power, **characterized** in that the
20 converter (4) is connected to the stator and provided for feeding or withdrawal substantially less power than the maximum power, to combine direct connection and converter connection to the grid.
7. Device according to claim 6, **characterized** in that the windings of the permanent magnet
25 machine (5) is divided in groups, segments or dishes, one part thereof being connected to the converter (3) and another part connected directly to the grid with a grid connection (2),
8. Device according to claim 6, with multiple machines, **characterized** in that one or more is fed by
30 a converter.
9. Device according to claim 6, **characterized** in that the converter (3) is rated for less than about 50% of the total power.
10. Device according to claim 7, **characterized** in that it is provided for use of all windings for
35 double feeding (Figure 3).

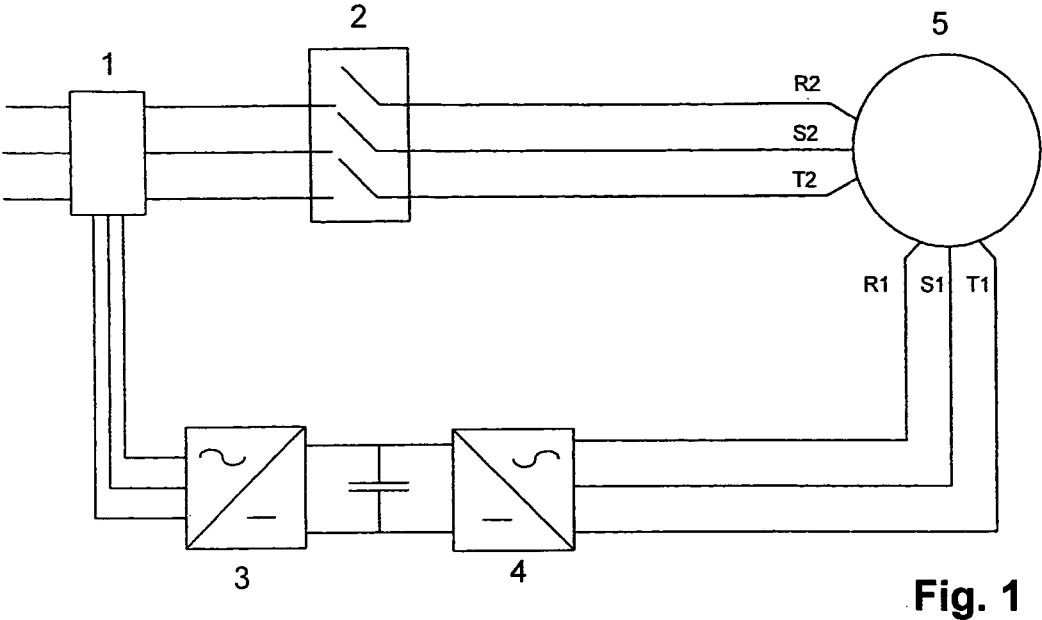


Fig. 1

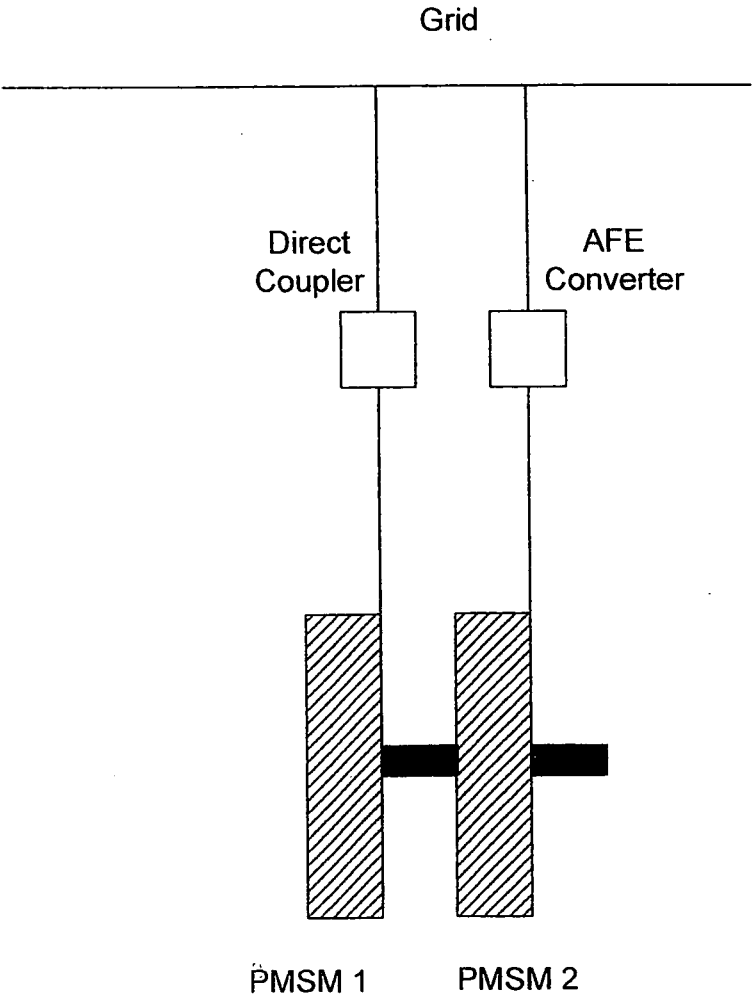


Fig. 2

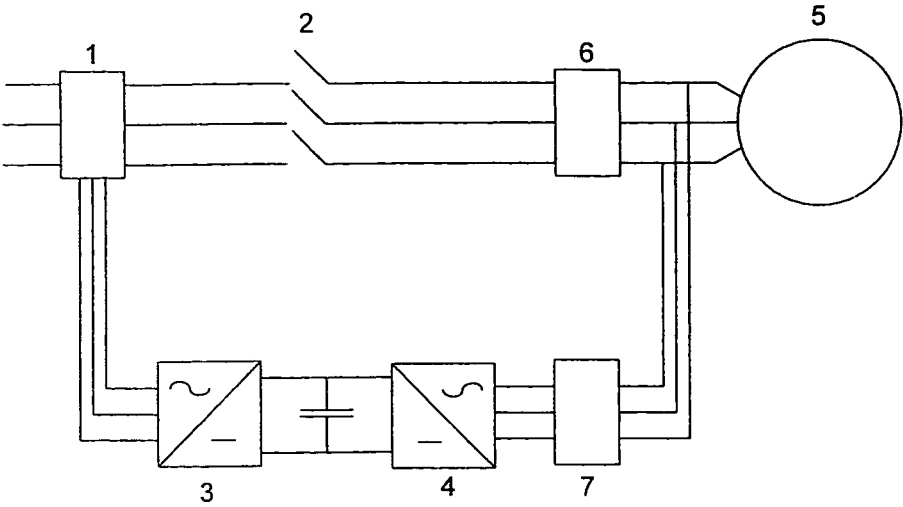


Fig. 3

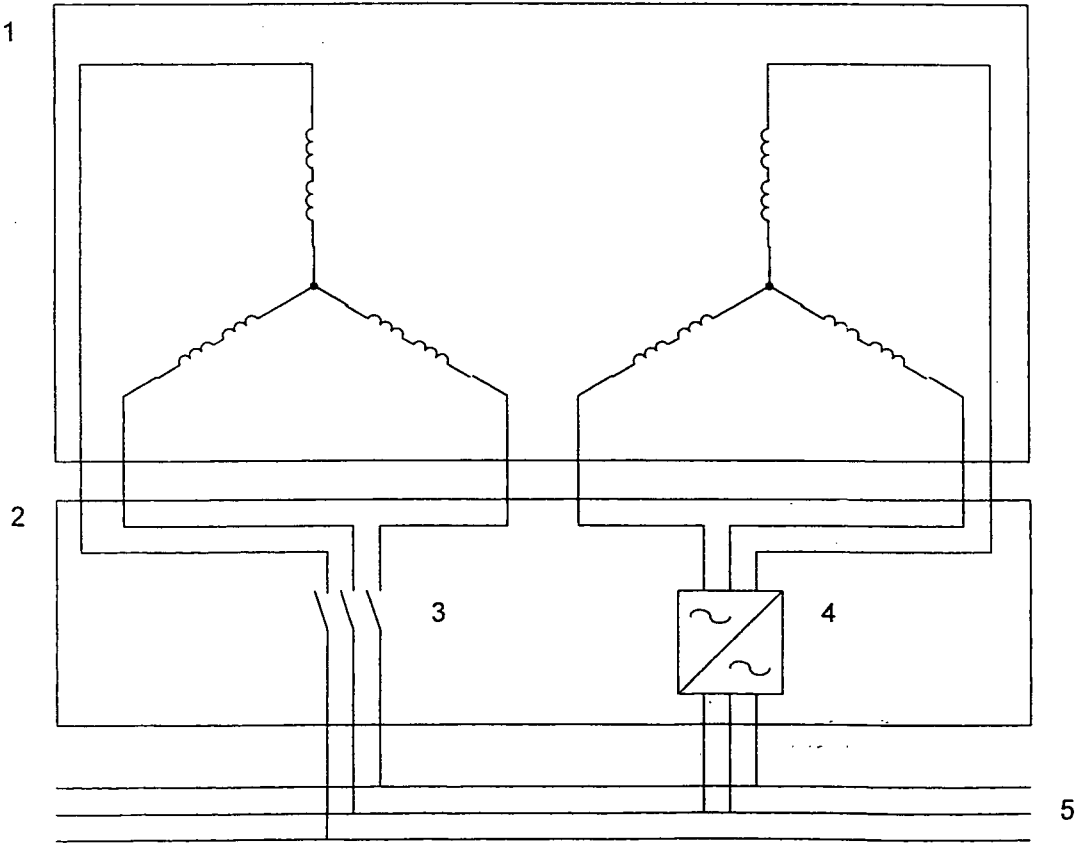


Fig. 4

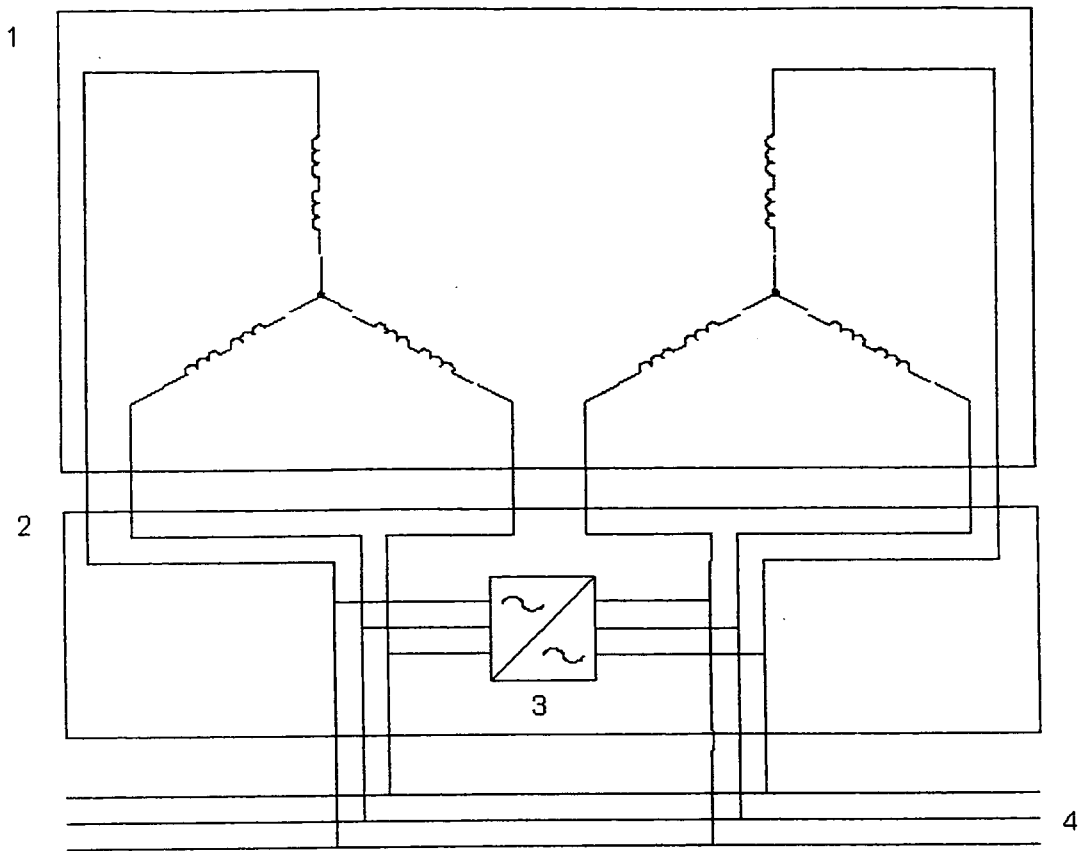


Fig. 5

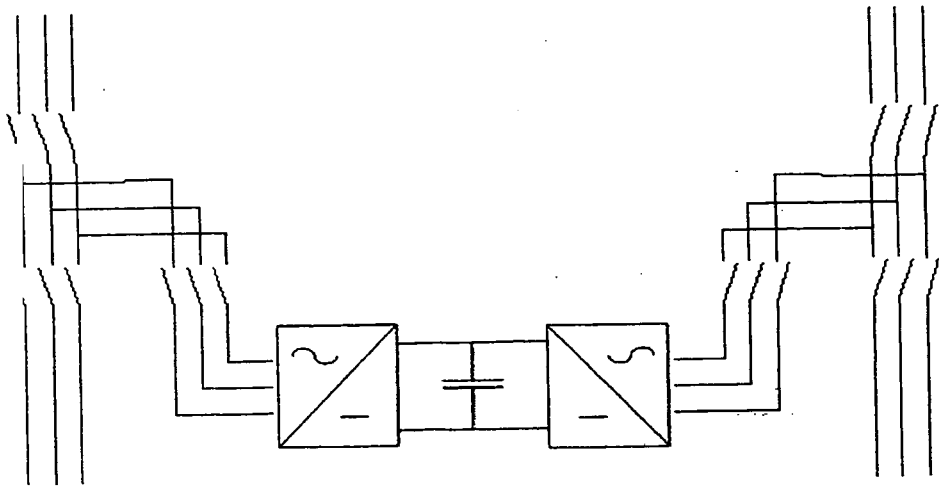


Fig. 6

INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2009/000436

A. CLASSIFICATION OF SUBJECT MATTER

IPC: see extra sheet

According to International Patent Classification (IPC) or to both national classification and IPC

B. FIELDS SEARCHED

Minimum documentation searched (classification system followed by classification symbols)

IPC: F03D, H02J, H02K

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

SE,DK,FI,NO classes as above

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

EPO-INTERNAL, WPI DATA, PAJ

C. DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
X	WO 2007027141 A1 (ABB RESEARCH), 8 March 2007 (08.03.2007), page 20, line 22 - line 23, figures 1,4, abstract --	1-10
A	DE 10210164 A1 (HENSCHER, M. ET AL), 18 Sept 2003 (18.09.2003), figure 6, abstract --	1-10
A	US 20050200337 A1 (D. SCHREIBER ET AL), 15 Sept 2005 (15.09.2005), figure 1, abstract --	1-10

☒ 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

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INTERNATIONAL SEARCH REPORT

International application No.

PCT/NO2009/000436

C (Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

Category*	Citation of document, with indication, where appropriate, of the relevant passages	Relevant to claim No.
A	DE 19651364 A1 (NORDEX ENERGIE-ANLAGEN GMBH), 25 June 1998 (25.06.1998), figure 1, abstract --	1-10
A	US 6411067 B1 (H. BJÖRKLUND), 25 June 2002 (25.06.2002), abstract -- -----	1-10

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Cited literature, if any, will be enclosed in paper form.

INTERNATIONAL SEARCH REPORT

Information on patent family members

International application No.

PCT/NO2009/000436

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