GOLDWIND

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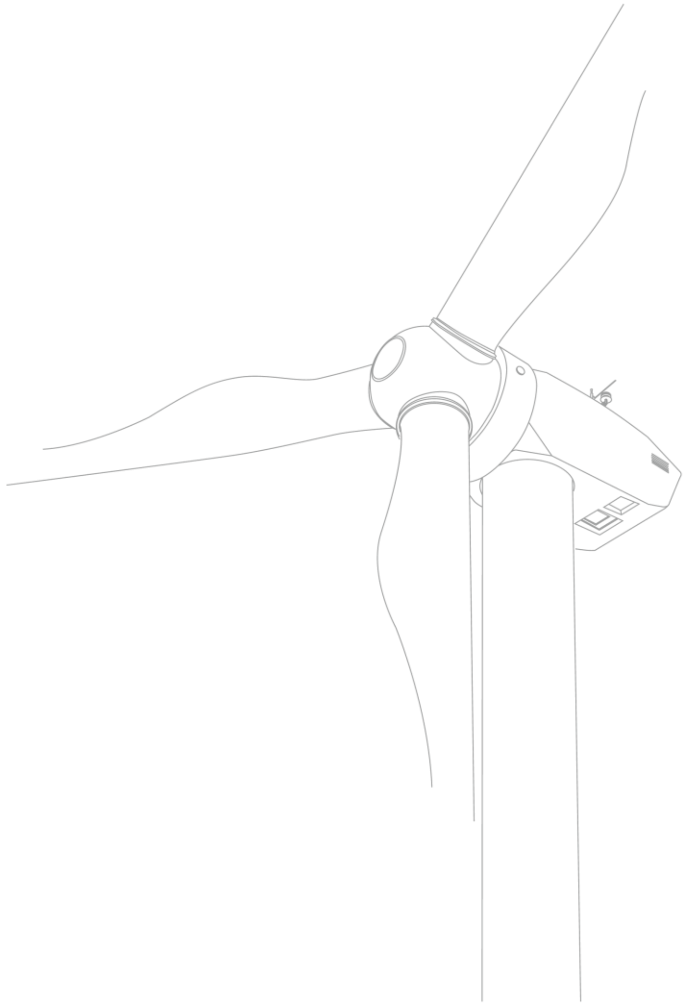
GW155-4.5 V40R02C100 Wind Turbine

Technical Specification



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36 pages

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FOREWORD

The document is drafted in accordance with the rules given in the ISO/IEC Directives, Part 2.

The document is under the jurisdiction of Xinjiang Goldwind Science & Technology Co., Ltd. (hereinafter referred to as Goldwind) and applies to Goldwind and its subsidiaries.

The document is prepared by Mechanical Technology Department of R & D SBU.

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This is the first edition.

The technology content of this document is identical to GW-08FA.0579 Edition A.

GW155-4.5 V40R02C100 Wind Turbine Technical Specification

1 Scope

This document describes the design of GW155-4.5 V40R02C100 wind turbine.

This document is applicable to GW155-4.5 V40R02C100 wind turbine with flexible generation capabilities.

2 Normative references

The following documents are referred to in the text in such a way that some or all of their content constitutes requirements of this document. For dated references, only the edition cited applies. For undated references, the latest edition of the referenced document (including any amendments) applies.

IEC 61400-1-2005, *Wind turbines. Part 1:Design requirements*

IEC 62305-1-2010, *Protection against lightning. Part 1:General principles*

IEC 61400-24-2010, *Wind turbines. Part 24:Lightning protection*

IEC 61400-21-2008, *Wind turbines. Part 21:Measurement and assessment of power quality characteristics of grid connected wind turbines*

DIN EN 61000-6-4-2011, *Electromagnetic compatibility (EMC). Part6-4: Generic standards. Emission standard for industrial environments (IEC61000-6-4:2006+ A1:2010); German version EN61000-6-4:2007+ A1:2011*

DIN EN 61000-6-2-2006, *Electromagnetic compatibility (EMC). Part6-2: Generic standards. Immunity for industrial environments (IEC61000-6-2:2005); German version EN61000-6-2:2005*

Q/GW 201073-2014, *Wind turbines General requirements for electromagnetic compatibility*

Q/GW 201083-2014, *Wind turbines General design specification for electromagnetic compatibility immunity*

GL IV-1-2010（EN）, *Guideline for the Certification of Wind Turbines*

3 Overall design

3.1 General

GW155-4.5 V40R02C100 direct-drive permanent-magnet wind turbine has a design featuring horizontal axis, three blades, and upwind arrangement of rotor, variable-speed variable-pitch regulation, direct drive, and external rotor. Figure 1 shows the overall design for grid connection of permanent magnet synchronous generator.

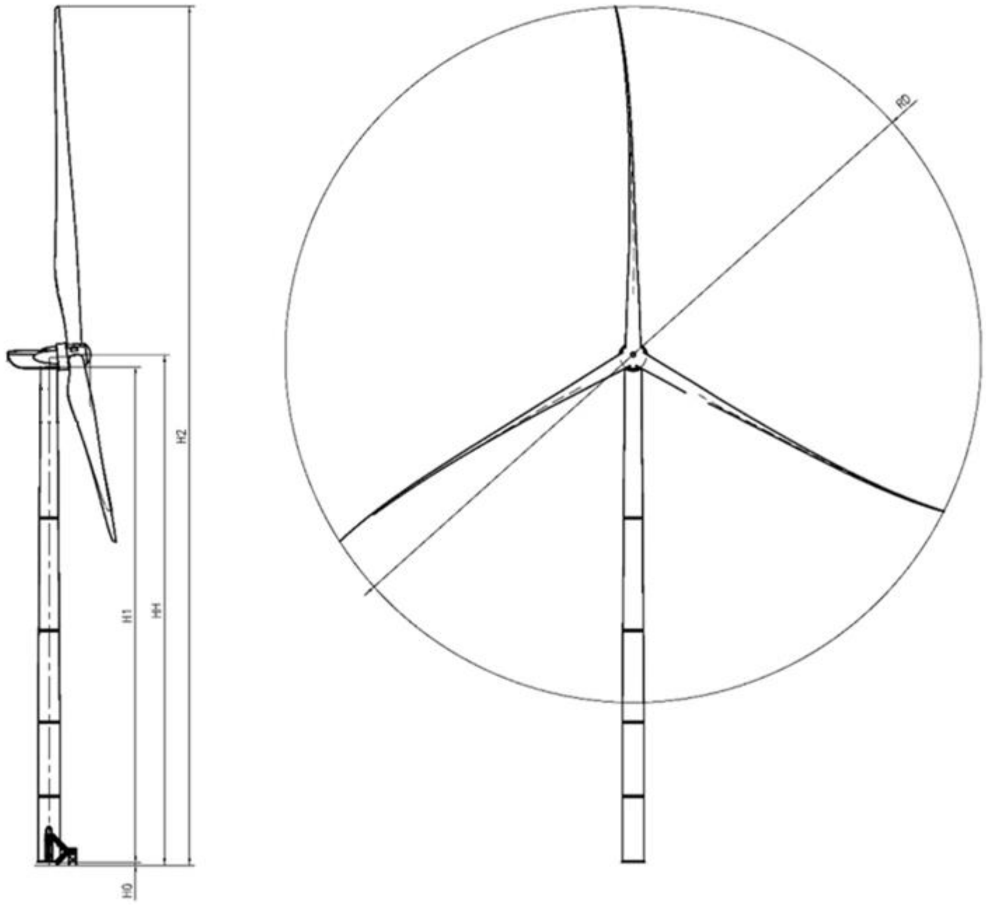


Figure 1 – Appearance of GW155-4.5 V40R02C100 direct-drive wind turbine

The general parameters of GW155-4.5 V40R02C100 wind turbine are shown in Table 1:

Table 1 – GW155-4.5 V40R02C100 wind turbine

Wind turbine	Blades	Hub height HH m	Diameter of rotor RD m	Tip height H2 m
GW155-4.5 V40R02C100	GW76	110	154.85	187.53±0.5
		95		172.53±0.5

For power control, wind turbine adopts variable-speed variable-pitch control (VSVP). Specifically, variable-speed control is adopted when the wind speed is below the rated value and variable-pitch control when the wind speed is above the rated value. The pitch system adopts flexible tooth belt to control the pitch angle.

Wind turbine adopts multipolar external rotor permanent magnet synchronous generator, whose rotor is directly connected with generator rotor. The generator is of forced ventilation cooling type. It does not require excitation by grid and operates at a low speed.

Configured in an AC-DC-AC manner, wind turbine's full-power converter system transforms the low frequency alternating current produced by generator to direct current by rectification, then inverts the current to alternating current that has the same frequency, and phase as the grid. The electricity is finally delivered to the grid through transformers. It fits the 50 Hz/60 Hz grid, under rated voltage, allows a wide range of wind turbine power factor regulation (capacitive 0.9 ~ perceptual 0.9), and uses liquid cooling mode.

The pitch system can adjust the blade pitch angle according to the control system requirements, control rotor speed and torque, perform feathering and stop wind turbine. The pitch system consists of pitch motor, pitch gearbox, gear, tooth belt, and pitch bearing, etc.

The automatic yawing system can determine the direction of nacelle according to signals from the wind vane. When the wind direction changes, the control system enables the yawing drive to align the nacelle with wind. The yawing system can control the damping during operation and adopts a design to optimize the yawing speed, enabling more stable yawing rotation.

Consisting of hydraulic pump, motor, hydraulic valve, accumulator, oil tank, connecting pipes, etc, the hydraulic system provides power for the yawing brake system, generator rotor brake system and rotor lock pin.

The automatic lubrication system for yaw system is consist of lubrication pump, grease valve, distributor, lubrication pinion, lubrication lines, etc. It is used to lubricate the raceway and tooth surface of yaw bearing. The automatic lubrication system for main bearing of generator consists of lubrication pump, distributor, lubrication lines, etc. It is used to lubricate the raceway of generator's main bearing. The automatic lubrication system for pitch bearing consists of lubrication pump, distributor, lubrication lines, etc. It is used to lubricate the raceway of pitch bearing.

The braking system uses blade feathering to realize air braking.

The design of wind turbine gives due consideration to the human-machine interface. The hollow shaft design of generator allows a large work space in nacelle and provides convenience for inspection and repair by operators. Besides, an electric lifter is available for tools and spare parts.

The electrical control system is based on the PLC. Its control circuit is composed of the master controller PLC and its functional expansion modules.

3.2 Class of wind turbine design

IEC 61400-1 defines four classes of wind turbine design for different wind classes, as shown in Table 2.

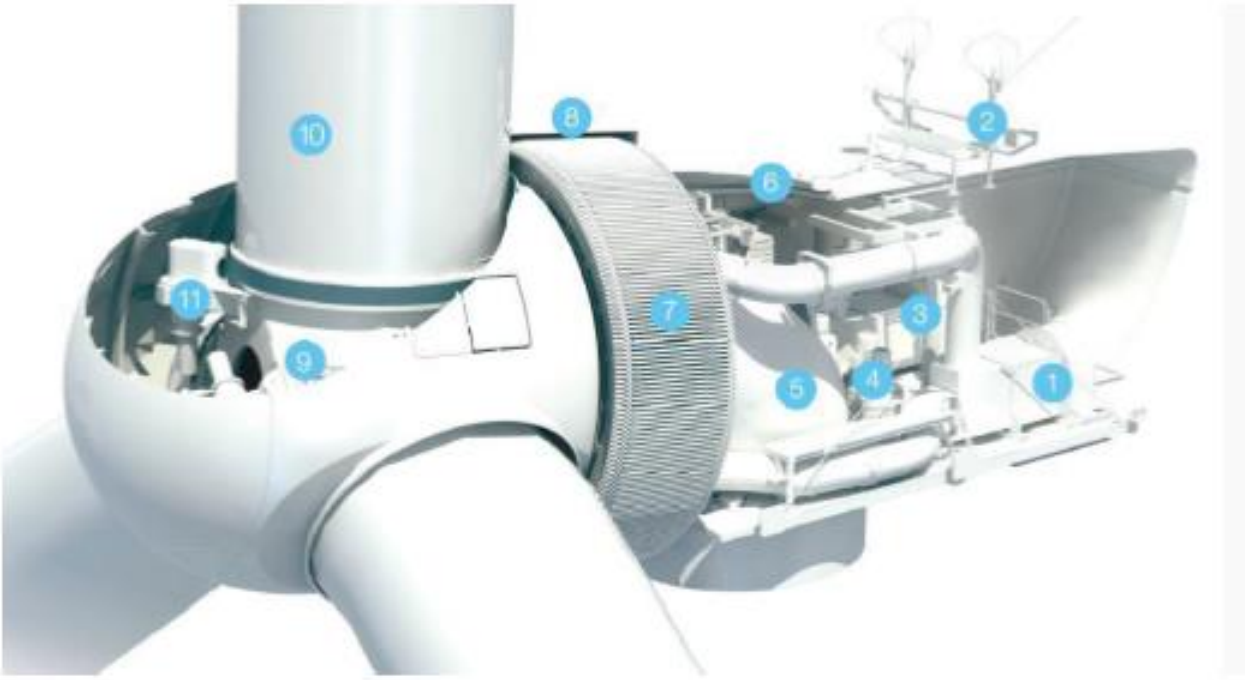
Table 2 – Classification of classes of wind turbine design

<table>
<tr><th>Wind class</th><th>I</th><th>II</th><th>III</th><th>S</th></tr>
<tr><td>Vref (m/s)</td><td>50</td><td>42.5</td><td>37.5</td><td rowspan="5">Class defined by the designer</td></tr>
<tr><td>Vave (m/s)</td><td>10</td><td>8.5</td><td>7.5</td></tr>
<tr><td>A Iref(-)</td><td>0.16</td><td>0.16</td><td>0.16</td></tr>
<tr><td>B Iref(-)</td><td>0.14</td><td>0.14</td><td>0.14</td></tr>
<tr><td>C Iref(-)</td><td>0.12</td><td>0.12</td><td>0.12</td></tr>
<tr><td colspan="5">GW155-4.5 V40R02C100</td></tr>
</table>

Wind calss	ⅡC, IIIB
Notes: Vref: reference wind speed at the hub height; Vave: annual average wind speed at the hub height; A: higher turbulence characteristic class; B: lower turbulence characteristic class; Irf: is the expected value of the turbulence intensity at 15 m/s; S: class defined by the designer. Suitable turbine type selection should consider the site specific wind resource, turbulence intensity, etc.	

3.3 Structure of wind turbine and layout of nacelle

The GW155-4.5 V40R02C100 direct-drive wind turbine mainly consists of blades, hub, pitch system, generator rotor, generator stator, yawing system, wind measurement system, base frame, and generator cooling system, etc., as shown in Figure 2.



1. Generator cooling system 2. Wind measurement system 3. Auxiliary hoist 4. Yawing system 5. Base frame 6. Nacelle cover 7. Generator stator 8. Generator rotor 9. Hub 10. Blade 11. Pitch system

Figure 2 – Structure of GW155-4.5 V40R02C100 direct-drive wind turbine

3.4 Characteristics of GW155-4.5 V40R02C100 direct-drive wind turbine

3.4.1 Advantages compared with the existing direct-drive wind turbines in current international market

a) Higher generator efficiency and wider speed (6 rpm to 9.5 rpm);
b) Permanent-magnet external rotor, simpler structure, no excitation loss; smaller than traditional electrically excited generator and a lower failure rate. Requiring no carbon brush and slip ring, less maintenance, and a higher availability.
c) Pitch system adopts tooth belt to achieve flexible drive without lubrication and maintenance.
d) Pitch system adopts brushless AC motor and adopts capacitor as standby power supply, achieving a longer service life and less maintenance.
e) The design of nacelle gives due consideration to the human-machine interface so as to provide as much convenience as possible for inspection and repair work. An elevator or ladder aiding apparatuses may be equipped in tower depending upon customer's demands to facilitate and ease operators during maintenance.

3.4.2 Advantages of wind turbines in the international market

As grid-connected wind power capacity grows, the grid connection requirements become increasingly strict. GW155-4.5 V40R02C100 wind turbine is equipped with a full-power converter, which can be easily adjusted to satisfy the requirements on different grid condition.

By using the same full-power converter, the permanent-magnet generator is also isolated from the grid and will have no influence to outside, the output of wind turbine presents voltage source characteristics (converter), independent of power source (generator).

The basic operation mode of GW155-4.5 V40R02C100 wind turbine is the constant power factor mode independent of grid voltage.

3.5 Flexible power regulation

GW155-4.5 V40R02C100 wind turbine achieves collaborative operation of various parts thanks to its integrated design. During operation, the output power of wind turbine is dynamically adjusted according to the dispatch demands of grid, external environment, and the conditions of wind turbine, realizing flexible power regulation.

4 Specific technical description of wind turbine

4.1 Rotor

The rotor structure and dimensions are as shown in Figure 3, Figure 4, and Figure 5.

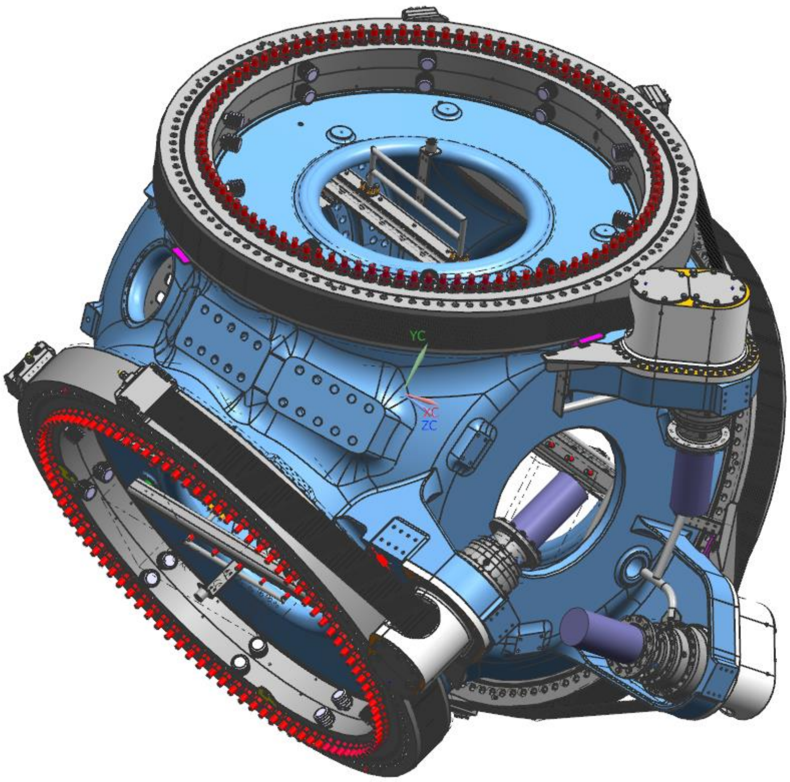


Figure 3 – Structure of rotor system

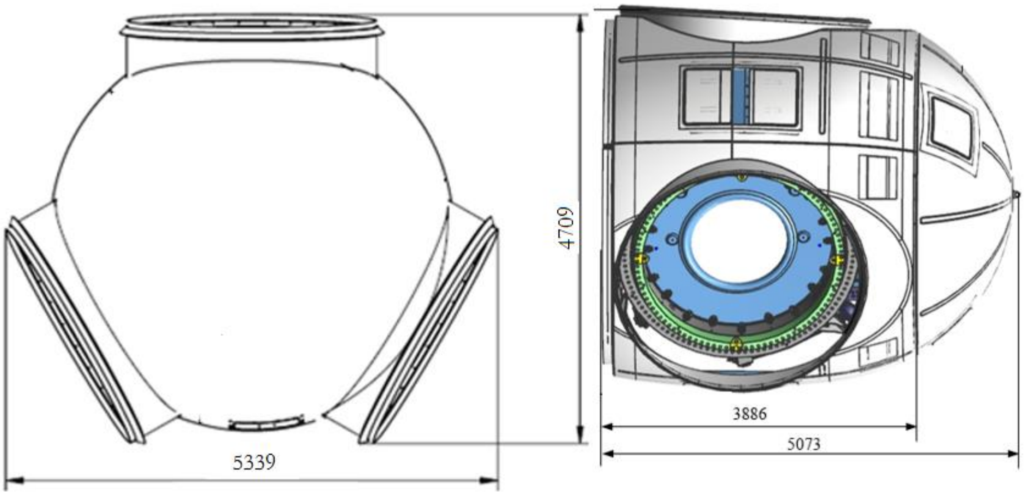


Figure 4 – Transportation dimension of rotor system

GW155-4.5 V40R02C100 direct-drive wind turbine employs a three-blade, upwind, and horizontal-axis overall design. Each blade has an independent pitch system, which actively regulates the pitch angle of blade. The blade is made of glass fiber reinforced epoxy and it is equipped with lightning protection system, the downlead of which can direct the lightning current on blade into the ground through the tower. Pitch bearing connects blade and cast iron hub.

The pitch angle of blade may be regulated by pitch drive system according to wind speed and power output. In the pitch drive system, pitch drive motor drives pitch reducer and tooth belt drives pitch bearing to adjust the pitch angle of blade. The tooth belt in pitch drive system is made from high strength rubber. It requires no lubrication and maintenance and is less sensitive to external impact loads. See Figure 5.

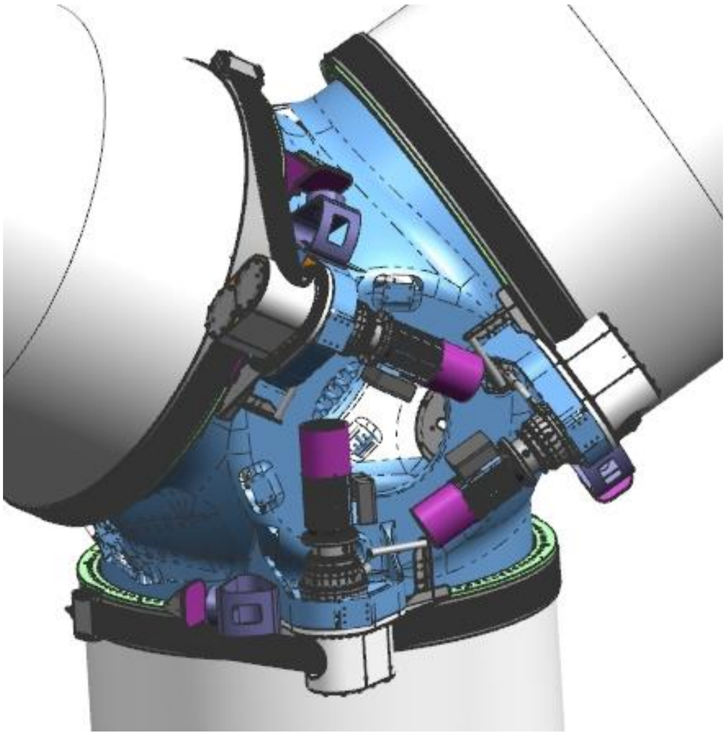


Figure 5 – Pitch drive system

Rotor is connected with main shaft via two single-row tapered roller bearings, and the main shaft is fixed to the base frame. During wind turbine maintenance, the rotor can be locked with the locking pin.

4.2 Technical characteristics of pitch system

The pitch system regulates the pitch angle of blade through pitch drive system and thus regulating the output power of wind turbine. When wind turbine reaches rated power, its output power remains constant. In addition, the pitch angle control during operation of wind turbine can effectively reduce the loads on wind turbine.

4.2.1 Blade

According to customer demands, options of increasing power devices (vortex generator) and noise suppression devices (trailing edge serrations, etc.) shall be provided.

The blade has been subjected to static strength, rigidity and frequency tests, as shown in Figure 6. Besides, a fatigue test is conducted in accordance with GL IV-1-2010 (EN) standard and aviation product experimental technologies. The test results show that the blades have a design service life of no less than 20 years.

Figure 6 – Test on blade

4.3 Generator

The generator is a multi-pole permanent magnet synchronous generator with simple structure, reliable operation performance, high efficiency, small size, and other advantages. GW155-4.5 V40R02C100 direct-drive permanent magnet synchronous generator has a speed range of 6 rpm to 9.5 rpm, 112 poles, a rated voltage of 760 V±3%, and the winding insulation grade of F.

The outline diagram of generator is as below:

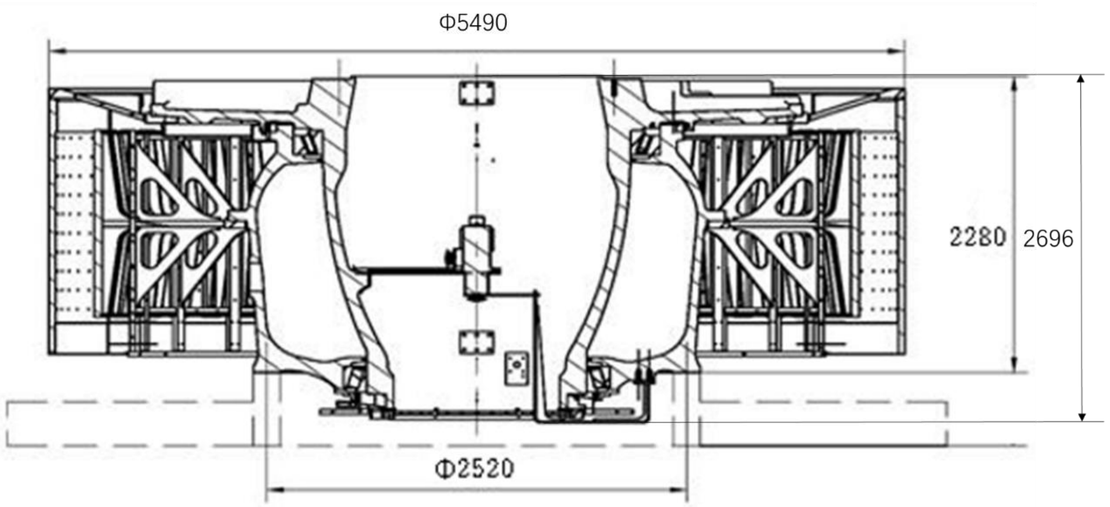


Figure 7 – Dimensions of generator

The generator consists of stator, rotor, stator shaft, rotor shaft, and other accessories. The stator is of flexible support structure and consists of stator support, core and winding, and other accessories. The rotor consists of rotor support and permanent magnets.

The generator has double windings and six-phase outputs. The stator employs a fractional slot winding arrangement to further eliminate the influence of harmonics. The unique arrangement of rotor poles reduces vibration and noise.

The stator winding adopts VPI vacuum impregnation. The excellent insulation structure and insulation processing technology can ensure reliable insulation.

The generator adopts two single-row tapered roller bearings, which make the axial dimensions of generator more compact. Maintenance personnel can enter rotor from the inside of generator. The door between the generator and base is provided with an advanced safety lock, which together with the electrical control system, protects the safety of personnel going in and out of rotor.

The generator adopts active air cooling. Cooling air in nacelle enters the generator from the air inlet, passes the winding end, magnetic pole and radial ventilation duct to cool down the relevant components in generator, and thus taking away the internal heat of generator. Then, the hot air generated is gathered by the air collection device.

The hot air gathered by the wind collection device is directly discharged outside the nacelle. At the same time, the atmospheric pressure difference between the inside and outside of nacelle can supplement cold air in the nacelle. Moreover, when the cold air outside the nacelle enters the nacelle, the fresh air can be filtered via the ventilation hole at the rear of nacelle cover and filter. This kind of cooling mode applies to relatively mild environmental conditions, such as dry onshore areas.

Using cool air in nacelle for cooling significantly improves the heat dissipation efficiency of generator and reduces the size of generator. Such cooling system is simple but reliable and has a lower fault rate. Furthermore, at the inlet of generator, dustproof measures are taken to prevent dust in nacelle from entering generator, creating a good work environment and increasing generator's reliability.

GW155-4.5 V40R02C100 wind turbine is of external rotor design. Compared with electrically excited wind turbine of the same power rating, GW155-4.5 V40R02C100 wind turbine has a smaller size and outer diameter. The following figure shows the comparison between the two structures.

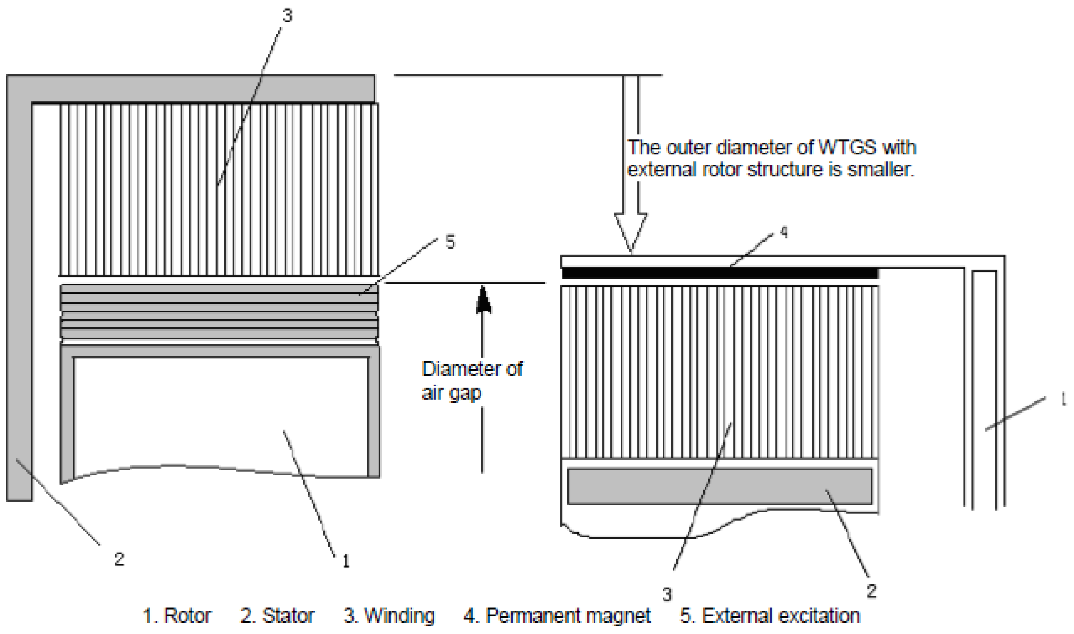


Figure 8 – Comparison between external rotor and internal rotor of generator

The two structures have the same air gap diameter and the same output power. The later has a smaller weight due to smaller diameter of generator, which facilitates road transportation. Furthermore, in the external rotor structure, external cool air may also cool down the permanent magnets in rotor, which further improves the reliability of generator.

4.4 Characteristics of permanent magnets

Goldwind permanent magnet generator uses highly-magnetic sintered NdFeB whose coercive force is high enough to avoid loss of magnetism under high temperature. To ensure reliable magnetism of permanent magnet, abundant work as follows were performed：

a) The magnetism of permanent magnet after demagnetization by short-circuiting at high temperature is checked and calculated. It shows that the operating point of permanent magnet is higher than the knee point of demagnetization curve with a safety factor required.
b) In the design of generator, demagnetization due to reversing field generated under special operating conditions is duly considered. All performance parameters of the permanent magnet selected can ensure that the operating point of permanent magnet is above the knee point under overloading, high temperature short circuit, lightning and no permanent demagnetization will occur.
c) The control system of wind turbine is provided with various protections, such as over temperature, over current, under voltage, etc. Under abnormal working conditions, the control system can provide complete and reliable protection for the generator.
d) As the NdFeB permanent magnet contains active rare earth element, which is easily oxidized and rusted, the reliable foreign potting adhesive and encapsulation technologies are adopted during the process of manufacturing to increase the sealing of permanent magnet with a view to enhancing the anti-corrosion characteristic of permanent magnet. With strict control on the curing temperature of adhesive, an even and tight protective adhesive film can be developed on the surface of magnet, which significantly improves the anti-corrosion ability of permanent magnet.

4.5 Design of nacelle

The base frame can transfer the static and dynamic loads of rotor and generator to the tower. In addition, the nacelle is equipped with control cabinet, hoist, yawing system, heat exchange system, etc. inside and a wind measurement system outside. See Figure 9 for the nacelle appearance.The nacelle can be divided into three parts by nature:

a) Castings transferring loads;

b) A working platform for the maintenance personnel;

c) A shell made of fiber reinforced plastics;

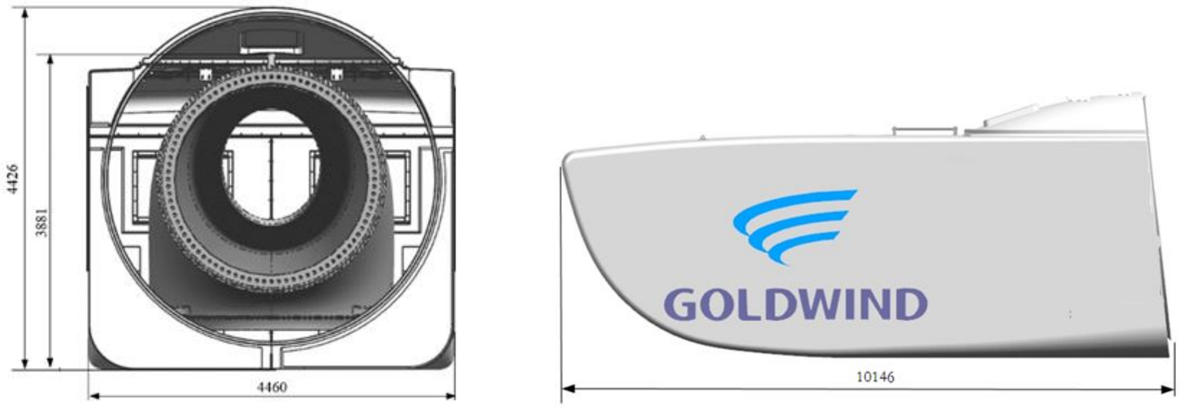


Figure 9 – Nacelle

4.6 Braking system

Goldwind 4.2MW direct-drive wind turbine is equipped with three independent blade pitch systems. Wind turbine can separately control the feathering angle of the three blades for air braking to stop wind turbine safely. The three redundant systems can ensure the safety of wind turbine. Mechanical locking pins is installed in the generator. The mechanical locking pins work when the hydraulic system allows pressure build-up and are released when the pressure reduces. They mainly serve to control the position of generator rotor, so as to lock and unlock the rotor for maintenance.

4.7 Yawing system

The GW155-4.5 V40R02C100 wind turbine adopts active yawing to align with the wind. Two independent sensors (anemometer and wind vane) are provided at the top of nacelle. The wind vane detects the difference between wind turbine direction and prevailing wind direction. When the wind direction changes, the controller will control the six yawing drive devices to align the nacelle with the prevailing wind direction according to the signal from the wind vane.

This yawing system has following features:

a) The yawing bearing is a four-point contact ball bearing designed with "zero clearance" to improve the stability of wind turbine operation and the resistance to impact loads.

b) Use the multi-motor drive with smooth torque characteristic to optimize the yawing speed of wind turbine and minimize the impact under various operating conditions in the wind farm.

c) Hydraulic yawing brakes are used. When wind turbine is out of operation, the yawing brake locks the nacelle securely. During yawing, a certain residual brake pressure is kept, which can make yawing more stable and avoid possible vibration.

d) The electromagnetic brake situated on the drive shaft of yawing motor can provide fail-safe protection. In case of external faults (such as outage or loss of pressure in the hydraulic system), the electromagnetic brake can keep the yawing system of wind turbine reliably locked.

e) The gear of yawing speed reducer has hard surface processed by grinding after carburizing and hardening which can avoid long-time abrasion and thus prolong the service life.

f) The yawing gear also has hard surface and the outer ring gear adopts a special technology which increases the hardness of tooth surface to above HRC50 and thus avoids long-time abrasion.

g) The PLC control system of wind turbine can ensure that wind turbine can automatically untwist cables under low wind speed, avoiding loss of power generation due to cable untwisting under high wind speed.

4.8 Tower

The tapered steel tower is the main supporting structure of wind turbine. The yawing bearing in the nacelle is directly connected to the tower flange by bolts so as to transfer the load on the upper section of wind turbine to the foundation through tower.

For manufacture and transport reasons, the tower is fabricated in several sections, which are connected by forged flanges. Wind turbine foundation is of gravity anchor type, where tower and foundation are connected by flanges.

The tower is equipped with ladders and fall protection devices inside, as well as aiding apparatus or elevators upon the request of customer. Rest platforms are provided inside the tower at intervals along the height direction, and all tower tubes are provided with platforms and lamps.

The generator-side power cables (Copper cable is used for twisted cable section and copper cable or aluminum alloy cable can be used for vertical fixed laying section in the tower) and control cables are laid downward inside the tower. Control cable adopts optical fiber communication, with strong anti-interference ability. A certain length of Cable torsion section is designed to provide effective protection for the cable of this section and prevent the cable from torsion during yaw. Wind turbine untwists automatically after the nacelle yaws several rounds (the extreme torsion angle is about 900 degrees measured by yaw position sensor) in the same direction.

GW155-4.5 V40R02C100 are also available for reinforced concrete towers.

4.9 Foundation

Anchor foundation is recommended. The foundation drawings and data provided herein are preliminarily determined based on simple geological condition. The specific foundation should be designed specially according to local geological survey report.

4.10 Wind turbine operation and safety system

GW155-4.5 V40R02C100 direct-drive wind turbine is designed to operate automatically in all-weather condition. The whole operation is under automatic control. The safety and protection system consists of protection for controller software, independent safety-chain outside of the controller, and hardware protections for individual components. It will protect wind turbine in case of safety problems such as abnormal vibration, over speed, grid exception, and wind speed limit. Wind turbine supports automatic reset function. For instance, if the grid voltage or wind speed is extremely high, the electrical control system will reset automatically after system recovery and wind turbine will restart.

4.11 Control system

The electrical control system of GW155-4.5 V40R02C100 direct-drive wind turbine consists of main control cabinet, converter cooling cabinets, converter cabinets, top box, generator cooling box, three pitch boxes, sensors and connecting cables, etc., with functions of operation control, operation status monitoring, and safety protection.

The design of electrical control system can accommodate unattended operation, automatic operation, and status control and monitoring of wind turbine.

The electrical control system for GW155-4.5 V40R02C100 direct-drive wind turbine is based on PLC. Its control circuit is composed of the master controller PLC and its functional expansion modules. It is mainly capable of operation control, safety protection, faults detection and handling, operational parameters setting, data recording and displaying, and manual operations of wind turbine. The control system is equipped with multiple communication interfaces, which allow both local and remote communication. See Figure 10 for the block diagram of control system.

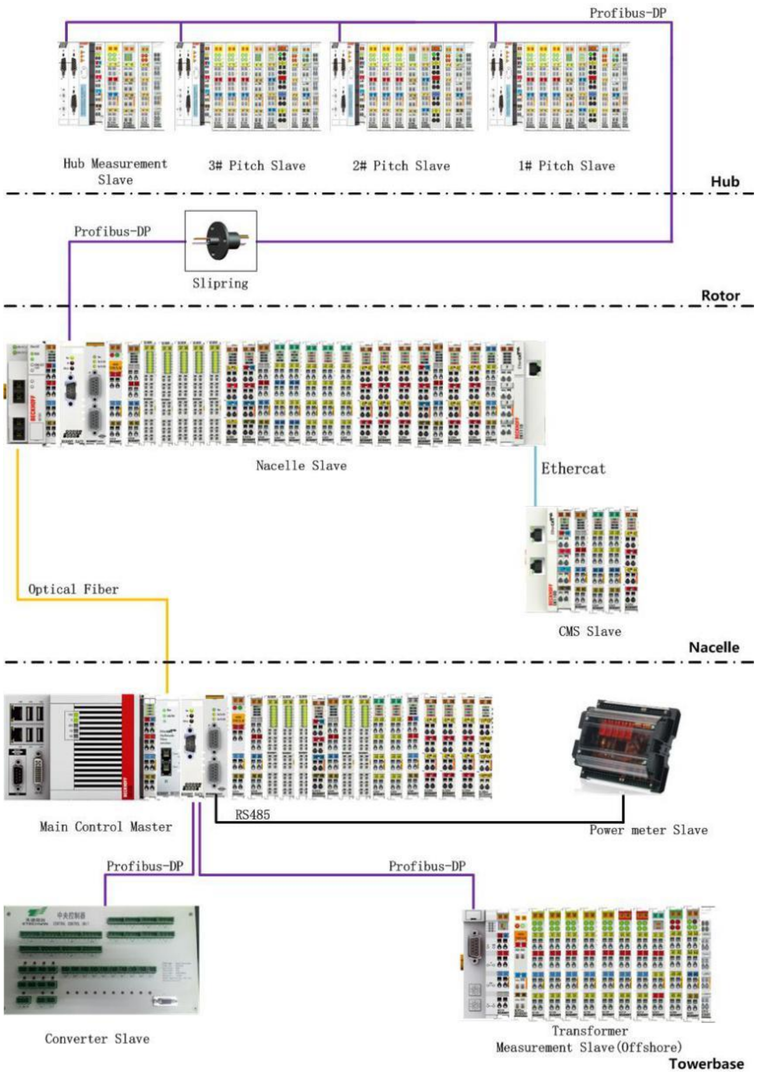


Figure 10 – Block diagram of control system of GW155-4.5 V40R02C100 direct-drive wind turbine

4.11.1 Main control cabinet

Main control cabinet is the main power distribution system of wind turbine, providing power to actuating mechanisms in wind turbine. It also collects data, processes input and output signals, decides logic functions, sends control commands to peripheral actuators, communicates with the top box and pitch box, receives various signals from top box and pitch system, as well as communicates with the central monitoring system and transmits data.

4.11.2 Top box

The top box collects signals from sensors and limit switch in the nacelle, collects and processes the signals of generator speed, wind speed, temperature and vibration.

It also drives the actuators such as hydraulic, lubrication and yawing mechanisms in nacelle to operate based on the control commands from the main control cabinet.

4.11.3 Pitch box

The pitch box is used to control the pitching of wind turbine, which means maintaining the rated output power by adjusting the pitch angle of blade. During system shutdown, it turns the blades to the feathering position and maintains wind turbine in stop or starting status.

4.11.4 Generator cooling box

Generator cooling box houses two independent frequency converters, which drive and control the operation of generator cooling fans.

4.11.5 Water cooling box

The water cooling box is used to control the operation of pumps, heaters and fans in water cooling system of converter according to the control commands from the main control cabinet.

4.11.6 Operation control

Operation control covers automatic start of wind turbine, grid connection of converter, dehumidification and heating of main parts, automatic track of wind direction by the nacelle, start and stop of hydraulic system, start and stop of heat exchanger, cable twisting and automatic untwisting, and automatic shutdown of wind turbine when the wind speed is lower than the cut-in wind speed.

4.11.7 Monitoring system

The monitoring system mainly monitors the voltage and frequency of grid, output current, power and power factor of generator, wind speed, wind direction, rotor speed, generator speed, conditions of hydraulic system and yawing system, temperatures of key equipment of wind turbine and ambient temperature. The controller controls the reliable operation of wind turbine according to the signals from the sensors.

4.11.8 Safety and protection system

The safety and protection system consists of protection for controller software, safe-chain independent of the controller, and hardware protections for individual components. Safe-chain protection acts in case of serious fault of wind turbine or as otherwise required.

4.11.9 Converter system

GW155-4.5 V40R02C100 direct-drive wind turbine is connected to grid through full-power converter and transformer. The main circuit of the converter system applies AC-DC-AC configuration and transmits the electricity generated by the permanent magnet synchronous generator to the grid via transformer. GW155-4.5 V40R02C100 direct-drive wind turbine is provided with two groups of converters in parallel. The topology of converters is shown below:

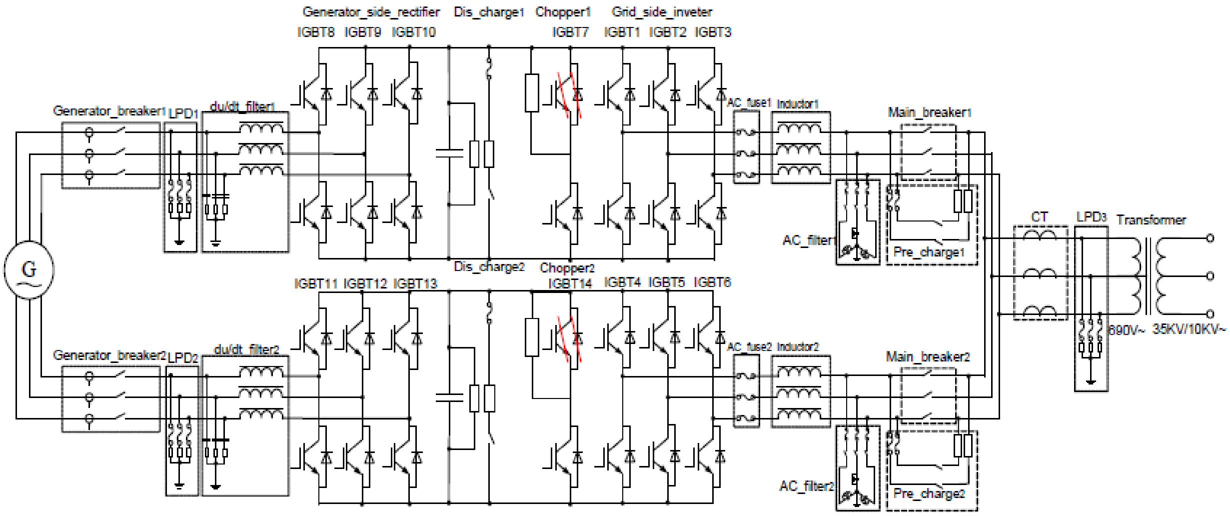


Figure 11 – Schematic diagram of main circuit of converter system of GW155-4.5 V40R02C100 direct-drive wind turbine

The full-power converter of GW155-4.5 V40R02C100 is well compatible with various kinds of grids conditions. In addition, it can achieve reactive power regulation and support the grid voltage in a wider range. Benefited from the advanced control strategy of the converter and the special design of the braking chopper module, wind turbine has a good low voltage ride through capability (LVRT Capability) to adapt to the grid fault and keep in connection with the grid for a certain period of time. Relying on the outstanding signal collection technology and interface technology, the electromagnetic compatibility of the converter system has been enhanced. For instance, the voltage sharing grounding method taken for the DC link effectively reduces the disturbance.

4.12 Pitch system

The main circuit of pitch control system is an AC-DC-AC circuit. The pitch motor adopts AC motor (see the figure below). Pitch speed or pitch motor speed is regulated by closed-loop frequency control. Compared with the pitch control system regulated by DC motor, this pitch system can avoid the disadvantages of DC motor such as wear of carbon brush, higher maintenance cost on the basis of ensuring good operation performance.

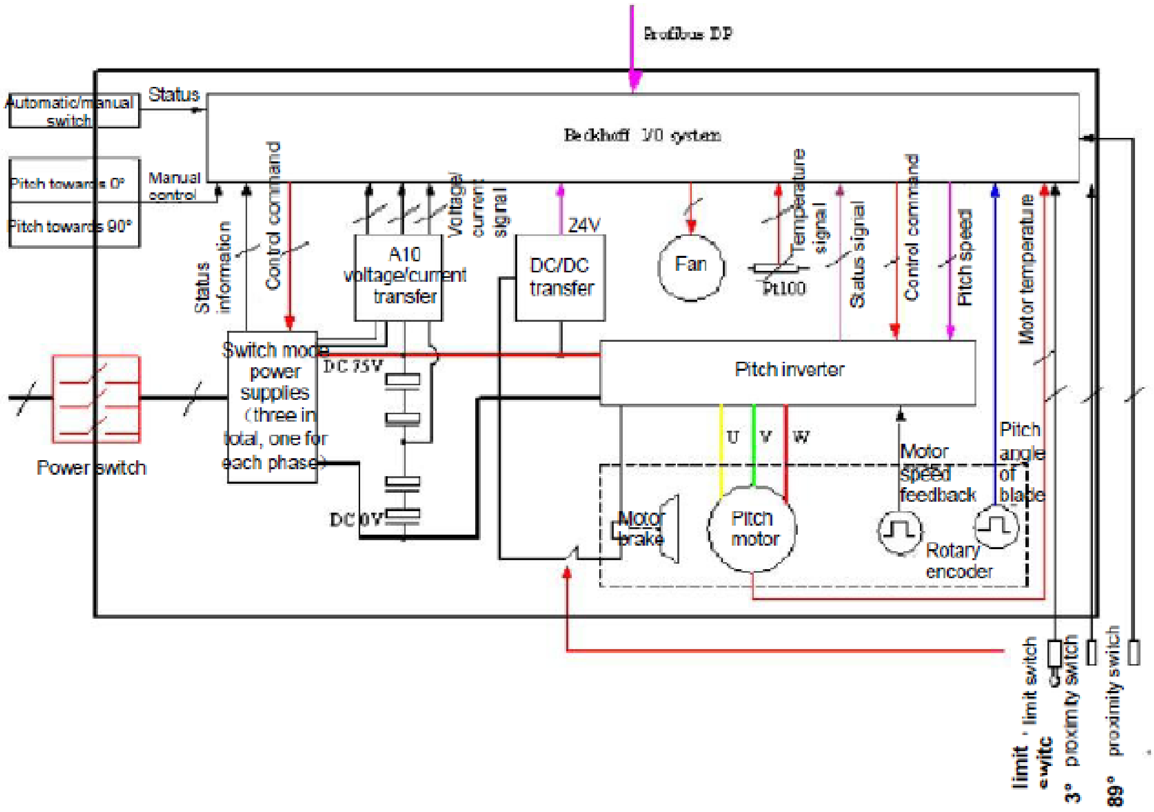


Figure 12 – Schematic diagram of pitch drive of GW155-4.5 V40R02C100 direct-drive wind turbine

The pitch box of each blade is equipped with a group of ultra-capacitors as backup power supply. The energy stored in the ultra-capacitors is adequate to feather the blades at the speed of 2°/s, while ensuring the normal operation of circuits in the pitch box. When power supply from the grid (supplied by slip ring) is lost, the backup power supply directly powers the pitch control system, ensuring normal operation of the whole pitch control system. To ensure the backup energy is enough, the pitch system monitor the voltage of ultra-capacitor. When the voltage of ultra-capacitor is below the setting value, the main control system will report a power-down fault of grid and stop wind turbine. Compared with the pitch system adopting sealed lead-acid batteries as backup power supply, the pitch system employing ultra-capacitor has the following advantages:

a) Higher charge current and shorter charge time;
b) The rectification module for converting AC to DC also acts as a charger, so no charge/discharge circuit is required;
c) The capacity of ultra-capacitor is less influenced by age increase;
d) Longer service life;
e) Maintenance-free;
f) Smaller and lighter.

4.13 Lightning protection

For towering objects in field, it is difficult to completely protect them from lightning strokes. The lightning protection system for wind turbine can lead the lightning current to the ground when wind turbine is struck by lightning to minimize the current flowing into equipment, protect equipment and personnel to the greatest extent and minimize losses. The lightning protection system of GW155-4.5 V40R02C100 wind turbine is designed following such principle. From blade tip to wind turbine foundation, all parts are provided with tight lightning protection measures. The lightning protection is designed according to LPL of protection as specified in IEC 62305.

The GW155-4.5 V40R02C100 wind turbine is divided into several EMC lightning protection zones according to applicable standards. The inside and outside of nacelle, tower and main control room can be divided into three zones: LPZ0, LPZ1 and LPZ2, as shown in Figure 13. In different lightning protection zones, different protection measures are provided, mainly including lightning receiving and conducting system, shielding, wiring, and equipotential bonding. These measures are designed by fully considering the properties of lightning. The division of wind turbine into lightning protection zones has been proved simple and effective.

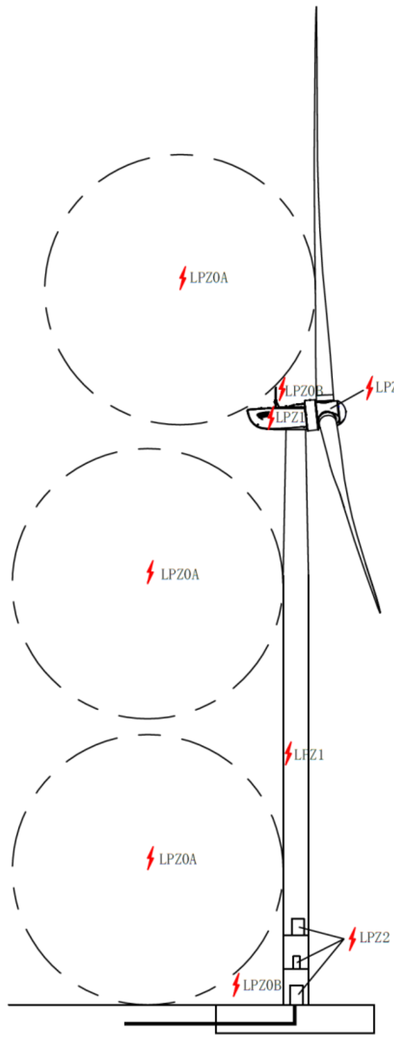


Figure 13 – Lightning protection system of wind turbine

The conductors embedded in blade lead the lightning current from the air termination system to the metal flange at the blade root and then to nacelle via hub.

Except for bolts, conductors are used for connecting the nacelle baseplate and upper tower tube, and each tower tube.

Lightning arresters are installed on the support of wind detection device on nacelle top to conduct the lightning current to the nacelle base through the ground cable in case of lightning strike, avoiding conduction of lightning current along the drive system.

All components inside the nacelle are connected through the ground cable to the nacelle base which is a spheroidal graphite iron casting. The ground cable should be short and straight where practical. Lightning current is led into the ground through tower, copper cables, and earthed foundation, as shown in the figure below.

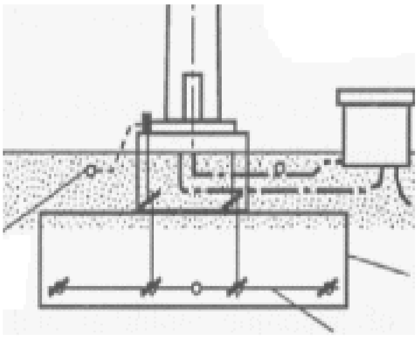


Figure 14 – Electrical connection of foundation

Designed according to GL code, the grounding system of wind turbine complies with IEC 62305. Grounding rings are provided for the foundation to allow for a grounding power frequency resistance of a single wind turbine no greater than 4Ω.This can further reduce the grounding resistance by extending the grounding network, so as to lead the lightning current to the ground and avoid dangerous overvoltage.

4.13.1 Lightning receiving and conducting system

As the uppermost part of wind turbine, blades are most likely to be struck by lightning, and they are one of the most expensive parts of wind turbine. Therefore, it is extremely important to protect the blades against lightning. The research results show that full insulation of blades cannot reduce the risk of lightning strike, however, on the other side, it will increase the severity of damage. In addition, in many cases, the back side of blade tip is struck by lightning.

The lightning protection of the blades is designed in accordance with IEC 61400-24 Wind Turbines—*Part 24: Lightning Protection*. A metal air termination system is installed at blade tip. A copper conductor is used to reliably connect the air termination system to the lightning lead on hub (see the figure below). According to IEC 61400-24, to achieve grade I lightning protection of wind turbine, the cross-sectional area of blade lightning protection copper conductor should not be less than $50mm^2$.

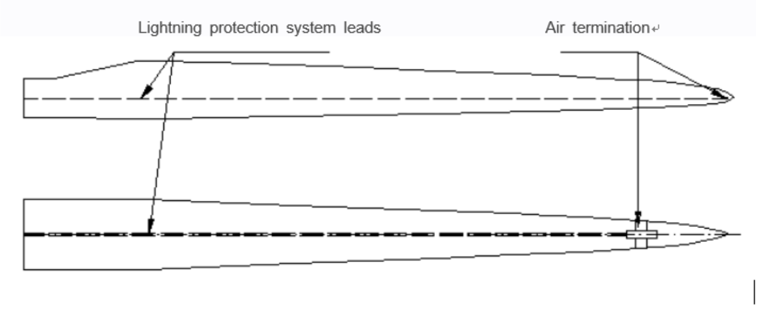


Figure 15 – Lightning protection system for blades

4.13.2 Overvoltage protection and equipotential system

The overvoltage protection and equipotential bonding in lightning protection system of GW155-4.5 V40R02C100 wind turbine conform to relevant provisions of IEC 62305. At zone boundaries, lightning and surge protective devices are provided to protect the active lines (including power supply lines, data lines, and measurement and control lines) against lightning.

To prevent lightning-induced damage, use a busbar to connect the metal framework, metal devices, and electrical and communication equipment in the nacelle with external conductors near the ground to make them have equal potential. Then connect them to grounding devices.

The lightning current collected at the nacelle base is transferred to the tower, and then to the grounding network via two APs located at the bottom of the tower.

4.13.3 Isolation protection

For the control system subject to damage caused by lightning-induced overvoltage, more rigorous isolation protection is provided for GW155-4.5 V40R02C100 direct-drive wind turbine:

a) The control cabinet is made of steel sheet to provide sound shielding effect;
b) Isolation transformer is provided for the control power supply;
c) Opto-isolator or varistor is provided at the input ports of sensors and computers to provide isolation protection;
d) The cables are well shielded when laid.

4.14 Monitoring system

The monitoring system of Goldwind wind turbine can be generally classified into central monitoring system and remote monitoring system. The central monitoring system consists of local communication network, monitoring computers, protection devices and central monitoring software. Its main functions serve to ease the centralized management and control of wind turbine by operators. The remote monitoring system consists of central monitoring computer, network equipment (router, exchanger, ADSL equipment and CDMA module), data transmission medium (telephone line, wireless network and Internet), remote monitoring computer, protection system and remote monitoring software. Its main functions serve to enable remote users to view the operation status and historical data in real time (see Figure 16 for the structure of monitoring system).

4.14.1 Local communication network

In the local communication network, wind turbines are physically connected by cables or optical fiber cables. The transmission medium is selected based on the geographical conditions of wind farm, wind turbine quantity, distance between wind turbines, distance between wind turbine and central monitoring room, project investment and basic requirements for communication rate. The network is available in chain, star, tree, and other structures. The specific connection mode should be determined according to the arrangement of wind turbines with consideration given to the convenience of site construction. See Figure 16 for the structure of monitoring system of wind farm.

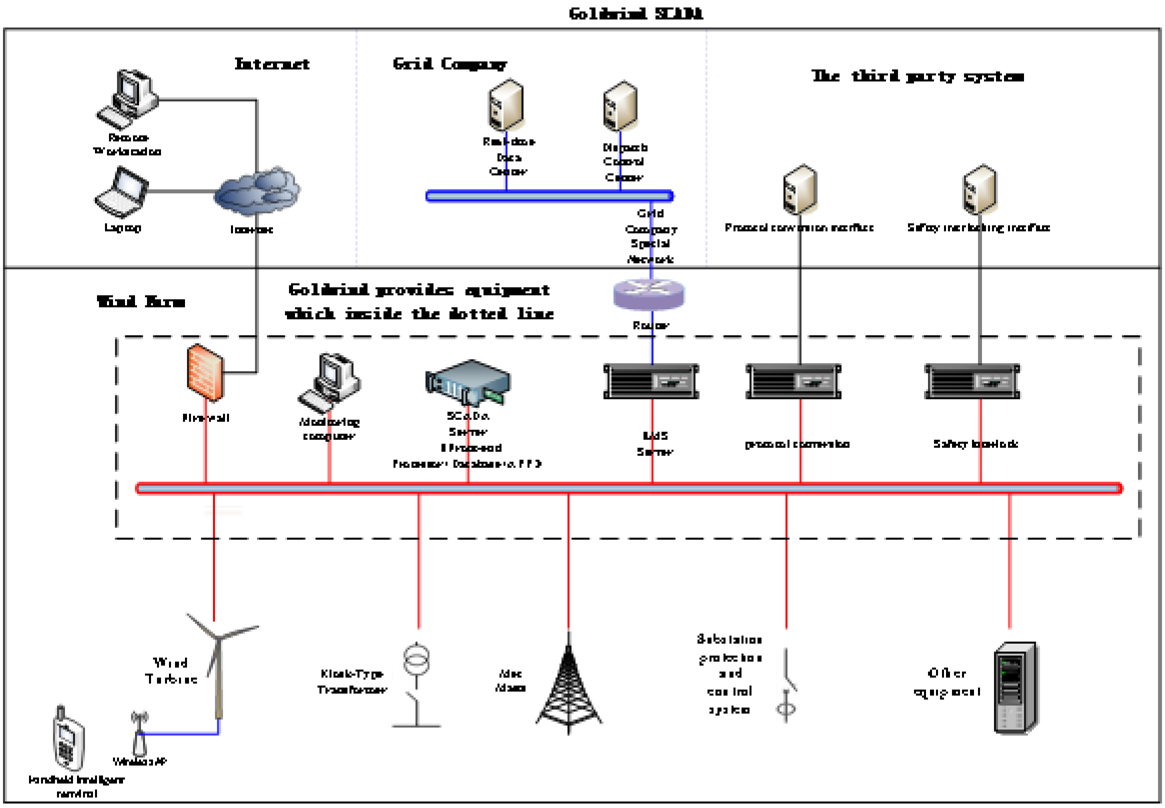


Figure 16 – Structure of monitoring system for GW155-4.5 V40R02C100 direct-drive wind turbine

4.14.2 Central monitoring software

The central monitoring system is a platform for personnel of wind farm to monitor and control wind turbine and obtain wind turbine data. Goldwind developed different central monitoring systems for different protocols according to owners' requirements. Its main functions are as follows:

a) Monitoring;

b) Control;

c) Recording and storage;

d) Alarm;

e) Permission setting (protection);

f) Plotting;

g) Reporting;

h) Printing;

i) System log and wind turbine control command log;

j) Wind turbine parameter setting;

k) Time synchronization of wind turbine.

4.14.3 Remote monitoring system

According to the remote data monitoring requirements of electric power industry, private network can be used as the transmission medium to ensure the data security. If network router and firewall are equipped, optical fiber, ISDN, ADSL, CDMA, GPRS etc. can also be used to connect the Internet, and VPN can be used to realize remote monitoring and control. In this case, remote monitoring computer becomes one client of the local communication network and is capable of remote monitoring of wind turbines. The system manager can set access authorities (especially control authority) for remote clients.

4.14.4 Remote monitoring software

The remote monitoring terminal is exactly the same as the central monitoring terminal with the remote monitoring function performed prudently in accordance with the operation and management rules of different wind farms. If remote monitoring function is enabled, it may be achieved by connecting VPN network, so that remote monitoring system has the same functions as central monitoring system.

4.14.5 EMC design

a) The design of EMC shall comply with DIN EN 61000-6-4 Electromagnetic Compatibility (EMC)—*Part 6-4: Generic Standards—Emission standard for Industrial Environments* and DIN EN 61000-6-2 Electromagnetic Compatibility (EMC)—*Part 6-2: Generic Standards—Immunity for Industrial Environments*.

b) The EMC shall be designed according to company standard Q/GW 201073-2014 *General Requirements of Electromagnetic Compatibility of Direct-drive Permanent Magnet Wind Turbine Generator System* and Q/GW 201083-2014 *Specifications for Design of Electromagnetic Compatibility Immunity of Wind Turbine Generator System*.

4.15 Grid connection

Wind turbines are each provided with one transformer to connect with grid. To save cost, two wind turbines can be provided with one transformer. The transformers are placed outside the tower, dominated by combined transformers, which feature advantages including high safety and reliability, advanced technical performance, low loss, easy installation and use, less maintenance, environment-friendly, simple structure, small size, combination design, and intelligent control. The power transmission circuit is connected with the low-voltage side of combined transformer via main switch for incoming lines and buried cables, with terminals Dyn11. See Figure 17 for the schematic diagram for grid connection. The switch cabinet on high-voltage side in the figure contains lightning protection devices.

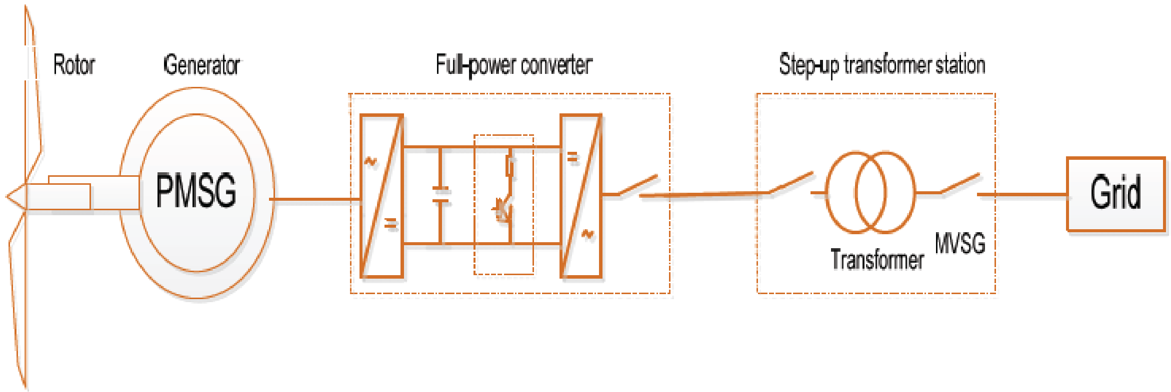


Figure 17 – Schematic diagram for grid connection of GW155-4.5 V40R02C100 wind turbine

In the power transmission circuit, transformer and medium voltage circuit breaker serves as both transformer and protector and it protects transformer from damage in case of faults in the line and grid. The grounding system is connected to flat iron via cables at the grounding point in electrical control cabinet. The galvanized flat iron is grounded at two points led from wind turbine foundation ring, thus connecting with the grounding system of prefabricated transformer. The grounding resistance is lower than 4Ω. Neutral line of lower-voltage cable is connected with the grounding point in box, forming NPE system.

The start-up and grid connection process of wind turbine is described as follow: Wind direction sensor detects the wind direction and enables yawing controller to operate, aligning wind turbine with wind direction. Meanwhile, wind speed is being measured (The generator rotor rotates as long as there is wind. Rotor flux rises with the increase of wind speed, i.e., the terminal voltage of generator grows gradually). When wind speed exceeds cut-in wind speed, the control of full-power converter makes the system output voltage equal to grid voltage and makes the system frequency suitable for grid connection. At the same time, the phase difference between grid voltage and generator's terminal voltage is also being measured. When such difference becomes zero (zero crossing point), the power element IGBT of converter is conducted, thus achieving grid connection (all these conditions in GW155-4.5 V40R02C100 wind turbine can be realized through converter system, which makes the wind turbine's output power reach grid connection conditions through phase loop lock control and SPWM regulation).

5 Technical description of grid connection

5.1 Operating voltage range of wind turbine

Generally, wind turbine is connected to the grid of wind farm via booster transformer. In China, the rated voltage on high-voltage side of such booster transformer is 10 kV or 35 kV, which can be adjusted according to the local grid, and the transformer is capable of no-load voltage regulation. The voltage on low-voltage side of transformer, i.e., the rated outlet voltage of wind turbine is generally 690 V.

The grid voltage deviation range for GW155-4.5 V40R02C100 wind turbine to operate normally is ±10% of rated voltage(690V).

5.2 Wind turbine operating frequency range

The grid frequency deviation range within which GW155-4.5 V40R02C100 direct-drive wind turbine can operate normally are as shown in Table 3.

Table 3 –Permissible operating time of wind turbine under different grid frequency deviation ranges

System frequency range 50 Hz	Technical requirements	System frequency range 60 Hz
46 Hz-47 Hz	Wind turbine can operate for at least 0.2s each time.	55.2 Hz-56.4 Hz
47 Hz-47.5 Hz	Wind turbine can operate for at least 2s each time.	56.4 Hz-57 Hz
47.5 Hz-52.5 Hz	Continuous operation	57 Hz-63 Hz
52.5 Hz~53 Hz	Wind turbine can operate for at least 2s each time.	63 Hz~63.6 Hz
53 Hz~54 Hz	Wind turbine can operate for at least 0.2s each time.	63.6 Hz~64.8 Hz

Primary and secondary frequency response cabability is available on GW155-4.5 V40R02C100 wind turbine with the application of Goldwind VSG and EMP system. Wind farm according to droop curves to help control freqency by utilizing inertia of rotating blades and fast reponse of full pover converter of wind turbine.

5.3 Active power control of wind turbine

Goldwind GW155-4.5 V40R02C100 direct-drive wind turbine may achieve control of maximum output power and active power output rise rate of wind turbine through pitch system. The active power control of wind turbine supports online control at local end. In combination of Goldwind's energy control platform, online remote control of wind turbine by central control system may also be realized. In case of normal shutdown of system (wind speed reduces or shutdown command is received), wind turbine can shut down normally in the preset mode. In case of emergency shutdown of system (overhigh wind speed or internal fault of wind turbine), wind turbine can protect itself and shut down safely.

Taking control of the maximum output power of wind turbine for example, wind turbine can control its absorption of wind energy by controlling the pitch angle of blade and further control its output within the rated range from 0 MW to 4.5MW. The main significance of such function is to control the overall output of wind farm. In windy weather or at excessively high grid frequency, especially, the control of output of wind farm is combined with power system dispatch to ensure safe and steady operation of grid system.

Taking the power output change rate of wind turbine for example, wind turbine controls its power rise rate by controlling pitching speed, so that sharp increase of wind speed would not lead to surge of power of the whole wind farm. The significance of this function is to reduce the impact on grid system during start-up and operation of wind turbine and ensure steady operation of wind farm in power system. In the early stage of construction, the active power rise rate, power rise rate during startup, active power output recovery rate after elimination of system fault, and other rates of wind farm may be set according to the requirements of grid corporation.

5.4 Reactive power control of wind turbine

GW155-4.5 V40R02C100 wind turbine is connected with grid via full-power converter. Its reactive power regulation mode is similar to STATCOM and can achieve quick stepless dynamic regulation of reactive power. The basic information is as follows:

a) The default power factor of GW155-4.5 V40R02C100 direct-drive wind turbine as delivered is 1. When wind turbine generates electricity normally, the reactive power at generator terminal (i.e., 690 V outlet) is 0 kVar, the power factor of wind turbine remains at 1;

b) GW155-4.5 V40R02C100 direct-drive wind turbine is capable of reactive power regulation under rated voltage (50 Hz or 60 Hz), and such reactive power is mainly used to control and stabilize generator terminal voltage and give assistance to stabilize the voltage at the point of grid interconnection. See Table 4 below (the performance not consider the transformer and generator effections), two options could be selected by coustomers. If more reactive current is needed during low active power output stage, technical solutions could be provide after the confirmation between coustomer and Goldwind.

c) The reactive power regulation of wind turbine is in a dynamic and continuous manner. It supports remote online regulation, or automatic regulation may be conducted according to preset values;

d) Under default control mode, the power factor of wind turbine output terminal on the line side is 1. When wind turbine is under the control of VSG, wind turbine can absorb or supply reactive power based on grid requirements; if not necessary, wind turbine may not absorb or supply reactive power.

e) When system voltage fluctuation exceeds ±10%, wind turbine can enter voltage ride through status.

Table 4 – Electrical performance of wind turbine (1 of 2)

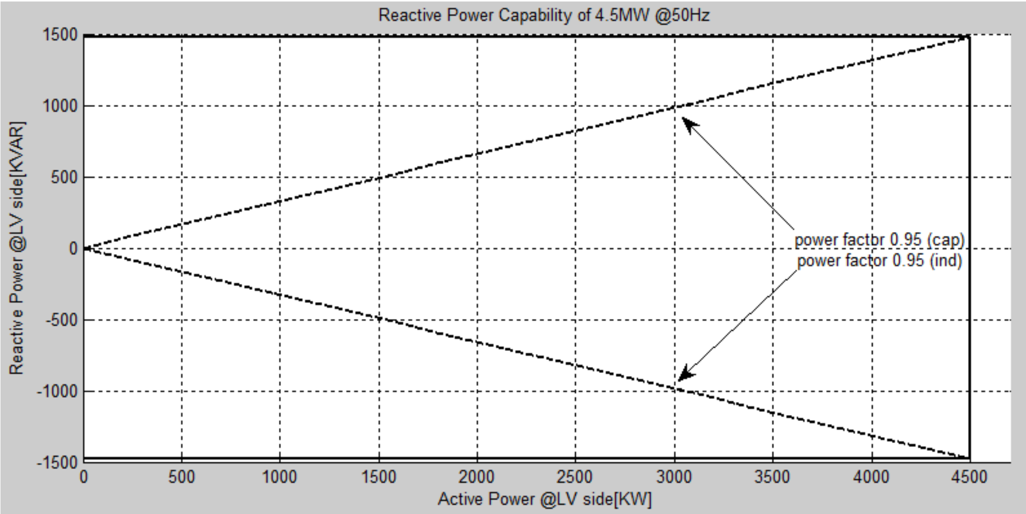
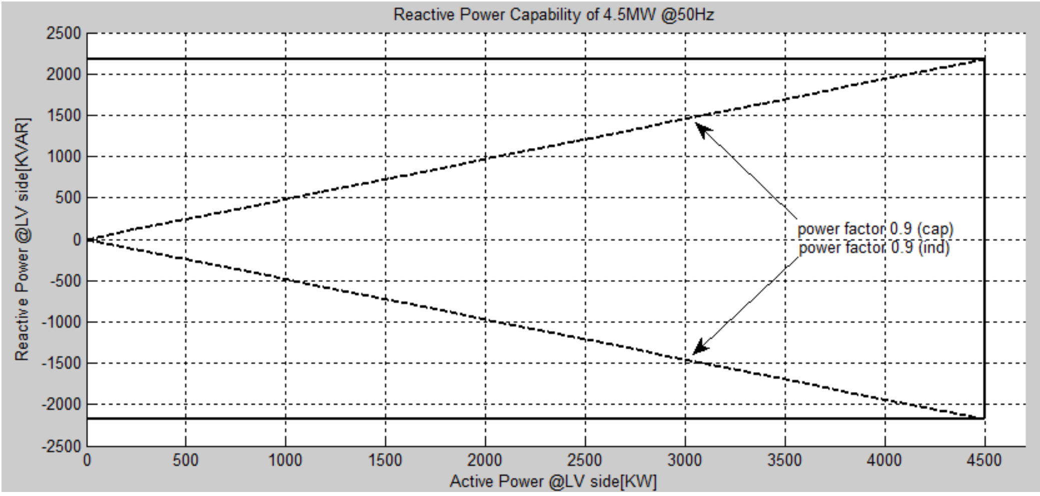
4500/50Hz (Option 1)	

Table 4 – Electrical performance of wind turbine (2 of 2)

4500/50Hz **(Option 2)**	

5.5 High and low voltage ride through of wind turbine

Goldwind 4.5MW wind turbine is capable of staying connected when terminal voltage deviations (both symmetrical and unsymmetrical voltage faults) are within protection setting outside normal operation state as shown in Figure 18:

During voltage fault ride through, Goldwind 4.5MW wind turbine is capable to provide reactive current support within its technical design limitation to help grid voltage recover and the full power converter reacts in response to positive sequence voltage. In default setting, turbine doesn't provide reactive current during unsymmetrical LVRT.

After the fault, active power output of wind turbine will recover to per-fault active power output state instantly or at a certain speed upon request (default setting – Pn recovery in 1 second).

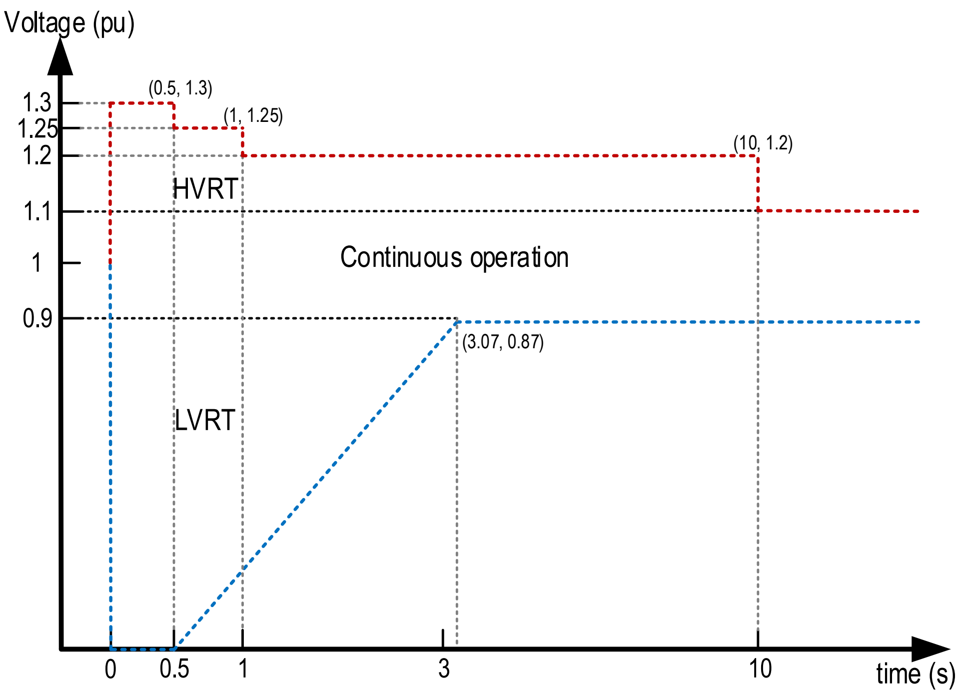


Figure 18 – HVRT and LVRT curve of wind turbine

Note: The DC part of main circuit of converter is equipped with full-power energy brake system. The power supplies to the controllers and key electric elements (circuit breaker in main circuit, etc.) are provided with UPS support systems, which ensure that the control system of wind turbine continues operating normally even if the grid has a fault.

5.6 Power quality of wind turbine and wind farm during operation

The power quality of wind turbine and wind farm during operation shall comply with IEC 61400-21 *Power Quality Requirements for Network Connected Wind Turbines*.

6 Adaptability of wind turbine to environment

6.1 Operating temperature

Considering the significant difference of ambient temperature in different areas, Goldwind optimized the working temperature of wind turbines and developed a series of wind turbines for different working temperature ranges, including wind turbines for normal temperature, low temperature. (See Table 5 for the detailed working temperatures of wind turbine).

Table 5 – Working temperature range of wind turbine

Wind turbine type	Wind turbine type
Operating temperature (°C)	-20~45（>35 derating）
Survival temperature (°C)	-30~50

6.2 Altitude

See Table 6 for the altitude applicable to Goldwind wind turbine.

Table 6 – Applicable altitude range for Goldwind wind turbine

Wind turbine type	Standard type
Altitude of area where wind turbine is installed (m)	0~2000 (included)

Goldwind developed high-altitude wind turbine for the environmental characteristics of high-altitude area (above 2000 m). In terms of insufficient output of wind turbine due to rarefied air in high-altitude area, Goldwind ensures annual power generation of wind turbine from the aspects of control strategy and blade type selection. In terms of electrical system insulation and dissipation problems due to low atmospheric pressure in high-altitude area, Goldwind optimized and upgraded the electrical equipment of wind turbine, including generator, converter system, pitch system, and main control system, thus ensuring the high reliability of high-altitude wind turbine.

6.3 Rate power

The wind turbine rate power can be adjust according the local ambient and customer reqirements.

The following picture shows the generator rate power change with the altitude and ambient temperature.

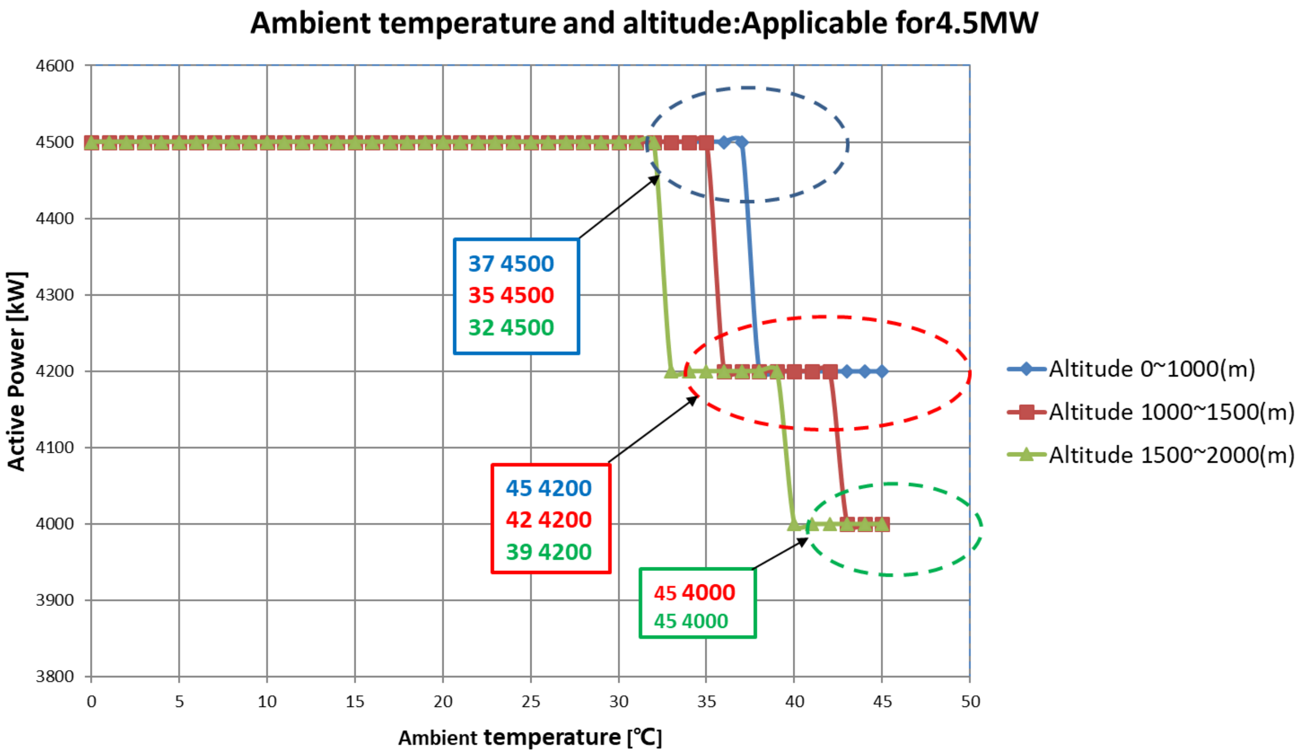


Figure 19 – Ambient temperature and altitude applicable for GW155-4.5 V40R02C100

7 Technical parameters of wind turbine

See Table 7 for main technical parameters to Goldwind wind turbine.

Table 7 – Main technical parameters of GW155-4.5 V40R02C100 wind turbine（1 of 3）

No.	Item	Unit	Parameters
1	Basic data of wind turbine		GW155-4.5 V40R02C100
1.1	Manufacturer/Model		Xinjiang Goldwind Science & Technology Co., Ltd/GW155-4.5
1.2	Rated power	kW	4500
1.3	Class of wind zone		IIC/IIIB
1.4	Power regulation method		Pitchable and Variable speed
1.5	Diameter of rotor	m	155
1.6	Hub height	m	110, 95, customized according to the project
1.7	Cut-in wind speed	m/s	2.5
1.8	Rated wind speed (static)	m/s	10.8
1.9	Cut-out wind speed (average value in 10 minutes)	m/s	24 (According to project, customized 26m/s cut-out wind speed)
1.10	Extremely high wind speed (average value in 3 seconds)	m/s	52.5
1.11	Design service life	year	⩾ 20
1.12	Availability	%	⩾95%
2	Blades		
2.1	Manufacturer/Model		GW76
2.2	Material of blade		fibre reinforced epoxy resin
2.3	Rated linear speed of tip	m/s	77
2.4	Swept area of wind turbine rotor	m^2	18869

Table 7 – Main technical parameters of GW155-4.5 V40R02C100 wind turbine（2 of 3）

3	Generator		
3.1	Manufacturer		Xinjiang Goldwind Science & Technology Co., Ltd.
3.2	Generator type		Permanent magnet
3.3	Rated power	KW	4800
3.4	Rated voltage	V	760V±3%
3.5	Rated current	A	2077
3.6	Protection class		IP54
3.7	Lubrication method		Grease filling/automatic lubrication system
3.8	Grease model		Mobil 460WT
3.9	Rated speed and speed range	Rpm	9.5(rated speed) 6~9.5
3.10	Insulation class		F
3.11	Number of poles		112
3.12	Frequency range of generator	Hz	5.6～8.867
4	Converter (full-power conversion)		
4.1	Number of phases	phases	3
4.2	Converter type		Full power converter
4.3	Apparent power	kVA	5155
4.4	Rated output voltage	V	690
4.5	Rated output current	A	4314 (power factor 0.9)
4.6	Output frequency variation range	Hz	50/60
4.7	Protection class		IP54
4.8	Rated power factor		±0.9
4.9	Modulation mode of power elements		SVPWM
4.10	Modulation mode of power elements		IGBT
4.11	Control mode of converter		Digital vector control
5	Main shaft		
5.1	Manufacturer		SINOJIT/NISSEI/Longma
6	Main bearing		
6.1	Manufacturer/Model		SKF/NTN/Timken/FAG
7	Braking system		
7.1	Primary braking system		Brake achieved by feathering of three blades
7.2	Secondary braking system		Rotor braking (for maintenance)

Table 7 – Main technical parameters of GW155-4.5 V40R02C100 wind turbine（3 of 3）

8	Yawing system		
8.1	Type/design		Motor drive/four-stage planetary gears for speed reduction
8.2	Control		Active alignment with wind/computer control
8.3	Yawing speed	°/s	0.28
8.4	Type of yawing bearing		Four-point contact ball bearing with outer ring
8.5	Lubrication method		Automatic grease filling (585k Plus)
9	Hydraulic unit		
9.1	Manufacturer/model		Hawe
10	Electrical control system		
10.1	Type of control unit		PLC
10.2	Control type		Distributed control
10.3	Main switch cabinet		Beijing Etechwin Electric Co., Ltd.
10.4	Control type of bus		EtherCAT
11	Lightning protection		
11.1	Lightning protection design criteria		In accordance with IEC 61400/-24-2010, IEC 62305 and in compliance with GL Guideline for the certification of wind turbines
11.2	Lightning protection measures		Electrical lightning protection, lightning protection at blade tips, etc.
11.3	Grounding resistance of wind turbine	Ω	If the average earth resistivity $\rho \leqslant 3000\ \Omega$.m , the power frequency grounding resistance R for each wind turbine should be less than 4 Ω.
12	Tower		
12.1	Type		Steel tower, Concrete tower
12.2	Anti-corrosion class		According to Q/GW 201175-2019 onshore wind turbine general anti-corrosion specification of tower

7.1 Specifications of main materials

See Table 8 for specifications of main matericals to Goldwind wind turbine.

Table 8 – Specifications of main materials

Component	Material	Material properties
Nacelle base	QT400-18AL	EN 1563 EN-GJS-18-LT
Hub	QT400-18AL	EN 1563 EN-GJS-18-LT
Generator rotor and stator shafts	QT400-18AL	EN 1563 EN-GJS-18-LT
Main bearing	Bearing steel	SKF/NTN/Timken/FAG
Yawing gear	42CrMo	EN10083-1
Yawing brake disc	Q345C	EN10025-2

7.2 Design standard for wind turbine vibration

See Table 9 for the design standard of vibration to Goldwind wind turbine.

Table 9 – Design standard for wind turbine vibration

Component	Allowable vibration limits
Nacelle	≤ 1.176 m/s^2

7.3 Dimensions and weights of major components

See Table 10 for the dimensions and weights of major components.

Table 10 – Dimensions and weights of major components

Components	Dimensions mm	Weight kg
GW76 blade	76200×4800	21900±3% of each
Rotor (excluding blades)	5339×4709×5073	40100±3%
Nacelle	10146×4460×4426	41400±3%
Generator	Φ5490×2696	100000±5%