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(54) Title: A VARIABLE ROTOR SPEED WIND TURBINE, WIND PARK, METHOD OF TRANSMITTING ELECTRIC POWER AND METHOD OF SERVICING OR INSPECTING A VARIABLE ROTOR SPEED WIND TURBINE

(57) Abstract: The invention relates to a variable rotor speed wind turbine (1) transmitting AC electric power to a utility grid (13). The wind turbine comprises at least one AC generator (7) and at least one power electronic converter unit (10). Further, it comprises means (10, 15, 20) for transforming at least one nominal output value of said generator to at least one different nominal input value of said at least one power electronic converter unit. The invention also relates to a wind park and a method of transmitting AC electric power to a utility grid (13) from a variable rotor speed wind turbine (1) as well as a method of servicing or inspecting a variable rotor speed wind turbine.

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A VARIABLE ROTOR SPEED WIND TURBINE, WIND PARK, METHOD OF TRANSMITTING ELECTRIC POWER AND METHOD OF SERVICING OR INSPECTING A VARIABLE ROTOR SPEED WIND TURBINE.

5 **Background of the invention**

The invention relates to a variable rotor speed wind turbine as specified in the preamble of claim 1, a wind park and a method of transmitting electric power to a utility grid from a variable rotor speed wind turbine as well as a method of servicing
10 or inspecting a variable rotor speed wind turbine.

Description of the Related Art

A wind turbine known in the art typically comprises a wind turbine tower and a wind
15 turbine nacelle positioned on top of the tower. A wind turbine rotor, comprising three wind turbine blades, is connected to an AC generator in the nacelle, as illustrated on figure 1. The AC generator is usually connected to an AC utility grid through a utility step up transformer.

20 However, the AC generator may also be part of a variable rotor speed wind turbine and consequently be connected to the utility grid through a power electronic converter.

Wind turbines have over the last decade evolved from small and simple power
25 generating units with almost no impact on the utility grid to advanced miniature power plants with substantial penetration into the utility grids. As a consequence, the requirements to the performance and characteristics of the wind turbine and especially the power components are getting more and more significant and restrictive.

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Most of the power components of a previous generation wind turbine have to be redesigned in order to cope with higher AC power ratings which results in an increasing development time for each next generation wind turbines.

5 From JP-A 2003-88190 it is known a variable rotor speed wind turbine with an AC generator connected to a utility grid through a power electronic converter. The Japanese document suggests to use a transformer in conjunction with the power electronic converter to dynamically raise the generated voltage output of the generator when the wind speed drops below a limit which normally indicates that the
10 wind turbine must be disconnected from a utility grid because of low generator voltage i.e. the ratio of the transformer is subsequently changed away from unity.

Further, it is known to use conversion from the initially described type of wind turbine's AC power into high voltage DC. DC power transmission provides certain
15 advantages over long distances e.g. a subsea cable from an offshore wind farm to the shore.

An object of the present invention is to establish technology which meets the requirements to modern wind turbines and especially the power components of the
20 wind turbines establishing an electric AC power to be transmitted into a utility grid.

A further object of the present invention is to establish technology which allows the power components to be chosen more freely and especially with a more freedom from the common restrictions between the power components.

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An even further object of the present invention is to establish a wind turbine system which in some aspect may be inspected and maintained while still being in operation.

The invention

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The invention provides for a variable rotor speed wind turbine transmitting electric power to an AC utility grid wherein said wind turbine further comprises at least one nominal output value transformer for transforming at least one nominal output value of said generator to at least one different nominal input value of said at least one power electronic converter unit.

Hereby it is possible to establish technology which meets the requirements to especially the power components of the wind turbines establishing an electric AC power to be transmitted into a utility grid. The transformation allows the power components to be chosen more freely and the common restrictions between the components may largely be avoided.

Further, power components such as the generator and power electronic converter may be chosen optimally in individual ratings and locations. The higher freedom in ratings and locations allows a more reliable, maintainable and serviceable wind turbine to be established.

The term "nominal value" should be understood as the rating and/or number of the power component as given by the manufacturer.

The term "power component" should be understood as any electric component associated with power generation in the wind turbine e.g. the AC generator, the power electronic converter units, switchgear and any transformer.

In an aspect of the invention, said AC generator is a high voltage polyphase synchronous or asynchronous AC generator e.g. an AC generator with M times three phases. The high voltage output from the AC generator reduces the losses in the cable connection of the generator to the nominal output value transformer.

The use of a synchronous AC generator establishes an efficient power generation system, and the use of an asynchronous or induction AC generator establishes a simpler and more robust power generation system.

- 5 In aspects of the invention, said AC generator is a synchronous generator magnetised electrically or by permanent magnets. Hereby, it is possible to establish an efficient (including an economical) and reliable power generation system e.g. in connection with a passive rectifier in the generator side of the power electronic converter unit.
- 10 In an aspect of the invention, said AC generator is a low-speed, high pole-number synchronous generator. Hereby, it is possible to avoid a gear in the wind turbine i.e. minimizing the number of mechanical components in the wind turbine.

- In an aspect of the invention, said AC generator is connected to said at least one
15 power electronic converter unit through said nominal output value transformer. Hereby is an advantageous embodiment of the invention achieved.

- In an aspect of the invention, said at least one power electronic converter unit include more than one unit. Hereby it is possible to create a modular and redundant parallel
20 construction wherein one failed unit may be replaced as a form of N-1 operation without disconnecting or stopping the wind turbine. Further, inspection and maintenance of a unit may also be performed while the other units continue their normal functionality. Consequently, a wind turbine with a high availability may be established as the power electronic converter is a less critical component.

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In an aspect of the invention, said more than one power electronic converter unit all have the same nominal values and/or are of the same type. Hereby, it is possible to enhance the serviceability of the wind turbine and especially diminish the storage number of necessary spare parts.

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In an aspect of the invention, said nominal output value transformer comprises a fixed transformation ratio. Hereby is an advantageous embodiment of the invention achieved.

- 5 In an aspect of the invention, said nominal output value transformer transforms the nominal generator voltage rating and/or number of phases. Hereby it is possible to use the different power components at their optimal values without restrictions.

- 10 In an aspect of the invention, said nominal output value transformer transforms a nominal voltage output value of the AC generator to a different nominal voltage input value of said at least one power electronic converter unit. Hereby it is possible to use the different power components at their optimal voltage values without restrictions including in the acceptable distances between the components.

- 15 In an aspect of the invention, said nominal output value transformer transforms a high voltage to a lower voltage e.g. from a value ranging beyond 3.300 Volt AC to a value less than 3.300 Volt AC of a power electronic converter unit such as a higher voltage between 3.300 and 15.000 Volt of the AC generator and a lower voltage between 690 and 3.300 Volt per power electronic converter unit.

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In a further aspect of the invention, said high voltage is chosen between the values of: 3.300, 4.160, 6.600, 10.000, 11.000 and 13.200 Volt, and said lower voltage is chosen between values of 690, 1.000, 2.200 and 3.300 Volt per power electronic converter unit.

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- The high voltage of the AC generator and the lower voltage per power electronic converter unit are advantageously matched such as 3.300/690 and 13.200/3.300 (AC generator voltage/voltage of the power electronic converter unit). The matched values are preferably the lowest AC generator voltages to the lowest voltage of the power electronic converter unit and vice versa. However, any relevant combinations
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of the mentioned AC generator voltage/voltage of the power electronic converter unit values are possible.

The lower voltage level in the power electronic converter enables the converter designer to overcome the limits of present power semiconductor technology. The designer is especially allowed to use power semiconductors with lower nominal voltage ratings instead of high voltage power semiconductors which are priced significantly higher. The serviceability of the power electronic converter units are also enhanced as the safety requirements are less rigorous at lower voltage levels.

In an aspect of the invention, said nominal output value transformer transforms a number of phases of the AC generator to a different number of phases of said at least one power electronic converter unit. The converter designer is allowed to reduce the content of harmonics in the power delivered to the AC generator by the different number of phases. The harmonics may be reduced or cancelled by a carefully selected angular displacement between the transformer phase windings.

In an aspect of the invention, said at least one power electronic converter unit is at least one AC-DC-AC converter. Hereby is an advantageous embodiment of the invention achieved.

In aspects of the invention, said at least one power electronic converter unit is connected to the utility grid through at least one utility grid transformer and said at least one utility grid transformer transforms the output voltage and/or number of phases of said at least one converter unit to the utility grid.

The transformation allows the components of the power electronic converter units to be chosen more freely and the wind turbine may thus be connected to a utility grid of a given high voltage value without restrictions.

The number of utility grid transformer phases may be used to reduce the content of harmonics in the power delivered to the utility grid by a carefully selected angular displacement between the phases.

5 In an aspect of the invention, said nominal output value transformer transforms three phases of the AC generator to a three phases of the utility grid through at least two parallel three-phase power electronic converter units such as three three-phase power electronic converter units. Paralleling of a plurality of power electronic converter units makes the power electronic converter highly redundant and allows service
10 during operation at reduced power in case one power electronic converter unit should fail.

In an aspect of the invention, said nominal output value transformer transforms M times three phases of the AC generator to three phases of the utility grid through at
15 least two parallel three phase power electronic converter units, such as a nine-phase AC generator to three three-phase power electronic converter units. Hereby it is possible with the number of phases to reduce or avoid harmonics in the generator and consequently achieve a higher torque density in the generator.

20 The phrase "parallel ... power electronic converter units" is to be understood as power electronic converter units connected directly in parallel or connected in parallel through winding connections of one or more transformers.

In aspects of the invention, the connection between the AC generator and said
25 nominal output value transformer comprises a minimum cable or busbar distance enabling the connection to extend out of the nacelle and at least said at least one power electronic converter unit is positioned outside the nacelle. The location of the power electronic converter unit outside the nacelle, gives a substantially reduction in weight and size of the nacelle and thus a reduction in the costs of assembly.
30 Removing the power electronic converter from the nacelle allows the manufacturer

to produce the wind turbine itself independent of local grid conditions as the layout of the nacelle is unaffected by changes in the electrical system.

5 In an aspect of the invention, at least said at least one power electronic converter unit is positioned in the tower of the wind turbine e.g. at a lower part of the tower such as at or in proximity of the tower foundation. The width of the tower at the foundation allows easy installation of the power electronic converter units.

10 In an aspect of the invention, at least said at least one power electronic converter unit is located outside the nacelle and tower of the wind turbine. Hereby, it is possible to locate the power electronic converter units in a separate place on the ground with an optimized environment for the units e.g. a place with more space and better climate control. Further, the ground location may reduce the price of the transformer and the power electronic converter units because these power components do not need the
15 same mechanical stability as if they were placed in the nacelle.

The separate place also enhances the serviceability of the wind turbine by being easier to access by service personnel.

20 It shall be emphasised that other places outside the nacelle may be chosen for the relevant power components beyond the abovementioned places. The power components may for example be positioned or suspended on the outside surface of the nacelle or on the tower surface above ground level.

25 In an aspect of the invention, the organization and location of the power electronic converter units enables redundancy in said wind turbine by N-1 operation. The established wind turbine is thus more reliable, maintainable and serviceable as the N-1 converter units may continue to transfer power while the last unit is being inspected, maintained or replaced if it has malfunctioned.

In an aspect of the invention, each of said at least one power electronic converter unit includes switchgear such as first switchgear in the connection before each unit and second switchgear in the connection after each unit. Hereby it is possible to inspect, maintain or replace the unit if it has malfunctioned while any remaining units may continue to transfer power. The nominal output value transformer and utility grid transformer may allow the use of lower voltage switchgear in relation to the AC generator and the utility grid. Consequently, inspection, maintenance or replacement of the power electronic converter units may be performed by workers under less rigorous precautionary measure.

In an aspect of the invention, at least one nominal output value transformer, at least one power electronic converter unit and at least one utility grid transformer form a power module. Each power module may be manufactured and delivered to the site of the wind turbine in one single container custom made to fit the local utility grid conditions.

In a further aspect of the invention, the number (N) of power electronic converter units is between 2 and 10 parallel units. Hereby, it is possible to establish redundancy in said wind turbine by N-1 operation as well as control of transmitted power per power electronic converter unit.

The invention also relates to a wind park such as an offshore wind park, said park comprising at least two variable rotor speed wind turbines according to any of claims 1 to 26, and in an aspect, power electronic converter units of different wind turbines are located in a common housing. The central housing of power electronic converter units further enhances the serviceability of the wind turbine by being easy to access by service personnel.

The invention also relates to a method of transmitting electric power to an AC utility grid from a variable rotor speed wind turbine, said method comprising the steps of:

generating AC power with at least one AC generator, transforming at least one nominal value of said AC generator to at least one different nominal input value of at least one power electronic converter unit with at least one nominal output value transformer, and converting the power to said AC utility grid with said at least one power electronic converter unit.

In aspects of the invention, at least one of said at least one power electronic converter unit is connected or disconnected with switchgear, and the transmitted power per unit of the remaining power electronic converter units is controlled e.g. controlled to a value close to a nominal power rating of said unit. Hereby it is possible to inspect or service a disconnected unit and maintain transmission of power from the remaining power electronic converter units e.g. by units controlled to a value close to a nominal power rating of the units.

The invention also relates to a of servicing or inspecting a variable rotor speed wind turbine transmitting electric AC power to a utility grid, said method comprising the steps of: transforming at least one nominal value of said AC generator to at least one different nominal input value of at least two power electronic converter units with at least one nominal output value transformer, transforming at least one nominal value of said at least two power electronic converter units with at least one utility grid transformer, disconnecting one converter unit under servicing or inspection of said unit from the nominal output value and utility grid transformers with switchgear, and operating the remaining units of the wind turbine in N-1 operation. Hereby is an advantageous embodiment of the invention obtained in relation to servicing or inspecting a variable rotor speed wind turbine.

Figures

The invention will be described in the following with reference to the figures in which

- fig. 1 illustrates a large modern wind turbine,
- fig. 2 illustrates the AC generator of the wind turbine connected to power
5 components placed outside the nacelle according to the invention,
- fig. 3 illustrates the wind turbine of the invention with an accompanying
curve showing the nominal voltage transformation,
- 10 fig. 4 illustrates the wind turbine of the invention with an accompanying
curve showing the number of phase transformation, and
- fig. 5 illustrates schematically the utility grid connection of the wind
turbine according to the invention,
- 15 fig. 6 illustrates schematically a first preferred embodiment of the wind
turbine including a plurality of power electronic converter units,
- fig. 7 illustrates schematically a second preferred embodiment of the
20 wind turbine including a multi-phase nominal output value
transformer,
- fig. 8 illustrates schematically a third preferred embodiment of the wind
turbine including a multi-phase utility grid transformer,
- 25 fig. 9 illustrates in more details a preferred embodiment of the wind
turbine according to the invention, and
- fig. 10 illustrates a fourth preferred embodiment including a plurality of
30 wind turbines with power modules in a common housing.

Detailed description

Fig. 1 illustrates a modern variable rotor speed wind turbine 1 with a tower 2 and a
5 wind turbine nacelle 3 positioned on top of the tower. The wind turbine rotor 4,
comprising three wind turbine blades 5, is connected to at least one AC generator
located in the nacelle 3 through a shaft that extends out of the nacelle front.

As illustrated in the figure, wind beyond a certain level will activate the wind turbine
10 rotor due to the lift induced on the blades and allow it to rotate in a perpendicular
direction to the wind.

The rotation movement is converted to electric power in the AC generator. From the
AC generator in the nacelle 3 the electric power is fed through a power electronic
15 converter and transmitted to a utility grid. The wind turbine may be a full scale or
double fed converter type of wind turbine with or without a gear.

The power generation in the wind turbine may be performed with more than one AC
generator such as between two and four AC generators.

20 Fig. 2 illustrates the invention wherein the AC generator 7 of the wind turbine 1 is
connected to a number of further power components. The power components include
a nominal output value transformer 10 and at least one power electronic converter
unit 11 including switchgear. The transformer 10 may for example transform a
25 nominal voltage or number of phases of the AC generator 7 to a different nominal
voltage or number of phases of the power electronic converter unit or units 11.

The figure also illustrates that the power electronic converter unit is connected to the
utility grid 13 through a utility grid transformer 12. The utility grid transformer may

for example transform a nominal voltage or number of phases of the power electronic converter unit to a different nominal voltage or number of phases of the utility grid.

The figure further illustrates three distances in between the wind turbine 1 and the utility grid 13.

The first distance, distance I, is the distance between the AC generator of the nacelle 3 and the primary windings of the nominal output value transformer 10. The first distance is a minimum cable or busbar distance which at least extends out of the nacelle 3.

The second distance, distance II, is the distance between the secondary windings of the nominal output value transformer 10 and the primary windings of the utility grid transformer 12.

The third distance, distance III, is the distance between the secondary windings of the utility grid transformer 12 and the utility grid 13.

The second distance is usually the shorter distance as the voltage rating of the distance is lower than the first distance and/or the third distance.

Fig. 3 illustrates the wind turbine 1 with an accompanying curve showing the nominal voltage transformation over the distance of the wind turbine power components. The curve illustrates the changing nominal voltage levels of the power components from the AC generator 7 to connection point of the wind turbine on the utility grid 13.

The nominal voltage value of the AC generator 7 may be in the range of 3.300 to 15.000 Volt AC e.g. 3.300, 4.160, 6.600, 10.000, 11.000 or 13.200 Volt in a preferred embodiment.

The nominal voltage value of the power electronic converter units may be less than 3.300 Volt AC e.g. in a range of approximately 690 to 3.300 Volt AC in a preferred embodiment such as 690, 1.000, 2.200 or 3.300 Volt per power electronic converter unit.

The nominal voltage value of the utility grid may be in the range from 10 to 36kV AC such as 10 kV, 11 kV, 20 kV, 22 kV, 24 kV, 30 kV, 33kV or 36kV AC at a utility grid frequency of 50 or 60 Hz.

Consequently, the curve initially shows the AC generator voltage, a voltage step down at the converter unit to a final voltage step up at the wind turbine connection to the utility grid.

Fig. 4 illustrates the wind turbine 1 with an accompanying curve showing the number of phases transformation over the distance of the wind turbine. The curve illustrates the changing number of phases of the power components from the AC generator 7 to the utility grid 13.

The phase number of the AC generator 7 is at least three e.g. three or nine phases in a preferred embodiment.

The phase number of the power electronic converter units is three phases per unit in a preferred embodiment.

The phase number of the utility grid is usually three phases, but could be two times three phases.

Fig. 5 illustrates schematically the utility grid connection of the wind turbine according to the invention.

The power components are illustrated with the AC generator 7 of the wind turbine being connected to the nominal output value transformer 10 and a power electronic converter unit 11. The power electronic converter unit 11 is connected to the utility grid 13 through the utility grid transformer 12.

The power electronic converter unit 11 is illustrated as a plurality of parallel power electronic converter units (11a, 11b, ..., 11N) i.e. at least two units. Each unit is further illustrated as comprising switchgear.

The figure further illustrates high voltage switchgear 25a, 25b at the AC generator 7 and the utility grid 13 e.g. to enable disconnection of the AC generator or the utility grid.

Fig. 6 illustrates schematically a first preferred embodiment of the wind turbine including a plurality of power electronic converter units 11.

The number of power electronic converter units 11a, 11b is schematically illustrated as two parallel units each including switchgear 19a, 19b and common connections to the nominal output value transformer 10 and utility grid transformer 12, respectively.

The first switchgear 19a of a unit is located in the connection to the nominal output value transformer 10 and may connect or disconnect the unit from the transformer 10. The second switchgear 19b is located in the connection from the unit to the utility grid transformer 12 and may connect or disconnect the unit from the transformer 12.

The switchgear 19a, 19b allow each power electronic converter unit 11a, 11b to be electrically connected to or disconnected from the other power components and thus establish or terminate the power transmission through the power electronic converter unit.

The transformers are connected to the AC generator 7 and the utility grid 13. The connection distance between the AC generator 7 and nominal output value transformer 10 is illustrated as significant e.g. at least beyond the nacelle limits.

5 Further parallel power electronic converter units may be used e.g. to enhance the redundancy of the converter system as well as to limit the power rating of each unit. The number of parallel converter units may for example be between 2 and 10 wherein the units together establishes the same power rating as one large converter.

10 Even further, the parallel converter units may be connected and disconnected in order to enhance the utilization of each unit in relation to the power rating of the unit.

Fig. 7 illustrates schematically a second preferred embodiment of the wind turbine including a multi-phase nominal output value transformer 10.

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The number of primary windings of the transformer is schematically illustrated as three three-phase windings transforming the AC power to two three-phase secondary windings on the power electronic converter side. Each secondary winding is connected to a power electronic converter unit with independent connections. The two parallel units 11a, 11b have a common connection to the utility grid transformer 12 as illustrated in fig. 6.

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Different combinations and numbers of transformer windings may be used e.g. to reduce the harmonic content in power supplied to the utility grid.

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Fig. 8 illustrates schematically a third preferred embodiment of the wind turbine including a multi-phase utility grid transformer.

The number of primary windings of the transformer is schematically illustrated as two three-phase windings transforming the AC power to three three-phase secondary

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windings. Each primary winding is connected to a power electronic converter unit with independent connections. Each secondary winding is connected to the utility grid 13 e.g. with a magnetic configuration to obtain angular displacement between phases.

5

As mentioned above, further parallel power electronic converter units may be used e.g. to enhance the redundancy of the converter system as well as to limit the power rating of each unit.

10 Fig. 9 illustrates in more details a preferred embodiment of the invention including the coupling of the AC generator 7, the first transformer 10, the power electronic converter units 11 and the utility grid transformer 12.

15 The AC generator 7 may be an eight-pole, three times three-phase high voltage squirrel cage induction generator, but could also be another number or type of generator e.g. at least two induction generators.

20 The power electronic converter unit 11 is subdivided in three parallel AC/DC/AC three-phase power electronic converter units, to process the generated power, each power electronic converter unit having a generator side active rectifier 21a, a DC link and a utility grid side inverter 21b.

25 The nine phases from the AC generator is by means of the cable 14 connected to separate sets of windings on the primary side of the nominal output value transformer 10. The secondary side of the transformer 10 is connected to the generator side of the three parallel three-phase power electronic converter units 11.

The primary side of the transformer has nine phases obtained by a proper angular displacement of the primary winding sets.

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On the secondary side of the transformer, three three-phase AC/DC/AC converter power units are used to process the generated power.

In another preferred embodiment the 9 phase AC generator is replaced by a 3 phase AC generator with corresponding number of phases on the primary side of the nominal output value transformer 10.

Fig. 10 illustrates fourth preferred embodiment including a plurality of wind turbines with power modules in a common housing.

Each wind turbine is constructed as described above with the power components: An AC generator 7, a nominal output value transformer 10, power electronic converter units 11, and a utility grid transformer 12. Every power component of the wind turbine beyond the generator is positioned in proximity of each other as a power module 21a and preferably together with similar power module 21b of other wind turbines in a common housing 23. The wind turbines and the common housing may be part of a wind park 24 transmitting AC power to the utility grid 13.

The invention has been exemplified above with reference to specific examples. However, it should be understood that the invention is not limited to the particular examples described above but may be used in connection with a wide variety of applications including applications comprising different combinations of the illustrated embodiments.

List:

1. Variable rotor speed wind turbine
2. Wind turbine tower
- 5 3. Wind turbine nacelle including an AC generator
4. Wind turbine hub
5. Wind turbine rotor with a wind turbine hub and a number of wind turbine blades
6. Rotating blades
- 10 7. AC generator
8. Power electronic converter
10. Nominal output value transformer for transforming at least one nominal output rating value or number of the AC generator to at least one different nominal input rating value or number of the converter unit
- 15 11. Power electronic converter and switchgear unit
- 11x. Power electronic converter and switchgear units
12. Utility grid transformer
13. Utility grid
14. Connection between the AC generator and the nominal output value transformer
- 20 15. Nominal output value transformer for transforming the nominal voltage output rating of the AC generator to a different voltage input rating of the power electronic converter unit
16. Connection between the nominal output value transformer and the power electronic converter unit
- 25 17. Connection between the power electronic converter unit and the AC utility grid transformer
18. Connection between the utility grid transformer and the AC utility grid
- 19x. Switchgear for connecting/disconnecting power electronic converter units
- 30

20. Nominal output value transformer for transforming a phase number of the AC generator to a different phase number of the power electronic converter unit
- 21a, 21b. Generator side passive or active rectifier, DC link and utility grid side inverter of the power electronic converter unit
22. Power module
- 22x. Power modules
23. Housing for power modules
24. Wind park
- 25a, 25b. High voltage switchgear such as AC generator and utility grid switchgear
- n. Phase number
- M. Integer value
- N. Number of power electronic converter and switchgear units
- U_{grid} Nominal utility grid voltage
- $U_{\text{converter}}$ Nominal voltage of the power electronic converter unit
- $U_{\text{generator}}$ Nominal voltage of the AC generator

Claims

1. A variable rotor speed wind turbine (1) transmitting electric AC power to a utility grid (13), said wind turbine comprising

at least one AC generator (7), and

at least one power electronic converter unit (11),

characterised in that

said wind turbine further comprises at least one nominal output value transformer (10, 15, 20) for transforming at least one nominal output value of said generator to at least one different nominal input value of said at least one power electronic converter unit.

2. A variable rotor speed wind turbine (1) according to claim 1 characterised in that said AC generator (7) is a polyphase synchronous or asynchronous AC generator.

3. A variable rotor speed wind turbine (1) according to claim 2 characterised in that said AC generator (7) is a synchronous generator magnetised electrically or by permanent magnets.

4. A variable rotor speed wind turbine (1) according to claim 2 or 3 characterised in that said AC generator (7) is a low-speed, high pole-number synchronous generator.

5. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said AC generator is connected to said at least one

power electronic converter unit (10) through said nominal output value transformer (10, 15, 20).

6. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said at least one power electronic converter unit (11) include more than one unit (11a, 11b).

7. A variable rotor speed wind turbine (1) according to claim 6 characterised in that said more than one power electronic converter unit (11a, 11b) have the same nominal ratings or number and/or are of the same type.

8. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said nominal output value transformer (10, 15, 20) comprises a fixed transformation ratio.

9. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said nominal output value transformer (10, 15, 20) transforms the nominal generator voltage and/or number of phases.

10. A variable rotor speed wind turbine (1) according to claim 9 characterised in that said nominal output value transformer (15) transforms a nominal voltage output value of the AC generator (7) to a different nominal voltage input value of said at least one power electronic converter unit (11).

11. A variable rotor speed wind turbine (1) according to claim 10 characterised in that said nominal output value transformer (15) transforms a high voltage to a lower voltage e.g. from a value ranging beyond 3.300 Volt AC to a value less than 3.300 Volt AC such as a high voltage between 5.000 and 15.000 Volt of the AC generator and a lower voltage between 690 and 3.300 Volt per power electronic converter unit (11a, 11b, 11N).

12. A variable rotor speed wind turbine (1) according to claim 11 characterised in that said high voltage is chosen between the values of:

5 3.300, 4.160, 6.600, 10.000, 11.000 and 13.200 Volt, and said lower voltage is chosen between values of

690, 1.000, 2.200 and 3.300 Volt per power electronic converter unit.

10 13. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said nominal output value transformer (20) transforms a number of phases of the AC generator (7) to a different number of phases of said at least one power electronic converter unit (11).

15 14. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said at least one power electronic converter unit (11) is at least one AC-DC-AC converter (21a-21c).

20 15. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said at least one power electronic converter unit (11) is connected to the utility grid (13) through at least one utility grid transformer (12).

25 16. A variable rotor speed wind turbine (1) according to claim 15 characterised in that said nominal output value transformer (20) and said utility grid transformer (12) transform three phases of the AC generator (7) to three phases of the utility grid (13) through at least two three-phase power electronic converter units (11) such as three three-phase power electronic converter units (11a, 11b, 11N).

17. A variable rotor speed wind turbine (1) according to claim 15 characterised in that said nominal output value transformer (20) and said utility grid transformer (12) transform M times three phases of the AC generator (7) to three phases of the utility grid (13) through at least two three-phase power electronic converter units (11, 11a, 11b) such as a nine-phase AC generator to three three-phase power electronic converter units (11a, 11b, 11N).

18. A variable rotor speed wind turbine (1) according to any of claims 15 to 17 characterised in that said at least one utility grid transformer (12) transforms the output voltage rating and/or number of phases of said at least one power electronic converter unit (11) to the utility grid (13).

19. A variable rotor speed wind turbine (1) according to any of claims 15 to 18 characterised in that said at least one utility grid transformer (12) steps up the nominal output voltage of said at least one power electronic converter unit (11).

20. A variable rotor speed wind turbine (1) according to any of the proceeding claims characterised in that the connection (14) between the AC generator (7) and said nominal output value transformer (10, 15, 20) comprises a minimum cable or busbar distance (distance I) enabling the connection to extend out of the nacelle (3).

21. A variable rotor speed wind turbine (1) according to any of the proceeding claims characterised in that said at least one power electronic converter unit (11) is located outside the nacelle (3).

22. A variable rotor speed wind turbine (1) according to any of the proceeding claims characterised in that said at least one power electronic converter unit

(11) is located in the tower (2) of the wind turbine e.g. at a lower part of the tower such as at or in proximity of the tower foundation.

23. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that said at least one power electronic converter unit (11) is located outside the nacelle (3) and tower (2) of the wind turbine.

24. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that the organization and location of the power electronic converter units (11) enables redundancy in said wind turbine by N-1 operation.

25. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that each of said at least one power electronic converter unit (11) includes switchgear (19) such as first switchgear (19a) in the connection (16) before each unit and second switchgear (19b) in the connection (17) after each unit.

26. A variable rotor speed wind turbine (1) according to claim 25 characterised in that at least one nominal output value transformer (10, 15, 20), at least one power electronic converter unit, switchgear (19, 19a, 19b) and at least one utility grid transformer form a power module (22, 22a, 22b).

27. A variable rotor speed wind turbine (1) according to any of the preceding claims characterised in that the number (N) of power electronic converter units (11, 11a, 11b, 11N) is between 2 and 10 parallel units.

28. Wind park (24) such as an offshore wind park, said park comprising at least two variable rotor speed wind turbines (1) according to any of claims 1 to 27.

29. Wind park (24) according to claim 28 characterised in that power electronic converter units (11) of different wind turbines are located in a common housing (23).

5 30. Method of transmitting electric power to an AC utility grid (13) from a variable rotor speed wind turbine (1), said method comprising the steps of:

generating AC power with at least one AC generator (7),

10 transforming at least one nominal value of said AC generator (7) to at least one different nominal input value of at least one power electronic converter unit with at least one nominal output value transformer (10, 15, 20), and

15 converting the power to said AC utility grid (13) with said at least one power electronic converter unit (11).

31. Method of transmitting electric power to an AC utility grid (13) according to claim 29 with a variable rotor speed wind turbine (1) according to any of claims 1 to 27.

20 32. Method of transmitting electric power to an AC utility grid (13) according to claim 30 or 31, where at least one of said at least one power electronic converter unit (11) is connected or disconnected with switching gear (19) in the connections (16, 17) to said unit.

25 33. Method of transmitting electric power to an AC utility grid (13) according to claim 32, where the transmitted power per unit of the remaining power electronic converter units is controlled e.g. controlled to a value close to a nominal power rating of said unit.

30

34. Method of servicing or inspecting a variable rotor speed wind turbine (1) transmitting electric AC power to a utility grid (13), said method comprising the steps of:

- 5 transforming at least one nominal value of said AC generator (7) to at least one different nominal input value of at least two power electronic converter units (11, 11a, 11b, 11N) with at least one nominal output value transformer (10, 15, 20),

transforming at least one nominal value of said at least two power electronic
10 converter units with at least one utility grid transformer (12),

disconnecting one converter unit under servicing or inspection of said unit from the nominal output value and utility grid transformers (10, 12, 15, 20) with switchgear
(19), and

15 operating the remaining units of the wind turbine in N-1 operation.

35. Method according to claim 34 where said wind turbine is a variable rotor speed wind turbine (1) according to any of claims 1 to 27.

20

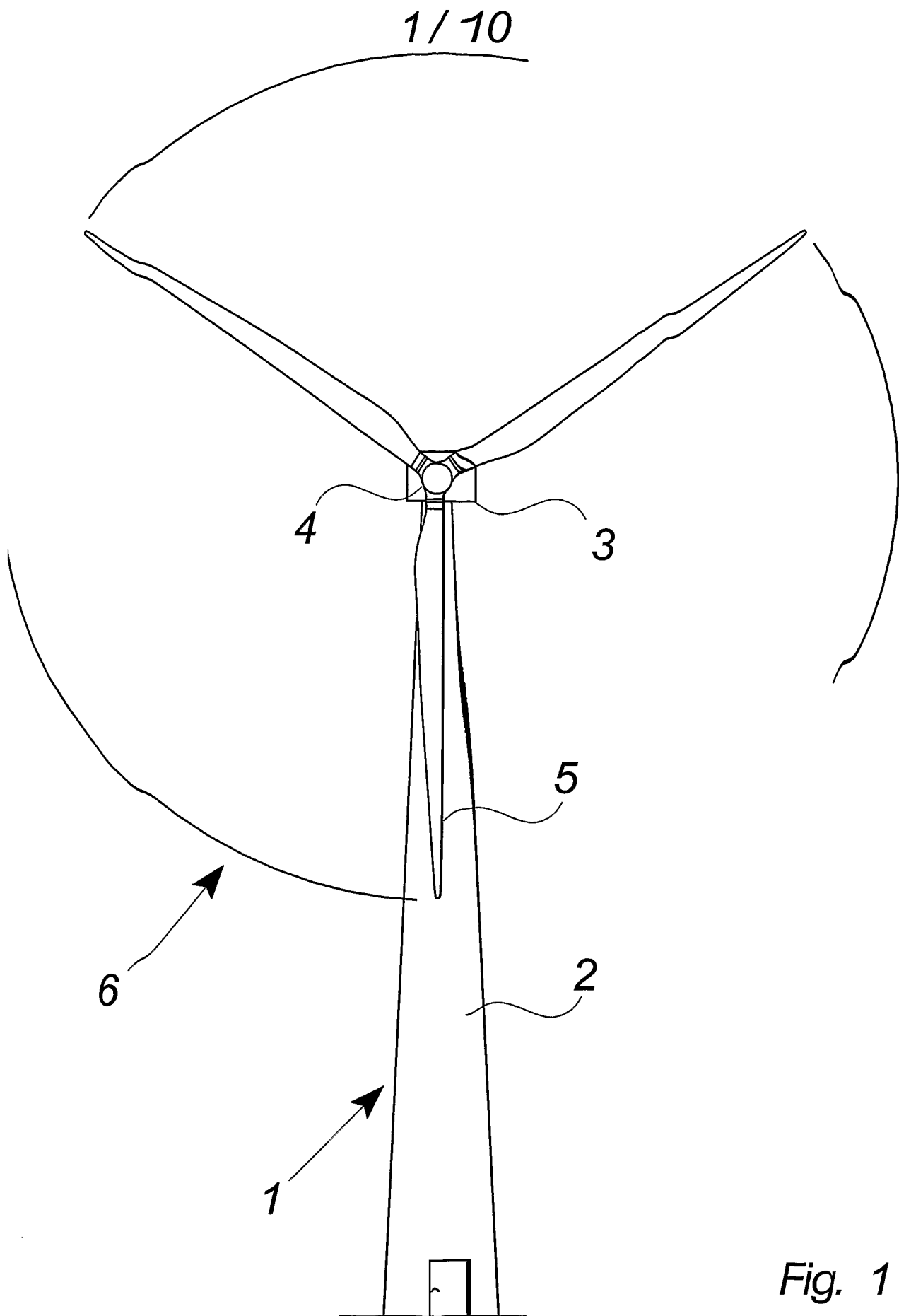


Fig. 1

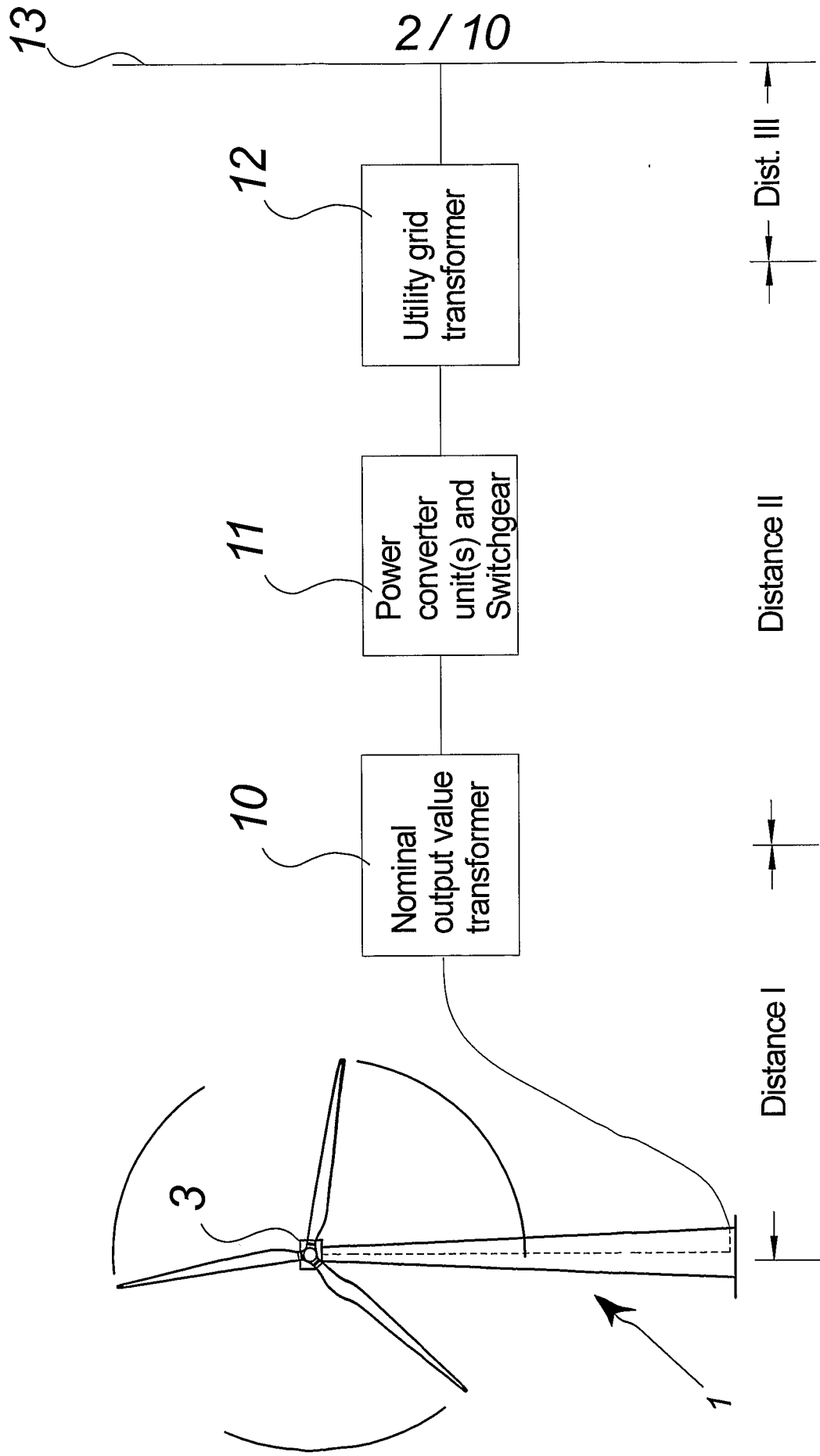
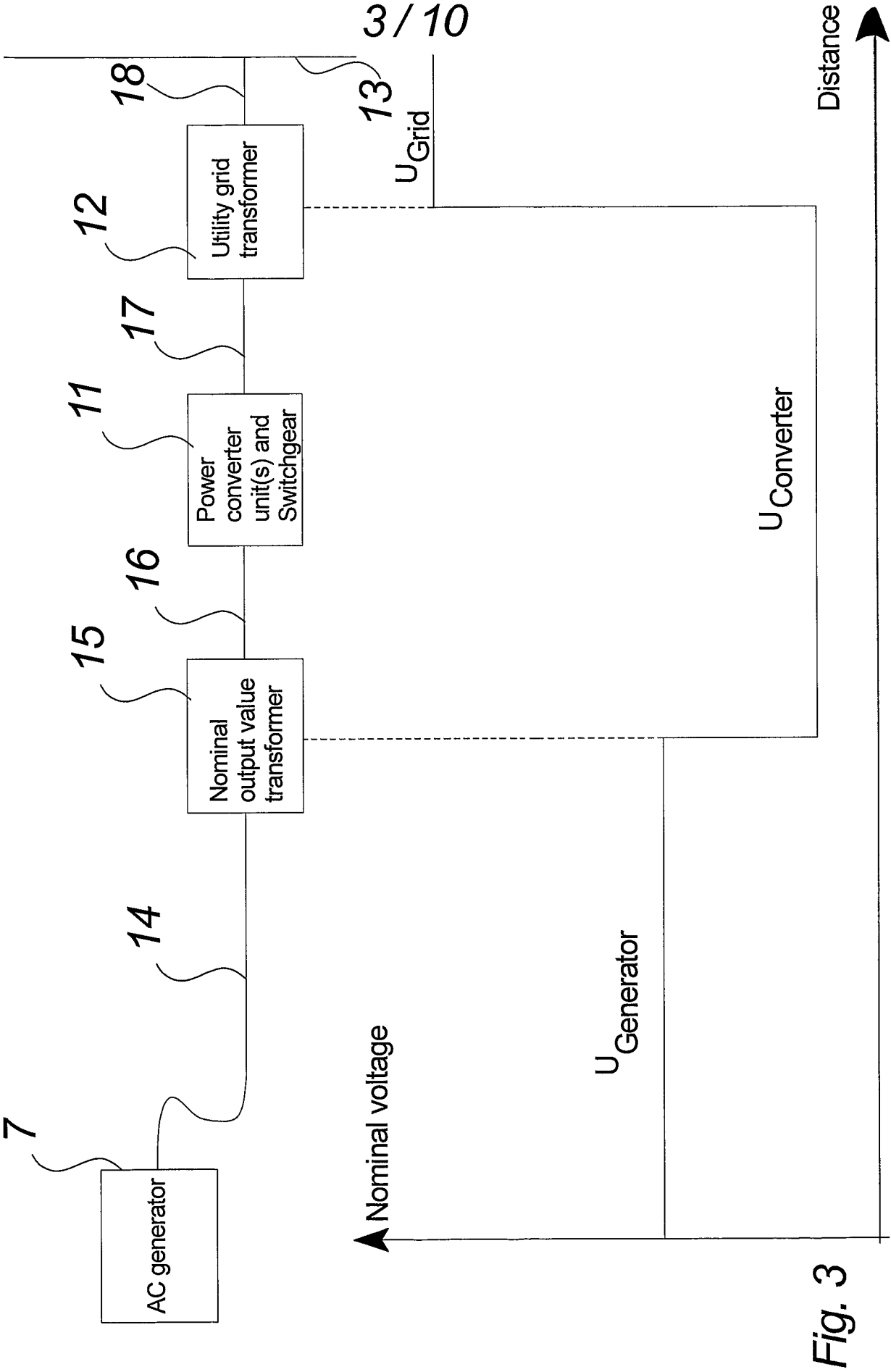
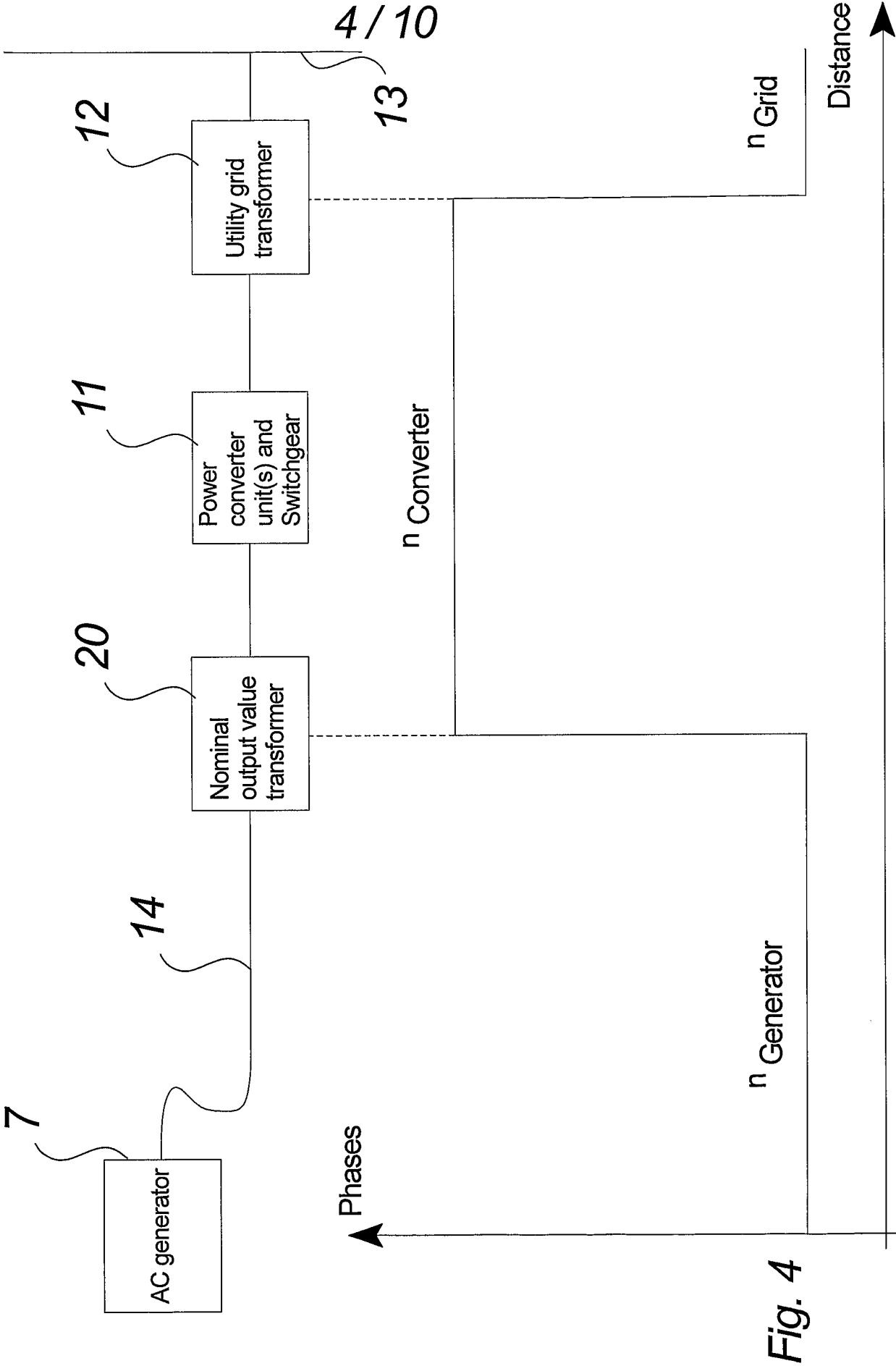


Fig. 2





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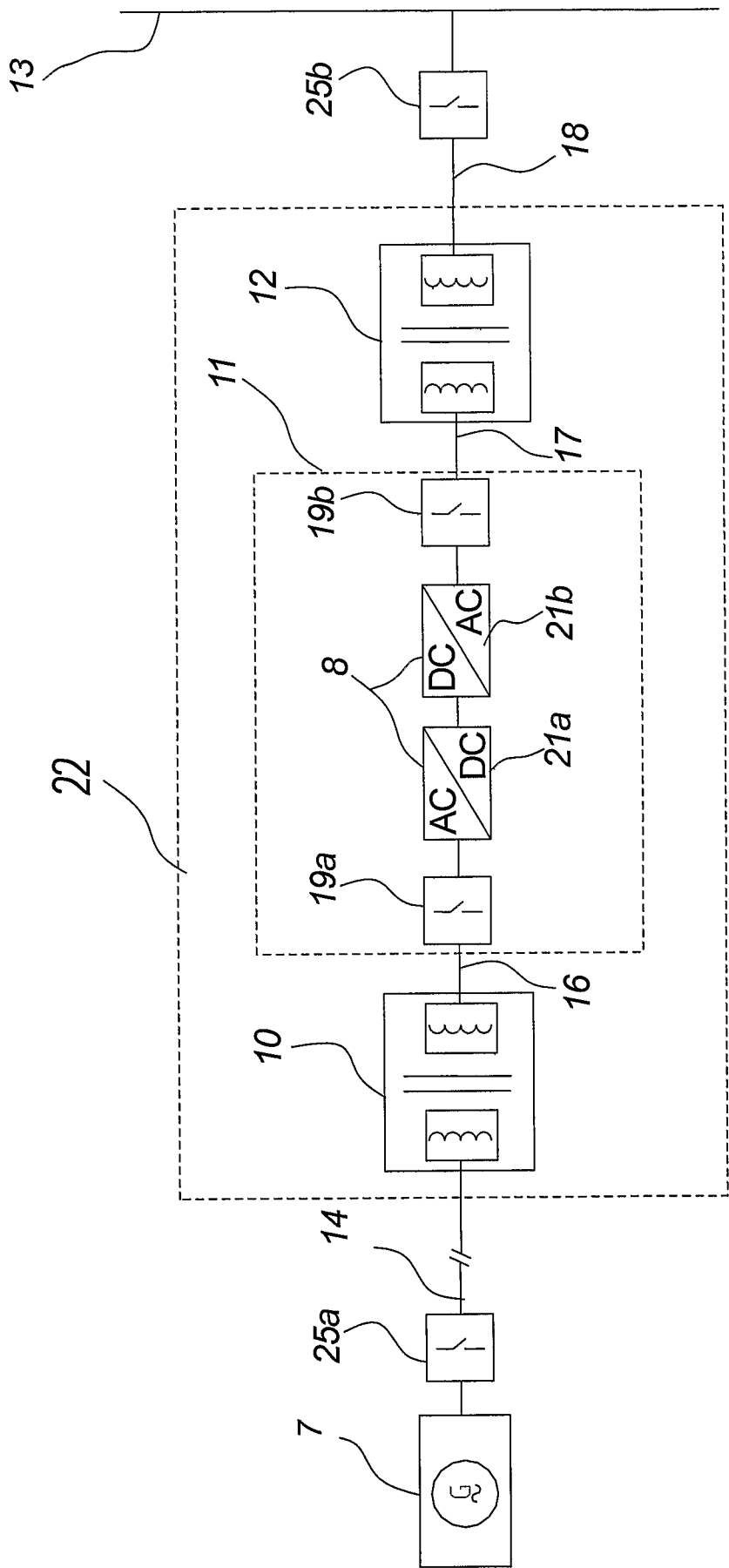


Fig. 5

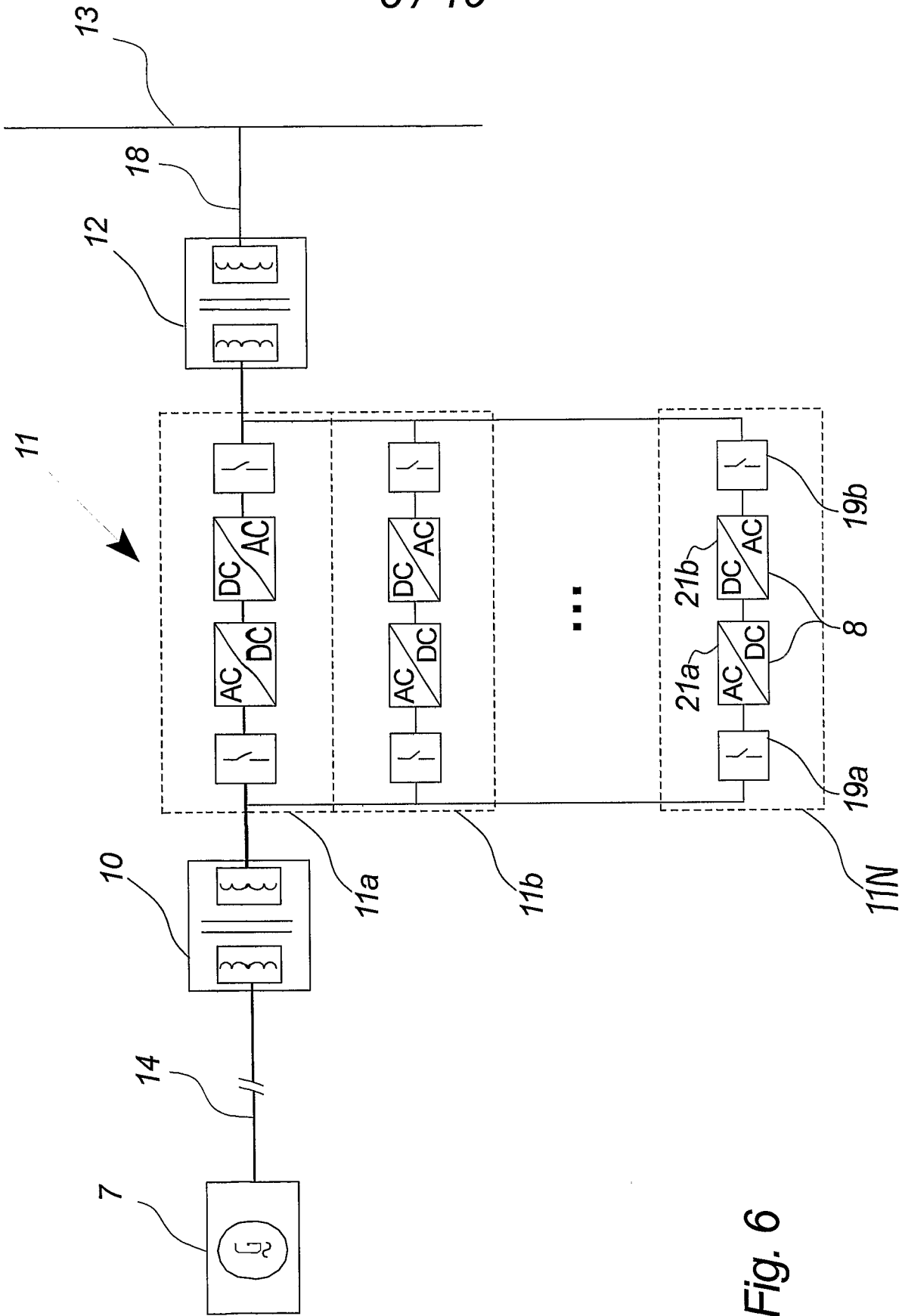


Fig. 6

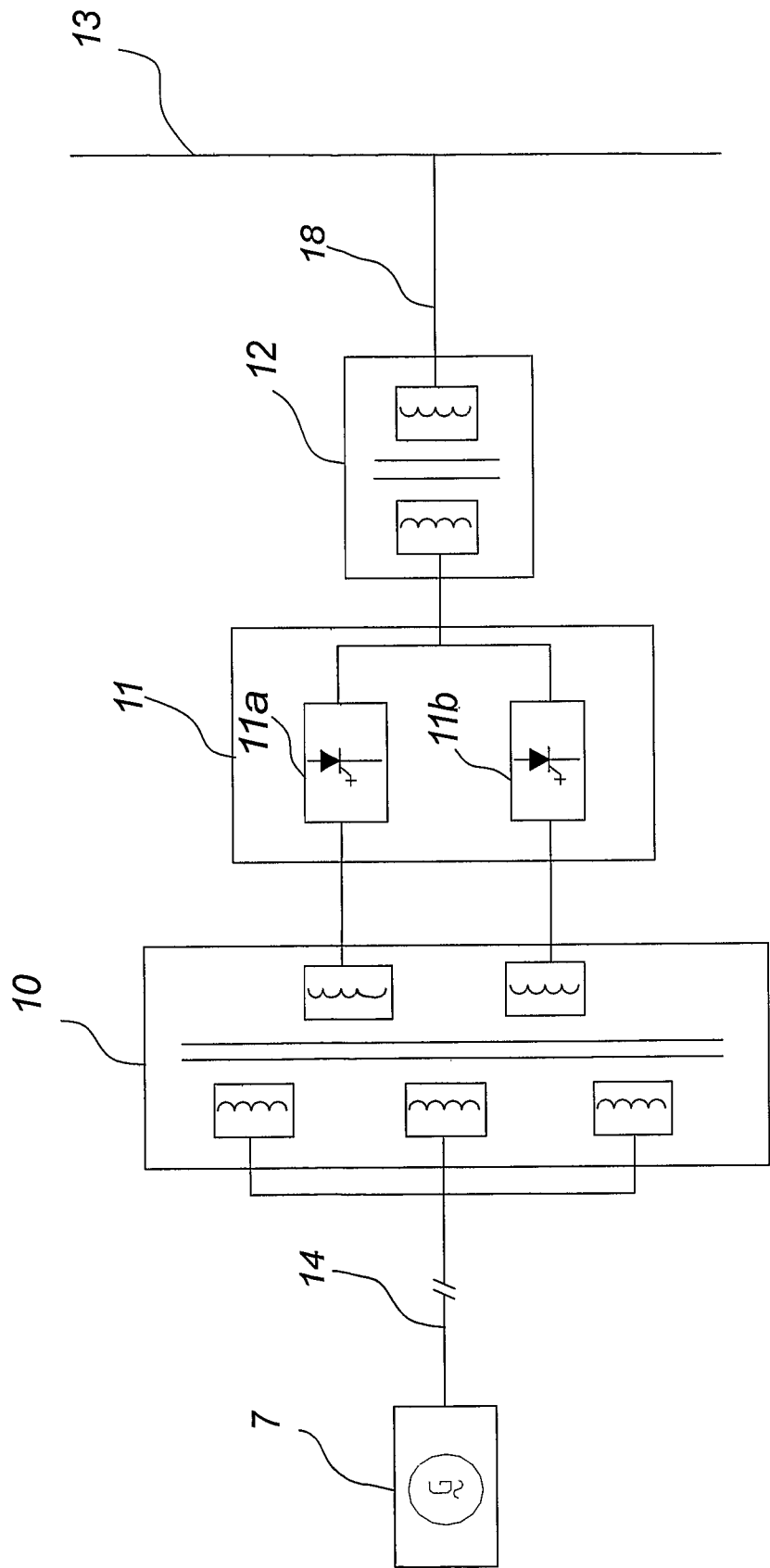


Fig. 7

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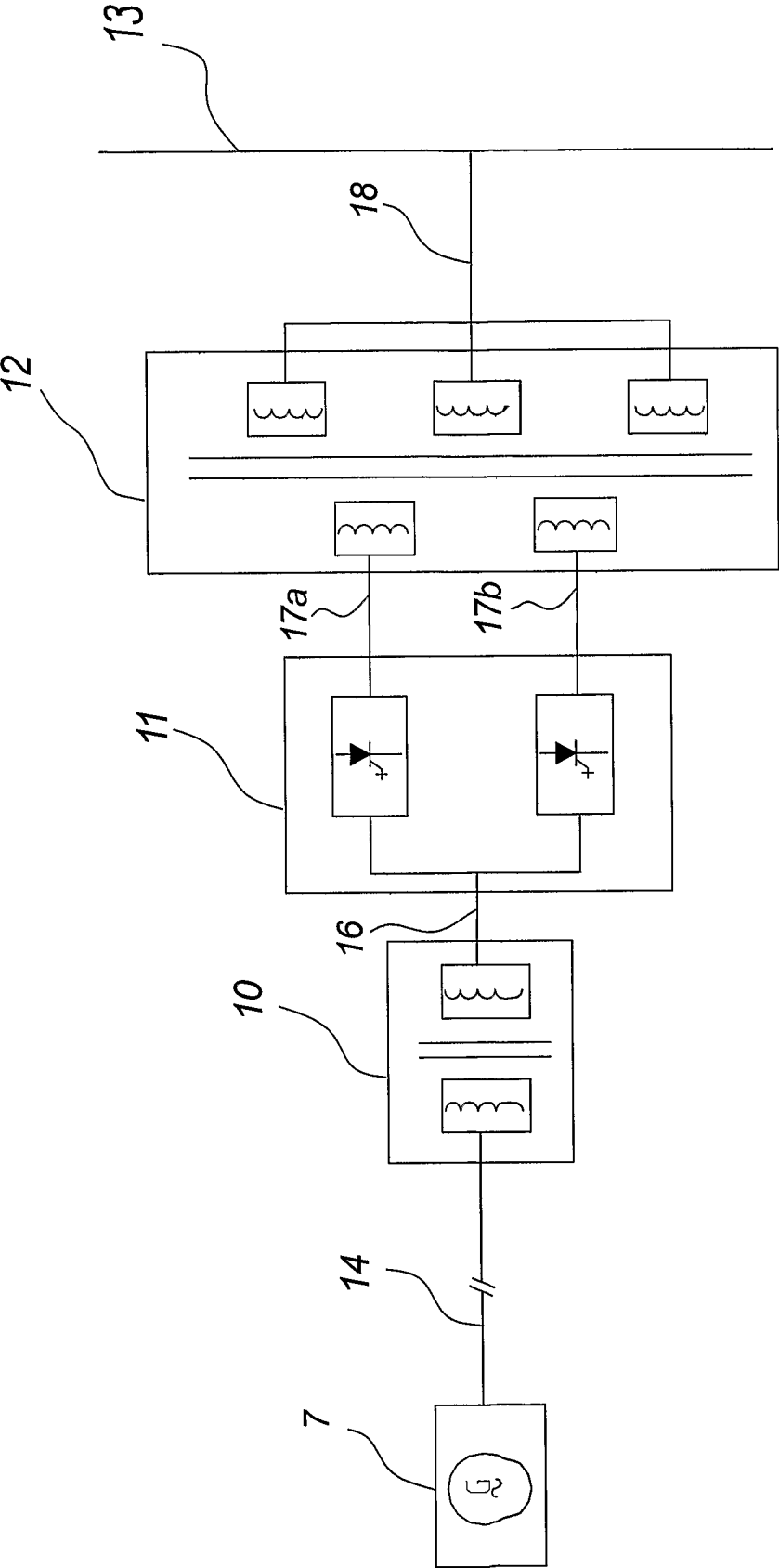


Fig. 8

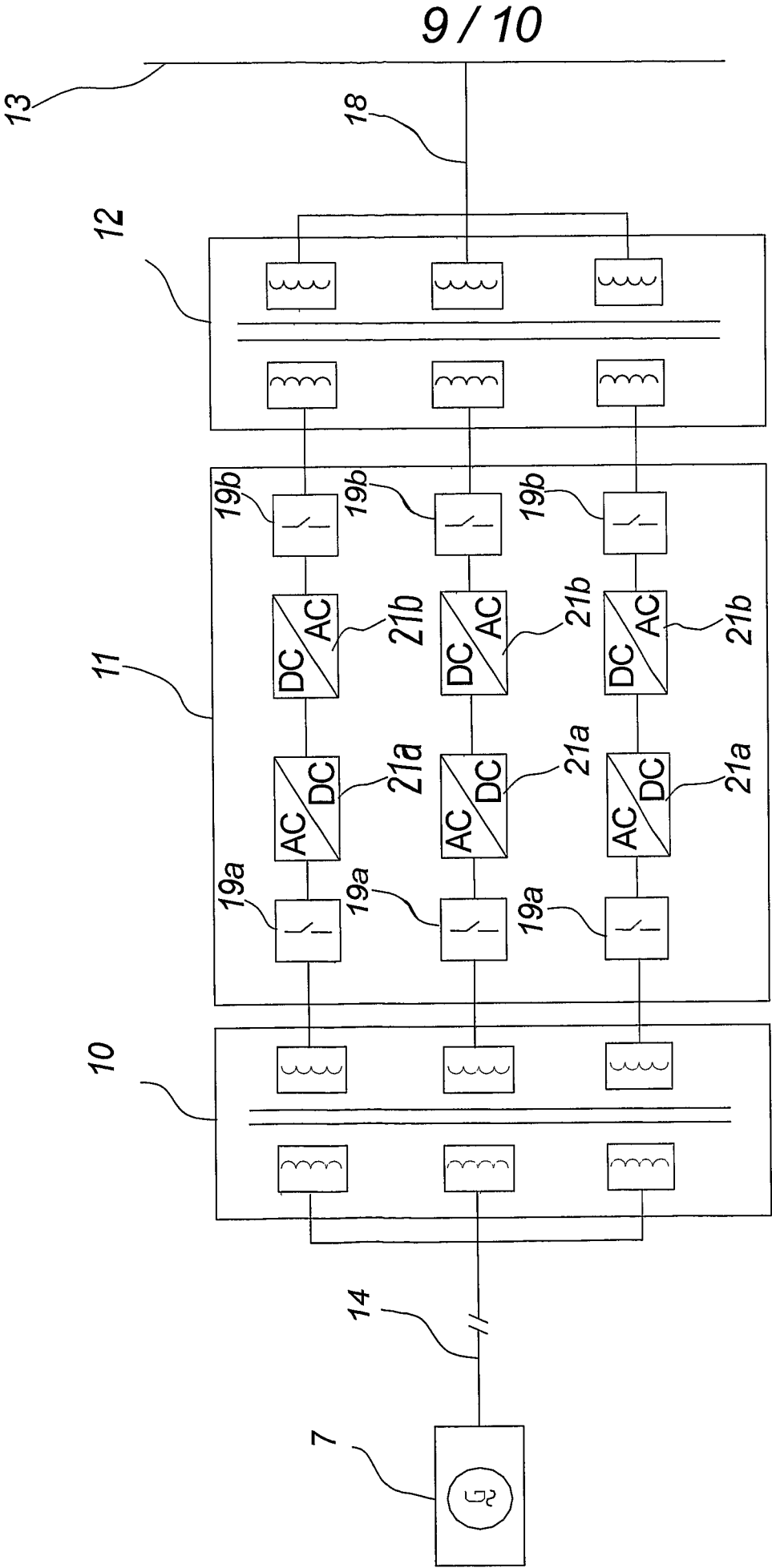


Fig. 9

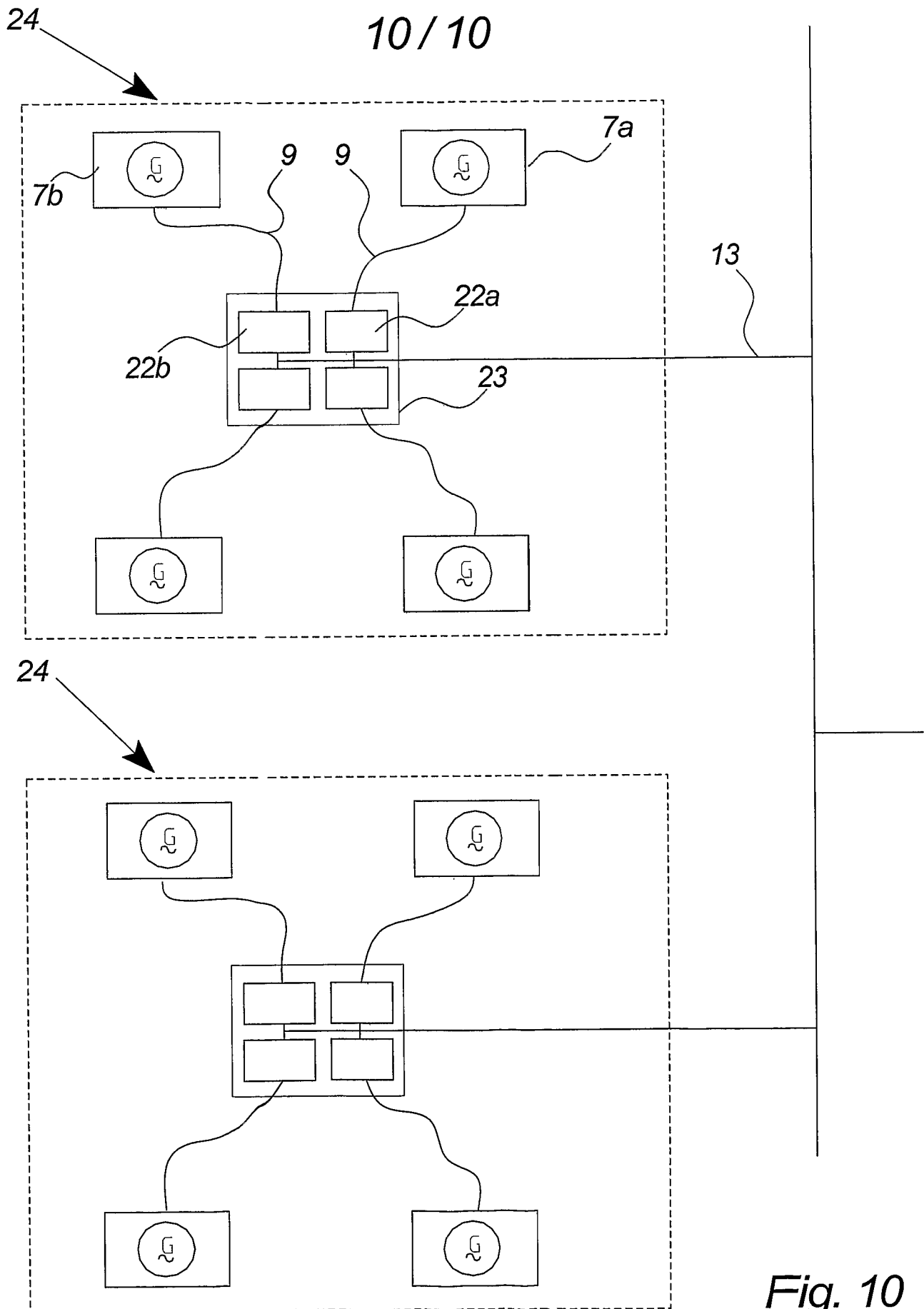


Fig. 10

INTERNATIONAL SEARCH REPORT

International application No

PCT/DK2005/000455

A. CLASSIFICATION OF SUBJECT MATTER
H02M5/458

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)
H02M H02J

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 practical, 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.
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Y	paragraphs [0039], [0042]; figure 7	6, 7, 13, 27
X	WO 00/73652 A (ABB AB; LEIJON, MATS; KYLANDER, GUNNAR) 7 December 2000 (2000-12-07) page 15, line 21 - line 34; figure 5	1, 30
Y	WO 03/015253 A (REN, SHAO KANG; SHI, AIMIN; SONG, XUE LIANG) 20 February 2003 (2003-02-20) figures 27, 33	6, 7
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☒ 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

10 March 2006

Date of mailing of the international search report

21/03/2006

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Gentili, L

INTERNATIONAL SEARCH REPORT

International application No

PCT/DK2005/000455

C(Continuation). DOCUMENTS CONSIDERED TO BE RELEVANT

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PCT/DK2005/000455

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