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CA 2971681 A1 2016/08/04

(21) 2 971 681

(12) DEMANDE DE BREVET CANADIEN
CANADIAN PATENT APPLICATION

(13) A1

(86) Date de dépôt PCT/PCT Filing Date: 2016/01/29
(87) Date publication PCT/PCT Publication Date: 2016/08/04
(85) Entrée phase nationale/National Entry: 2017/06/20
(86) N° demande PCT/PCT Application No.: EP 2016/051972
(87) N° publication PCT/PCT Publication No.: 2016/120467
(30) Priorité/Priority: 2015/01/30 (EP15153335.3)

(51) Cl.Int./Int.Cl. *F03D 1/00* (2006.01), *F03D 7/02* (2006.01), *F03D 9/11* (2016.01)

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(54) Titre : PROCEDE DE FONCTIONNEMENT D'UNE EOLIENNE SANS RACCORDEMENT AU RESEAU, ET EOLIENNE

(54) Title: METHOD OF OPERATING A WIND TURBINE WITHOUT GRID CONNECTION AND WIND TURBINE

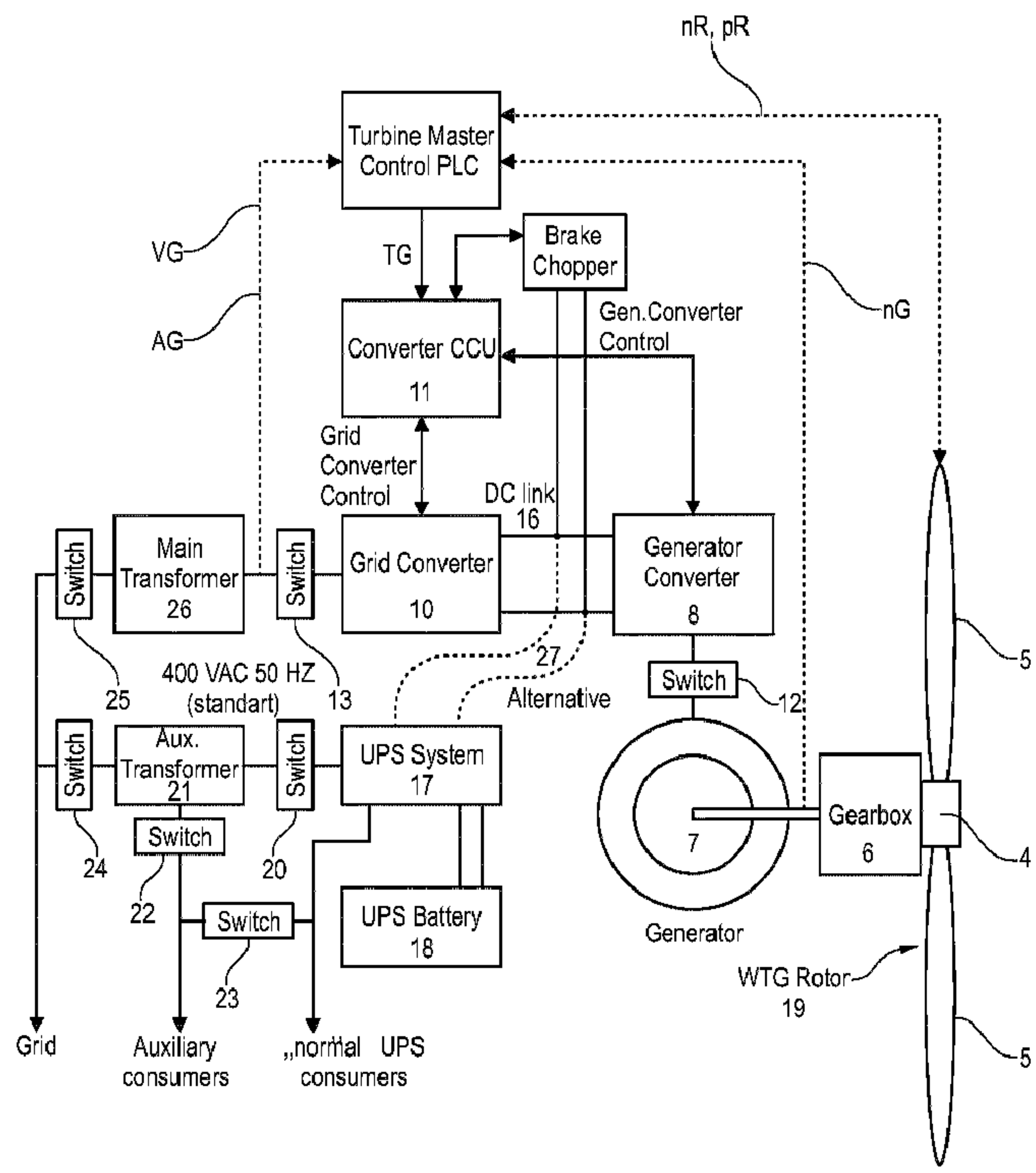

Fig. 2

(57) Abrégé/Abstract:
The present invention relates to a method of operating a wind turbine, a method of manufacturing a wind turbine and a wind turbine. The wind turbine comprises a permanent magnet (PM) synchronous generator, a main converter, a main converter

(57) **Abrégé(suite)/Abstract(continued):**
controller, a wind turbine master controller and an electrical power supply stage comprising an electrical energy storing device. A startup of the wind turbine can be performed using electrical energy from the electrical energy storing device independent from a power supplying grid and/or a combustion engine. After startup, the wind turbine can be operated in an island mode by controlling the intermediate voltage of the main converter by the main converter controller and retrieving power from the PM synchronous generator independent from the electrical energy storing device.

(12) INTERNATIONAL APPLICATION PUBLISHED UNDER THE PATENT COOPERATION TREATY (PCT)

(19) World Intellectual Property Organization
International Bureau

(43) International Publication Date
4 August 2016 (04.08.2016)

WIPO | PCT

(10) International Publication Number
WO 2016/120467 A1

(51) International Patent Classification:
F03D 1/00 (2006.01) *F03D 9/11* (2016.01)
F03D 7/02 (2006.01)

(21) International Application Number:
PCT/EP2016/051972

(22) International Filing Date:
29 January 2016 (29.01.2016)

(25) Filing Language: English

(26) Publication Language: English

(30) Priority Data:
15153335.3 30 January 2015 (30.01.2015) EP

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(81) Designated States *(unless otherwise indicated, for every kind of national protection available)*: AE, AG, AL, AM, AO, AT, AU, AZ, BA, BB, BG, BH, BN, BR, BW, BY, BZ, CA, CH, CL, CN, CO, CR, CU, CZ, DE, DK, DM, DO, DZ, EC, EE, EG, ES, FI, GB, GD, GE, GH, GM, GT, HN, HR, HU, ID, IL, IN, IR, IS, JP, KE, KG, KN, KP, KR, KZ, LA, LC, LK, LR, LS, LU, LY, MA, MD, ME, MG, MK, MN, MW, MX, MY, MZ, NA, NG, NI, NO, NZ, OM, PA, PE, PG, PH, PL, PT, QA, RO, RS, RU, RW, SA, SC, SD, SE, SG, SK, SL, SM, ST, SV, SY, TH, TJ, TM, TN, TR, TT, TZ, UA, UG, US, UZ, VC, VN, ZA, ZM, ZW.

(84) Designated States *(unless otherwise indicated, for every kind of regional protection available)*: ARIPO (BW, GH, GM, KE, LR, LS, MW, MZ, NA, RW, SD, SL, ST, SZ, TZ, UG, ZM, ZW), Eurasian (AM, AZ, BY, KG, KZ, RU, TJ, TM), European (AL, AT, BE, BG, CH, CY, CZ, DE, DK, EE, ES, FI, FR, GB, GR, HR, HU, IE, IS, IT, LT, LU, LV, MC, MK, MT, NL, NO, PL, PT, RO, RS, SE, SI, SK, SM, TR), OAPI (BF, BJ, CF, CG, CI, CM, GA, GN, GQ, GW, KM, ML, MR, NE, SN, TD, TG).

Published:
— *with international search report (Art. 21(3))*

(54) **Title**: METHOD OF OPERATING A WIND TURBINE WITHOUT GRID CONNECTION AND WIND TURBINE

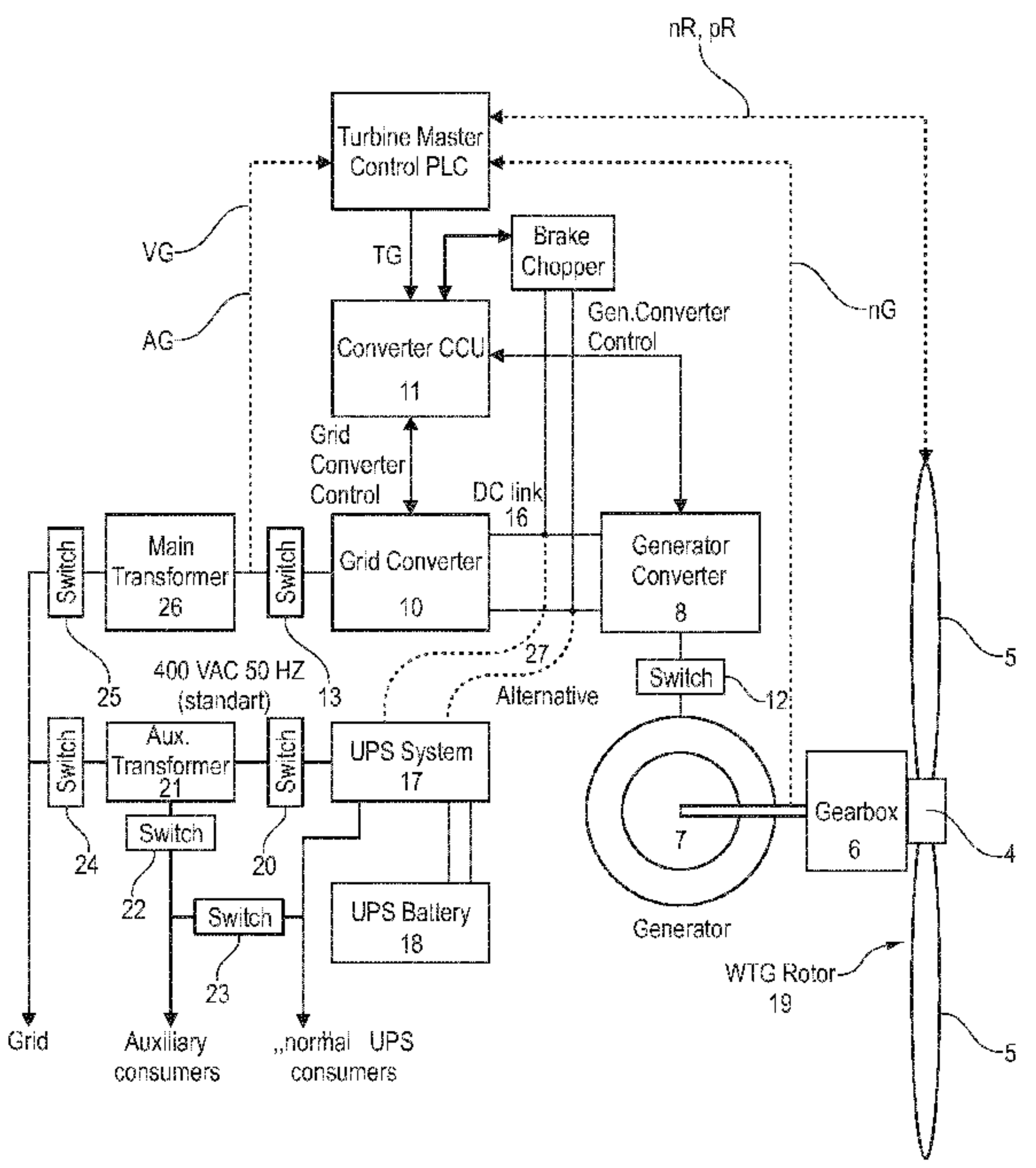


Fig. 2

(57) Abstract: The present invention relates to a method of operating a wind turbine, a method of manufacturing a wind turbine and a wind turbine. The wind turbine comprises a permanent magnet (PM) synchronous generator, a main converter, a main converter controller, a wind turbine master controller and an electrical power supply stage comprising an electrical energy storing device. A startup of the wind turbine can be performed using electrical energy from the electrical energy storing device independent from a power supplying grid and/or a combustion engine. After startup, the wind turbine can be operated in an island mode by controlling the intermediate voltage of the main converter by the main converter controller and retrieving power from the PM synchronous generator independent from the electrical energy storing device.

WO 2016/120467 A1

TITLE

Method of Operating a Wind Turbine without Grid Connection and Wind Turbine

FIELD OF INVENTION

The present invention relates to a method of operating a wind turbine, a method of manufacturing a wind turbine, a wind turbine, and a wind park.

BACKGROUND

It is generally known in the art to operate a wind turbine in an island mode. The term “island mode” relates to an operation without grid connection (grid-loss; grid failure) in which the wind turbine needs to operate independently from the grid.

Another general challenge for wind turbines, in particular off-shore wind turbines, relates to the first startup (or commissioning) of the wind turbines. In order to start normal operation, the wind turbine requires a certain amount of energy which can be supplied through the grid to which the wind turbine is connected. However, the grid (or the power supply through the grid) is often not yet available when the wind turbine is assembled and ready for startup. This can lead to damages of the wind turbine due to idleness.

In order to independently perform a startup or black start and avoid idleness, diesel generators can be provided which supply the necessary electrical energy to the wind turbine. However, this requires a large amount of fuel that needs to be carried to the wind turbine.

SUMMARY

It is an object of the invention to provide a method of operating a wind turbine, a method of manufacturing a wind turbine, a wind turbine and a wind park which ensure that the wind turbine can perform a startup or black start without grid connection or combustion generators.

In an aspect of the invention a method of operating a wind turbine is provided. The wind turbine comprises a permanent magnet (PM) synchronous generator, a main converter, a main converter controller, a wind turbine master controller and an electrical power supply stage (UPS). The electrical power supply stage can, for example be an uninterruptible power supply (UPS). The electrical power supply stage can comprise an electrical energy storing device. In a first aspect, a (first) startup or black start of the wind turbine can (exclusively) be performed using electrical energy from the electrical energy storing device independent from a power supplying grid and/or a combustion generator. The wind turbine can be operated in an island mode. In this island mode, the intermediate voltage (DC-link) of the main converter is controlled by the main converter controller. In other words, the internal electrical power supply is controlled by the main converter controller and not by the master controller of the wind turbine. Furthermore, in the island mode, power is retrieved from the PM synchronous generator and used for supplying the necessary internal components of the wind turbine. This means that the electrical energy storing device may only be used during startup or black start. It is not required for operating the wind turbine in the island mode. .

The electrical energy storing device can be charged in the island mode. This provides that the energy storing device is always charged after startup to store sufficient electrical energy to perform a subsequent startup and/or to ride through periods of lull wind (while waiting for a wind status). .

The necessary internal components that have to be powered during startup or black start can be referred to as a sub system or auxiliary operating system. This sub system or auxiliary operating system can advantageously be internal to the wind turbine.

The auxiliary operating system provides the possibility to operate, for example other sub systems like the yaw drive of the wind turbine such that the nacelle can be positioned according to the wind direction. The sub system can also be used to power subsystems like the pitch system and/or air conditioning system.

According to a further aspect, the wind turbine is stopped and/or brought in a safe operating state after before the next black start is performed. In other words, the step of transitioning from normal power production of the wind turbine to the island mode is performed in the safe operating state and/or when the wind turbine is stopped. As the wind turbine does not use additional power conversion hardware compared to a “standard wind turbine”, the island mode will not be entered seamless after grid fault. First, the turbine has to be stopped (or brought into safe operation state as, for example a low-rpm-idle-mode). The transition from normal power production to island mode can then be performed in this switch off state only.

Advantageously, the torque of the wind turbine is controlled by the main converter controller during island mode. This means that the torque is not controlled by the master controller of the wind turbine but by the main converter controller of the wind turbine.

The DC link voltage of the wind turbine can then also be controlled by the main converter controller. This can be done by field weakening of the PM synchronous generator and/or brake chopper control. The generator side converter can then only supply measurement data for computation.

Generally, the functionality of the wind turbine controller which is responsible for controlling the rotational speed and pitch of the rotor blades and the functionality of the main converter controller which is responsible for controlling the torque can both be limited during island mode.

Advantageously, in island mode, pitch control of the rotor blades of the wind turbine can be limited to values outside a tolerance band of rotor rotations per minute (nR) and/or generator rotations per minute (nG) such that the pitch is only adjusted below a minimum value of rotations per minute and above a maximum value of rotations per minute.

The minimum value for rotor rotations can be 6 rpm and the maximum value can be 14 rpm. The target value can be 10 to 11 rpm. The minimum value for generator rotations per minute can be 60 rpm and the maximum can be 140 rpm. The target value can be 100-110 rpm. The rpm values for the rotor and the generator are related to each other by the gearbox ratio. In this example, the gearbox ration is about 10.

In this aspect of the invention, the pitch of the rotor blades may advantageously only be adjusted if the number of rotations per minute leaves the tolerance band between the respective minimum and maximum value of rotations. This is done irrespective of the target value.

The wind turbine behaves similar to “high rpm idling” mode but including a variable power offset dependent on the requirements of the auxiliary operating system and the powered sub systems. The term “high rpm idling mode” means that the turbine operational state is an idling situation with a rotational speed close to normal load operation speed. In this mode, the normal loss of the generator down to the transformer can be 100 kW to 200 kW, and for specific wind turbines 80 kW. The loss of the gear may amount to 40 kW to 60 kW. This means that the total loss without the auxiliary operating system and any other sub systems can amount to round about 120 kW to 140 kW. Accordingly, a range of about 100 kW to 200 kW, in particular a value of 150 kW power is necessary in rpm idling mode. Dependent on the additionally powered sub systems (including the auxiliary operating system) the offset can have the following values:

- 50 kW to 70 kW in stationary operation;
- 100 kW to 120 kW for powering the yaw drive system, or
- 240 kW to 260 kW for starting the yaw drive system (transient).

In other words, in „island mode“, the turbine is operated similar to high rpm idling (= idling with a rotational speed close to normal load operation). Closed loop rotor speed control is carried out. Depending on the actual auxiliary power demand (of sub systems and auxiliary operating system) in island mode there will be a load offset in the range of e.g. 50 kW -300 kW compared to “normal” idling at high rpm.

The electrical energy storage device can be a battery, in particular a rechargeable battery. The minimum capacity of the electrical energy storage device can be 50 kWh. In an embodiment the electrical energy storage device can comprise lead acid batteries. The electrical energy storage device can be configured to store enough electrical energy for bridging at least one entire day (24h) calm period. Due to the large battery buffer the wind turbine can enter the island mode hours or even days after the stop without any dependency on external energy.

The present invention also provides a wind turbine (in particular off shore wind turbine) comprising a permanent magnet (PM) synchronous generator, a main converter, a main converter controller, a wind turbine master controller and an energy storage device. The wind turbine can be configured to perform a first startup of the wind turbine independent from external power supply by retrieving power from the energy storage device and subsequently transitioning into an island mode, wherein, in the island mode the main converter controller is configured to control torque and/or the an intermediate voltage (DC link voltage) of the main converter. Accordingly, the wind turbine according to these aspects of the invention can perform a startup or black start without external energy.

Furthermore, in the island mode, the main converter controller can be configured to control the DC link voltage by field weakening of the PM synchronous generator and/or brake chopper control.

Advantageously, in the island mode, the turbine master controller can be configured to only adjust a pitch angle of the rotor blades in response to a rotational speed of the generator and/or of the rotor and/or to cease sending torque requests to the main converter controller.

In an aspect, the wind turbine may further be configured to only perform pitch control of the wind turbine in island mode, if the rotor rotations per minute (nR) and/or generator rotations per minute (nG) is/are outside a tolerance range.

The present invention also provides a wind park comprising one or more wind turbines according to aspects and embodiments of the invention.

The present invention also provides a method of manufacturing a wind turbine. The method advantageously comprises the following steps: a complete burn-in of the wind turbine (preferably on-shore), disassembling of the wind turbine, re-assembling of the wind turbine at the final destination (advantageously off-shore), startup or black start of the wind turbine without connection to the grid only based on electrical energy supplied by the UPS or energy storage device and subsequently controlling the DC-link of the main converter by the main converter controller. Accordingly, the present invention provides a method of manufacturing a wind turbine including hot commissioning. This means that the wind turbine is initially assembled at a first location, for example on shore and then operated under full load (burn-in). The energy storage device is of course fully charged. Once the wind turbine is ready for operation, it is disassembled and carried to a second location, for example the final destination (for example off shore) and re-assembled.

BRIEF DESCRIPTION OF DRAWINGS

Further aspects and features of the invention ensue from the following description of preferred embodiments of the invention with reference to the accompanying drawings, wherein

FIG. 1 is a simplified schematic of a wind turbine according to an embodiment of the invention,

FIG. 2 is a simplified diagram illustrating normal operation and components of wind turbine to which the present invention applies;

FIG. 3 is a simplified diagram illustrating island mode according to an embodiment of the present invention, and

FIG. 4 is a diagram indicating a pitch control scheme according to an embodiment of the invention.

DETAILED DESCRIPTION OF EMBODIMENTS

FIG. 1 shows a simplified wind power plant or wind turbine 1 according to an embodiment of the invention. The wind power plant or wind turbine 1 comprises a supporting structure 2, which is based on a suitable foundation in the sea 3. By way of an example only, the wind power plant or wind turbine 1 is an offshore wind generator. The rotor hub 4 carries a plurality of rotor blades 5. A nacelle (not visible) is arranged at the top of the supporting structure 2, which may be for example a tower.

FIG. 2 is a simplified diagram illustrating operation and components of wind turbine 1 to which the present invention applies. FIG. 2 is a simplified illustration serving to explain a normal operation or normal energy production mode of the wind turbine 1.

The wind turbine 1 comprises rotor blades 5 and a rotor hub 4. There are further a gearbox 6, a permanent magnet synchronous generator 7, a main converter (or generator converter) 8, a wind turbine master controller 9, a grid converter 10 and a main converter controller 11. There is further a first switch 12 coupled between the PM synchronous generator 7 and the main converter 8 and a second switch 13 coupled between the grid converter 10 and the grid or main transformer 26.

The turbine master controller 9 is configured and coupled to send a desired torque value (torque request) TG to the main converter controller 11. The main converter controller 11 is configured to communicate with and to control main converter 8 and grid converter 10. The connection between the main converter 8 and grid converter 11 is referred to as direct current (DC) link 16.

Main converter 8 is configured to adjust the voltage and the current to match the resulting turbine power. Grid converter 10 (also referred to as grid side converter) is configured to control the DC link voltage and ensures the load equilibrium.

There is also a brake (or braking) chopper 15 coupled to the DC link 16. Braking chopper 15 is an electrical switch that limits the DC link voltage by switching the braking energy to a resistor where the braking energy is converted to heat.

Turbine master controller 9 also monitors and controls the rotation of the rotor 19 (rotor blades 5 and hub 4) and the pitch of the rotor blades 5. The pitch or pitch angle is indicated by pR and the number of rotations per minute (rpm) of the rotor 19 is indicated by nR. Pitch signal pR includes a desired pitch angle and a current pitch angle value of the rotor blades 5. Turbine master controller 9 further monitors and controls the number of rotations per minute (rpm) of the generator which is indicated by nG. Turbine master controller 9 also monitors the voltage VG and current VA at the grid or main transformer 26.

Finally, there is an electrical energy supply 17 including an electrical energy storage device 18. The electrical energy supply 17 can be a UPS. The electrical energy storage device 18 can be a battery or multiple batteries, in particular rechargeable batteries. In an embodiment, the electrical energy storage device can comprise or consist of one or more lead acid batteries having a minimum capacity of 50 kWh. The electrical energy storage device 18 can be configured to store enough electrical energy for bridging at least one entire day (24h) of a calm period.

The UPS system or energy supply 17 can be coupled through switch 20 to auxiliary transformer 21. Auxiliary transformer 21 can be coupled through switch 24 to the grid. Grid converter 10 is coupled through switch 13 to main transformer 26 which is coupled through switch 25 to the grid. Auxiliary transformer 21 is coupled to through switch 22 to any auxiliary power consumers (sub systems). Furthermore, UPS system 17 can be coupled to the normal UPS power consumers. Between the output of switch 22 and the output of the UPS system 17 there is another switch 23.

In an alternative embodiment, the UPS system may also be coupled to the DC link via a direct connection 27 which is only shown in dashed lines.

FIG. 3 is a simplified block diagram and illustration of the island mode of the wind turbine 1 according to aspects and embodiments of the invention. In the island mode, the turbine master controller 9 ceases to send torque requests TG to the main converter controller 11. In the island mode, the turbine master controller 9 still monitors the rotor speed nR (number of rotations of the rotor 19 per minute) and the number of rotations of the generator nG (number of rotations of the generator 7 per minute) and controls and adjusts the pitch or pitch angle pR of the rotor blades 5. The main converter controller 11 controls the voltage at the DC link 16. The grid converter 10 operates like a UPS and generates a fixed 50 Hz voltage for internal supply.

A startup or black start of the wind turbine 1 can be performed using, in particular exclusively, electrical energy from the UPS 17, in particular from the electrical energy storing device 18 independent from a power supplying grid and/or a combustion generator. The wind turbine can subsequently be operated in the island mode. In this island mode, the intermediate voltage (DC-link 16) of the main converter 8 is controlled by the main converter controller 11. In other words, the internal electrical power supply is controlled by the main converter controller 11 and not by the master controller 9 of the wind turbine 1. In the island mode, power is retrieved from the PM synchronous generator 7 and used for supplying all the necessary internal components of the wind turbine. This means that the power supply 17 including electrical energy storing device 18 (as shown in FIG. 2) may only be used during startup or a black start. Afterwards, the UPS or electrical energy storing device it is not required for operating the wind turbine 1 in the island mode.

The electrical energy storing device 18 (shown in FIG. 2) can be charged in the island mode. This ensures that the energy storing device 18 is always re-charged after startup to store sufficient electrical energy to perform a subsequent startup or black start.

The necessary internal components that have to be powered during startup can be referred to as sub systems and the auxiliary operating system of the wind turbine. The sub systems and the auxiliary operating system can be internal to the wind turbine. The auxiliary operating system provides the possibility to operate other sub systems like, for example the yaw drive (not shown) of the wind turbine such that the nacelle of the wind turbine 1 can be positioned according to the wind direction. The auxiliary operating system can also be used to power the pitch drive or an air conditioning system.

As the wind turbine does not use additional power conversion hardware compared to a “standard wind turbine”, the island mode may not be entered seamlessly after grid fault. The wind turbine 1 has to be stopped (or brought into safe operation state as, for example a low-rpm-idle-mode). The transition from normal power production to island mode can then be performed in this switch off state only.

The torque of the wind turbine is controlled by the main converter controller 11 during island mode. This means that the torque is not controlled by the master controller 9 of the wind turbine but by the main converter controller 11 of the wind turbine.

The DC link 16 voltage of the wind turbine 1 can then also be controlled by the main converter controller 11. This can be done by field weakening of the PM synchronous generator 7 and/or brake chopper control of the brake chopper 15.

FIG. 4 is a diagram indicating a pitch control scheme in island mode according to an embodiment of the invention. Accordingly, in the island mode, the pitch angle pR of the rotor blades is only adjusted if the number of rotations nG of the generator 7 and/or the number of rotations nR of the rotor 19 leaves a certain range. The diagram indicates the wind speed WS in m/s, the pitch angle pR of the rotor blades 5 in degrees and the number of rotations nG of the generator 7 in rpm (also referred to as generator speed) over time in seconds. In this embodiment, the upper limit for nG is 120 rpm and the lower limit is 80 rpm. The pitch angle is only adapted if nG exceeds 120 rpm or is drops below 80 rpm. It can be seen that the pitch angle pR remains constant over periods of several hundreds of seconds. This kind of tolerance band control has several advantages. The activity of the pitch adjustment is reduced which reduces use of the pitch adjustment system (pitch drive, gears etc.), the number of changes of the load conditions is reduced (thereby also reducing wear of the wind turbine), the amount of energy consumed by the pitch drive system is reduced and load on the wind turbine is generally reduces.

In other embodiments, the minimum value nR for rotor 19 rotations can be 6 rpm and the maximum value for nR can be 14 rpm. The target value for nR can be 10 to 11 rpm. The minimum value nG for generator rotations per minute can be 60 rpm and the maximum for nG can be 140 rpm. The target value for nG can be 100-110 rpm. The rpm values for the rotor and the generator are related to each other by the gear transmission ratio of the gearbox 7. In this example, the gearbox ratio is about 10:1

The electrical energy storage device can be a battery, in particular a rechargeable battery. The minimum capacity of the electrical energy storage device can be 50 kWh. In an embodiment the electrical energy storage device can comprise lead acid batteries (or another advantageous battery technology, like e.g. lead crystal). Due to the large battery buffer the wind turbine can enter the island mode hours or even days after the stop without any dependency on external energy.

In the island mode, the wind turbine behaves similar to “high rpm idling” mode but including a variable power offset dependent on the requirements of the auxiliary operating system and the powered sub systems. The term “high rpm idling mode” means that the turbine operational state is an idling situation with a rotational speed close to normal load operation speed. In this mode, the normal loss of the generator down to the transformer can be 100 kW to 200 kW, and for specific wind turbines 80 kW. The loss of the gear may amount to 40 kW to 60 kW. This means that the total loss without the auxiliary operating system and any other sub systems can amount to round about 120 kW to 140 kW. Accordingly, a range of about 100 kW to 200 kW, in particular a value of 150 kW power is necessary in rpm idling mode. Dependent on the additionally powered sub systems (including the auxiliary operating system) the offset can have the following values:

- 50 kW to 70 kW in stationary operation;
- 100 kW to 120 kW for continuously powering the yaw drive system, or
- 240 kW to 260 kW for starting the yaw drive system (transient).

In other words, in „island mode“, the turbine is operated similar to high rpm idling (= idling with a rotational speed close to normal load operation). Closed loop rotor speed control is carried out. Depending on the actual auxiliary power demand (of sub systems and auxiliary operating system) in island mode there will be a load offset in the range of e.g. 50 kW -300 kW compared to “normal” idling at high rpm.

Although the invention has been described hereinabove with reference to specific embodiments, it is not limited to these embodiments and no doubt further alternatives will occur to the skilled person that lie within the scope of the invention as claimed.

CLAIMS

1. A method of operating a wind turbine, the wind turbine comprising a permanent magnet (PM) synchronous generator, a main converter, a main converter controller, a wind turbine master controller and an electrical power supply stage comprising an electrical energy storing device, wherein the method comprises: performing a startup of the wind turbine using electrical energy from the electrical energy storing device independent from a power supplying grid and/or a combustion engine; operating the wind turbine in an island mode by controlling the intermediate voltage of the main converter by the main converter controller and retrieving power from the PM synchronous generator independent from the electrical energy storing device after startup.

2. The method according to claim 1 further comprising: charging the electrical energy storing device in the island mode.

3. The method according to claim 1 or 2, further comprising: powering a sub system which is internal to the wind turbine by the electrical energy storage device during startup.

4. The method according to claim 3, wherein the sub system is a yaw drive to position the nacelle according to the wind direction, and/or a pitch system for adjusting rotor blades and/or an air conditioning system.

5. The method according to any previous claim, further comprising: stopping the wind turbine and/or bringing the wind turbine in a safe operating state after a grid fault before performing the next startup.

6. The method according to any previous claim, further comprising: controlling a DC link voltage by the main converter controller by field weakening of the PM synchronous generator and/or brake chopper control.

7. The method according to any previous claim, further comprising: configuring the wind turbine master controller to adjust a pitch angle of the rotor blades in response to a rotational speed of the generator and/or of the rotor in island mode and controlling the torque by the main converter controller during island mode.

8. The method according to any previous claim, further comprising limiting pitch control of the wind turbine in island mode to values outside a tolerance band

of rotor rotations per minute (nR) and/or generator rotations per minute (nG) such that the pitch angle is only adjusted below a minimum value of rotations per minute and above a maximum value of rotations per minute.

9. A wind turbine comprising a permanent magnet (PM) synchronous generator, a main converter, a main converter controller, a wind turbine master controller and an energy storage device, the wind turbine being configured to perform a first startup of the wind turbine independent from external power supply by retrieving power from the energy storage device and subsequently transitioning into an island mode, wherein, in the island mode the main converter controller is configured to control torque and/or the an intermediate voltage (DC link voltage) of the main converter.

10. The wind turbine according to claim 9, wherein, in the island mode, main converter controller is configured to control the DC link voltage by field weakening of the PM synchronous generator and/or brake chopper control.

11. The wind turbine according to claim 9 or 10, wherein, the turbine master controller is configured to adjust a pitch angle of the rotor blades in response to a rotational speed of the generator and/or of the rotor in island mode.

12. The wind turbine according to anyone of claims 9 to 11, being further configured to only perform pitch control of the wind turbine in island mode, if the rotor rotations per minute (nR) and/or generator rotations per minute (nG) is/are outside a tolerance range.

13. A method of manufacturing a wind turbine comprising: assembling the wind turbine in a first location, completely burning-in the wind turbine under full load, disassembling of the wind turbine at the first location, re-assembling of the wind turbine at a second location; performing a startup or black start of the wind turbine without connection to a grid or a combustion generator only based on electrical energy supplied by an electrical energy storing device that is internal to the wind turbine and subsequently controlling the torque and/or DC-link of the main converter by the main converter controller.

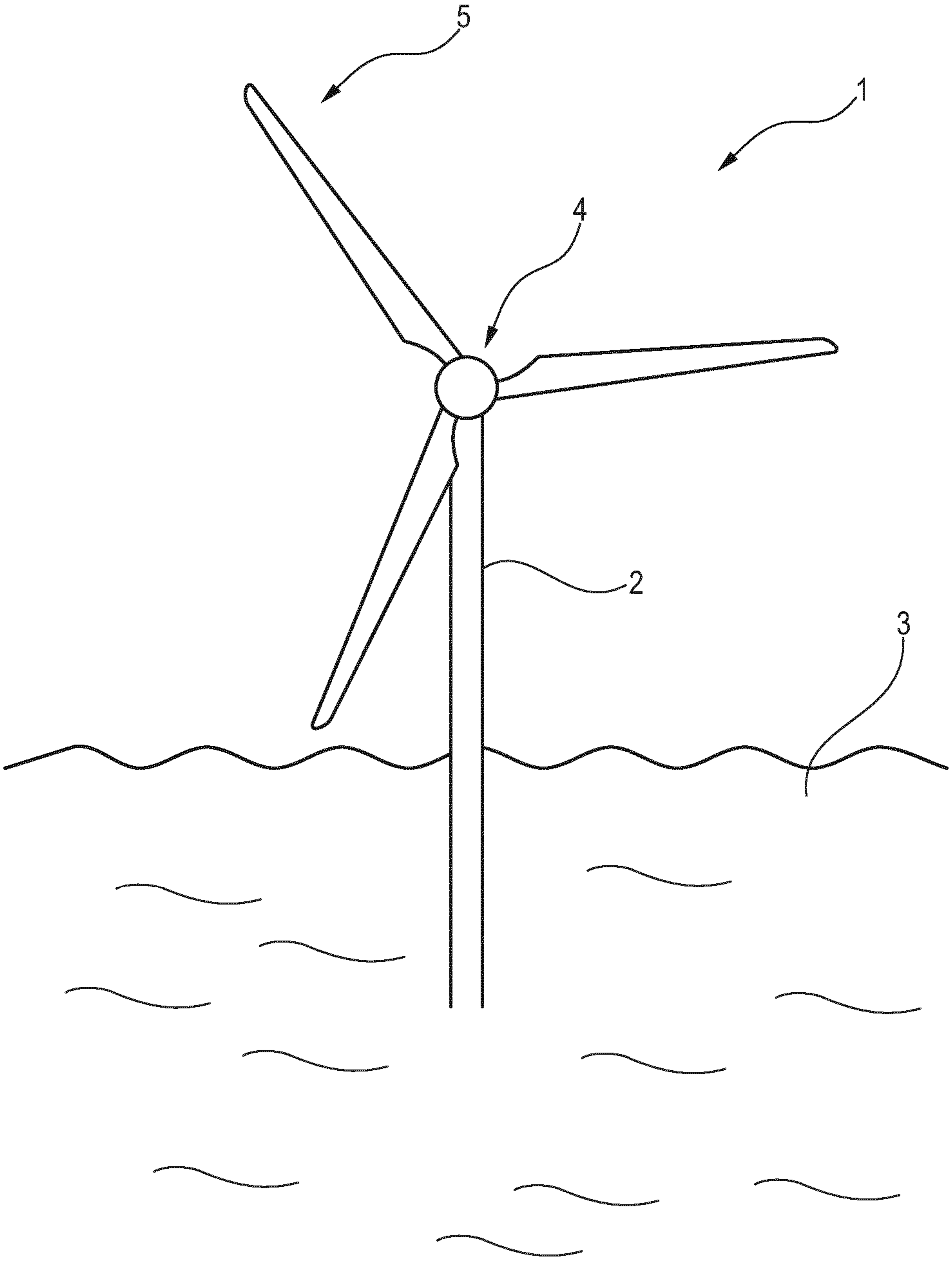
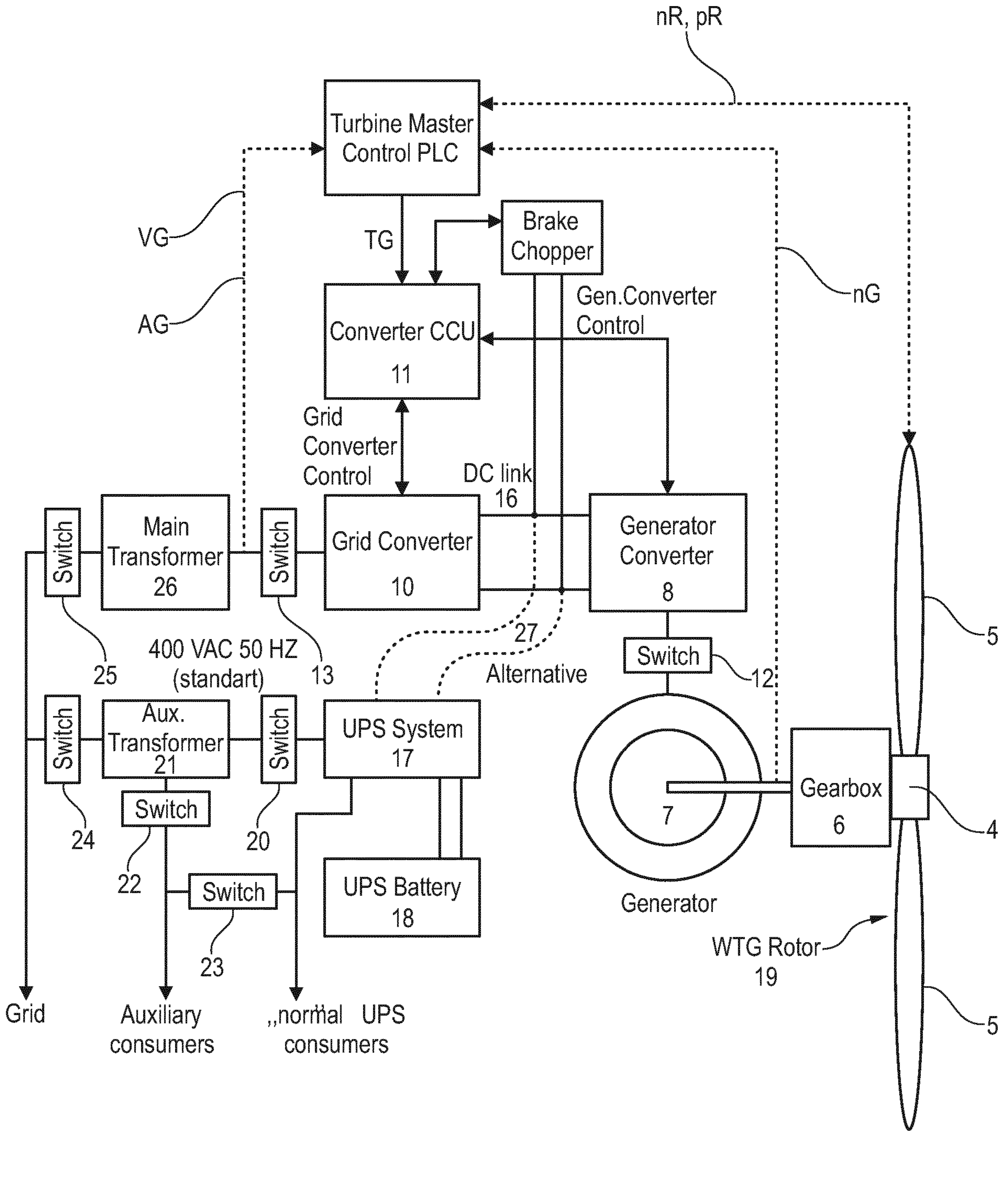


Fig. 1


nR, pR
Turbine Master Control PLC
VG
AG
TG
Brake Chopper
Converter CCU
11
Gen.Converter Control
nG
Grid Converter Control
DC link
16
Switch
Main Transformer
26
Switch
Grid Converter
10
Generator Converter
8
25
400 VAC 50 HZ (standart)
13
27
Alternative
Switch
12
5
Switch
Aux. Transformer
21
Switch
UPS System
17
Gearbox
6
4
7
Switch
24
20
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Switch
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18
Generator
WTG Rotor
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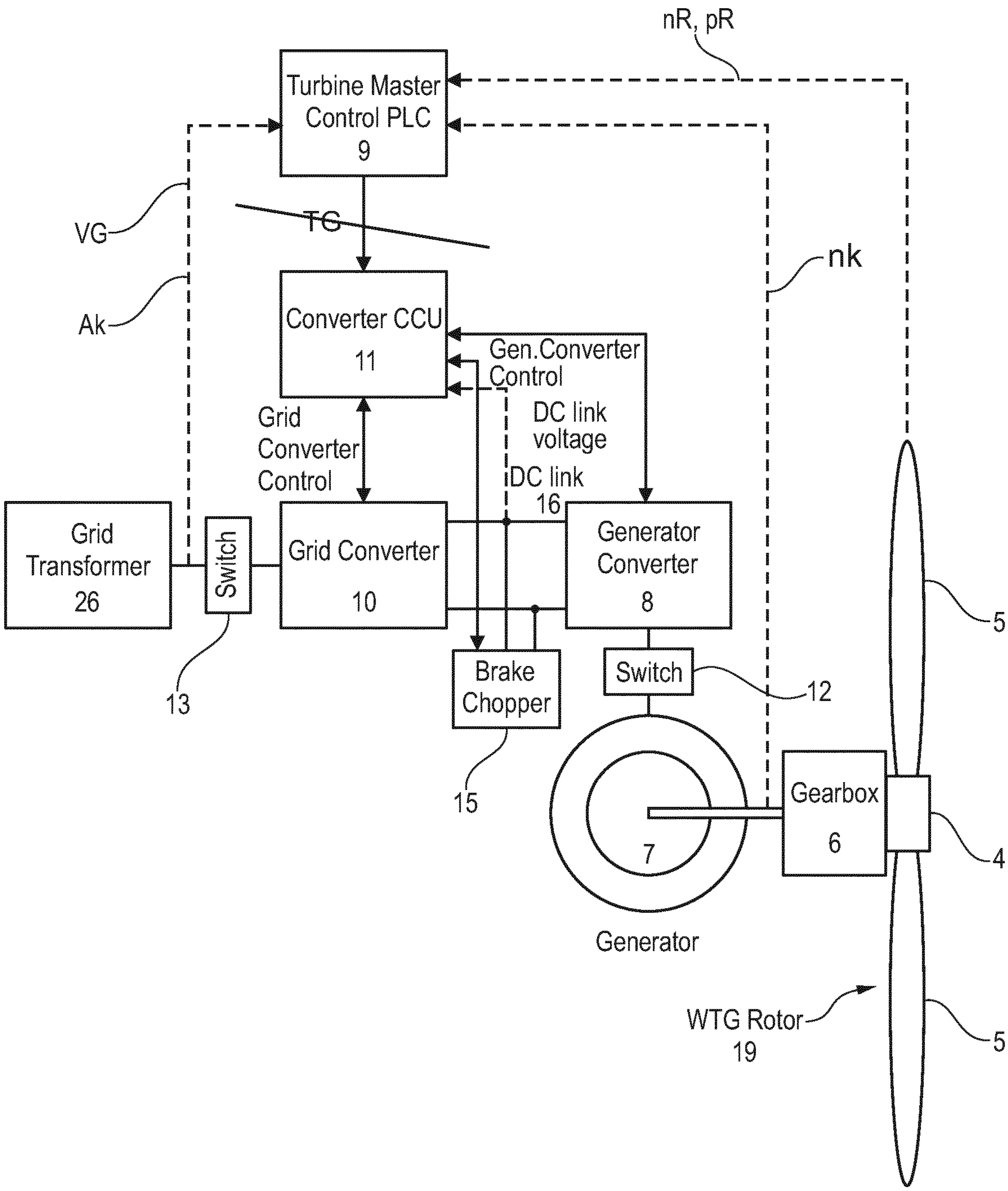
Fig. 2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VG
TG
Ak
nk
Converter CCU 11
Gen.Converter Control
DC link voltage
Grid Converter Control
DC link 16
Grid Transformer 26
Switch
Grid Converter 10
Generator Converter 8
13
Brake Chopper
Switch
12
15
Gearbox 6
7
Generator
5
4
WTG Rotor 19
5

Fig. 3

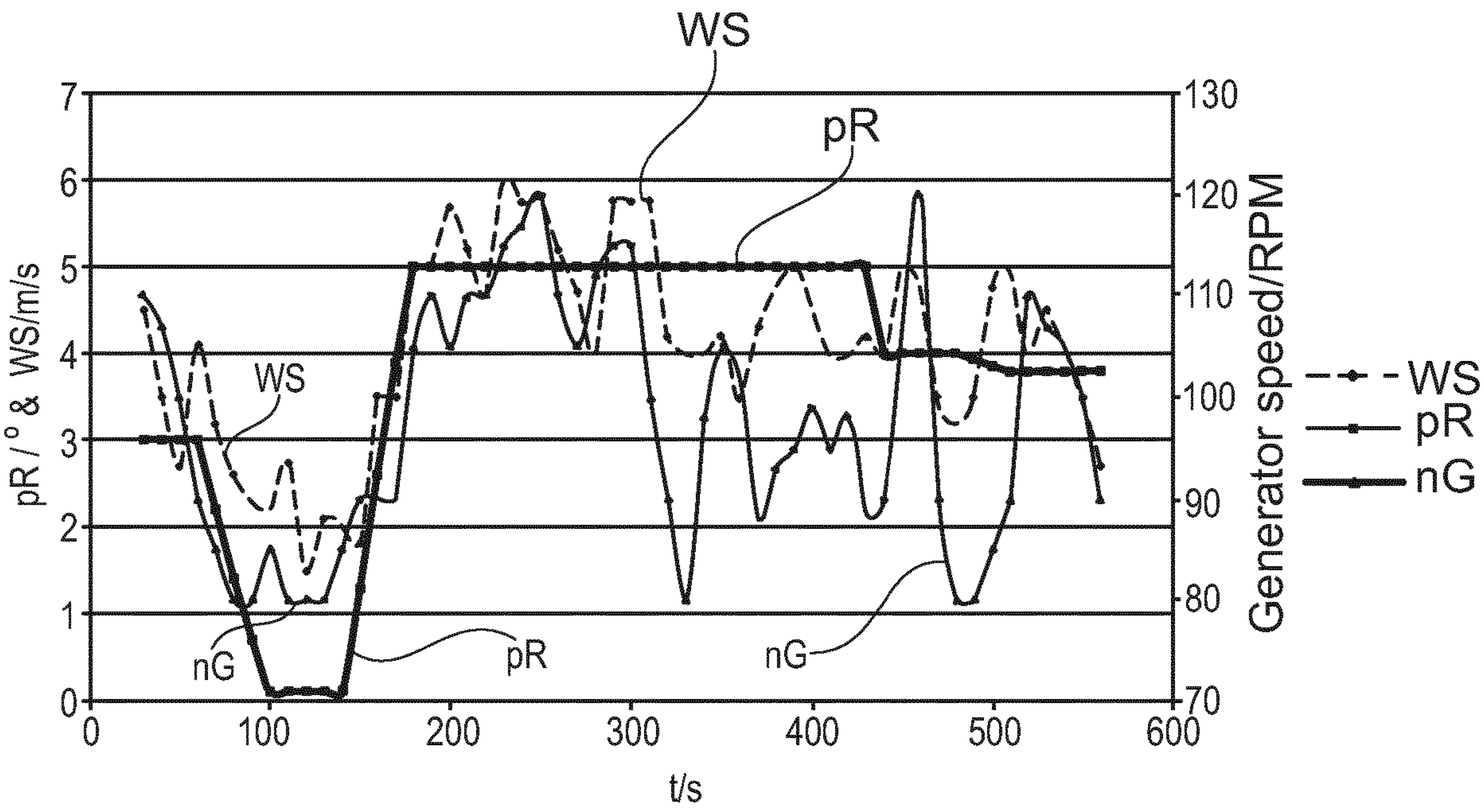
WS
pR
7
6
5
4
3
2
1
0
130
120
110
100
90
80
70
0
100
200
300
400
500
600
pR / ° & WS/m/s
Generator speed/RPM
t/s
WS
nG
pR
nG
WS
pR
nG

Fig. 4

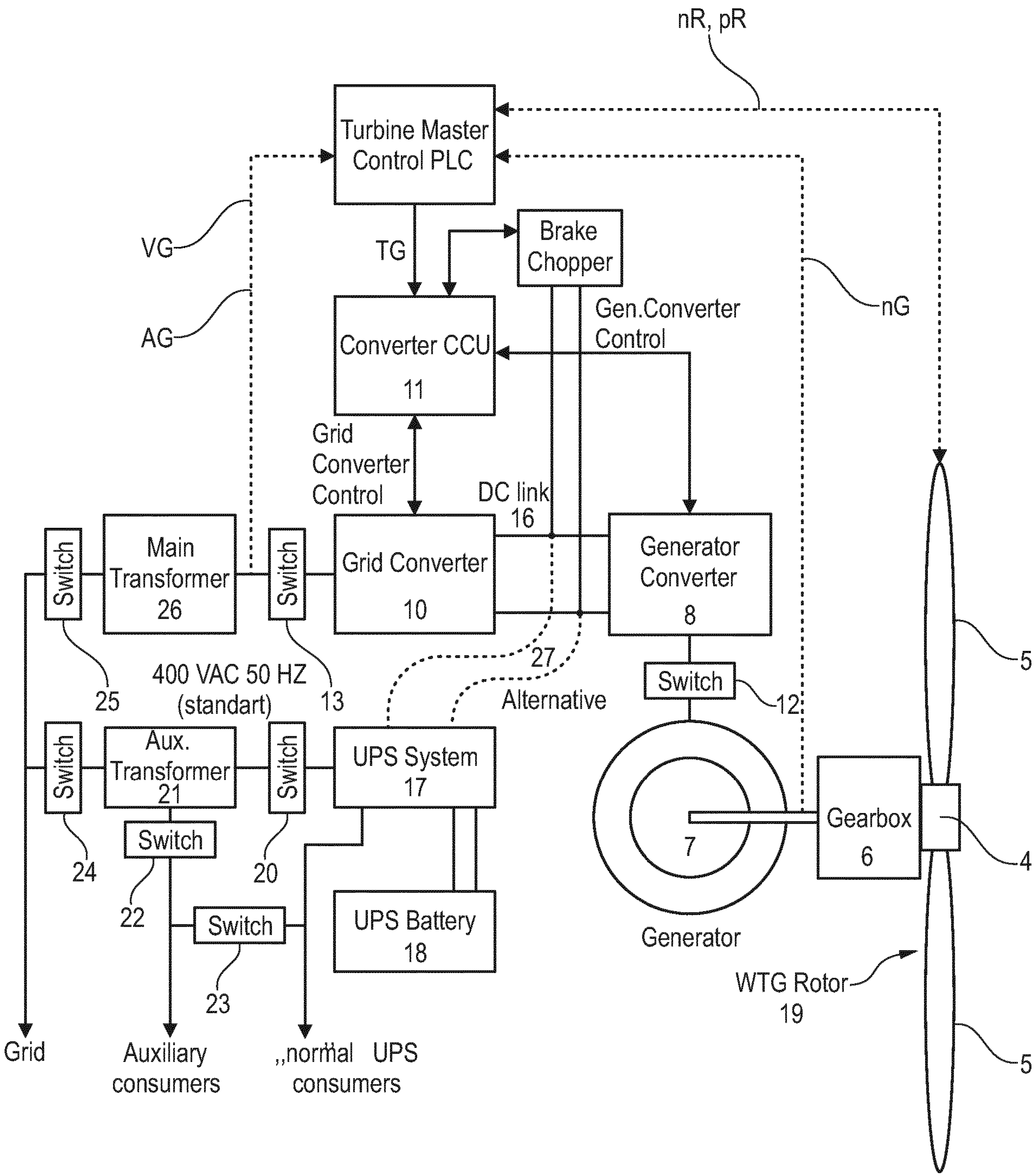
nR, pR
Turbine Master Control PLC
VG
AG
TG
Brake Chopper
Gen.Converter Control
nG
Converter CCU
11
Grid Converter Control
DC link
16
Switch
Main Transformer
26
Switch
Grid Converter
10
Generator Converter
8
5
25
400 VAC 50 HZ (standart)
13
27
Alternative
Switch
12
Switch
Aux. Transformer
21
Switch
UPS System
17
Gearbox
6
4
7
Switch
24
22
20
Switch
UPS Battery
18
Generator
WTG Rotor
19
23
5
Grid
Auxiliary consumers
,,normal" UPS consumers

Fig. 2