CITEL

SURGE PROTECTION FOR WIND TURBINES

www.citel.fr

LIGHTNING PROTECTION PRINCIPLES FOR WIND TURBINES

Wind turbines are generally located at exposed areas for better wind conditions, onshore wind turbines usually locate at prominent terrain like mountains region and offshore locate at coastwise, by the effect of location and the height of structure, wind turbines have higher annual estimated number of lightning strikes according to lightning location system.

In addition,due to the electric field distortion at the top of the blades as placed in certain geographical areas, particularly during winter, it may be relevant to increase the upward stream which will be established to connection with downward leader, so this initiative upward process will increase the possibility of lightning strike.

Adverse factors for wind turbines caused by lightning strike like blades damage and electrical and control systems malfunction, repairing work and downtime loss cost much by replacing the damaged components, especially for offshore wind turbines.

Compared to direct lightning strike, indrect effects from lightning strike is the greater threat to the failure cost for windturbines, it mainly causes by:

- Upstream leader developing from the wind turbines;
- lightning flashes attaching to the wind turbines;
- indirect lightning flashes (i.e. effect through LEMP of lightning flashes not affecting the wind turbines directly).

All types of lightning flashes generate lightning electromagnetic impulses (LEMP) on the connecting cables between the equipment, and the damage is mostly caused by insufficient impulse withstand voltage level of equipment components.

LEMP is the main threat leads to malfunction and failure for electrical and electronic systems, now the most efficient measures to reduce loss towards LEMP is using coordinated SPD protection consists of a set of SPDs properly selected.

STANDARDIZATION

The basic lightning protection principles for wind turbine should comply with international standards IEC 61400-24:2019 and IEC 62305 series.

IEC 61400-24 applies to lightning protection of wind turbine generators and wind power systems,IEC 62305 mainly introduce the basic lightning protection principles.

PROTECTION PRINCIPLES FOR WIND TURBINES

Lightning protection level(LPL)

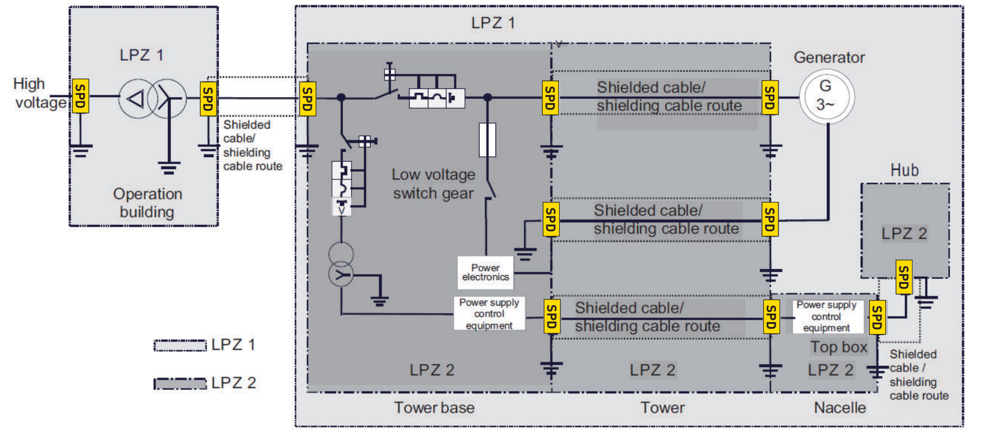
For the purposes of IEC 62305, four lightning protection levels (I to IV) are introduced. For each LPL, a set of maximum and minimum lightning current parameters is fixed.

According to IEC 61400-24, all subcomponents shall be protected in accordance with LPL I unless a detailed and documented risk assessment demonstrates that a protection level less than LPL I is economically optimal for specific wind turbines and locations.

Maximum values of lightning parameters according to LPL

First positive impulse			Lightning protection level LPL			
Current parameters	Symbol	Unit	1	2	3	4
Peak current	I	kA	200	150	100	
Impulse charge	Q_{SHORT}	C	100	75	50	
Specific energy	W/R	MJ/Ω	10	5,6	2,5	
Time paramerters	T_1/T_2	μs/μs	10/350			

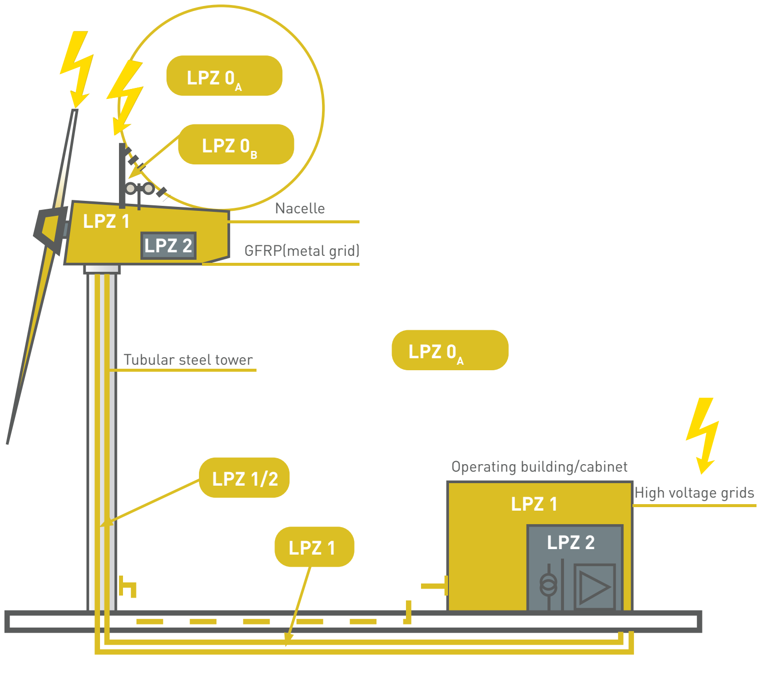
LIGHTNING PROTECTION ZONE(LPZ)



Surge protection measures (SPM) system by division of the electrical system according to protection zone

Protection measures such as LPS, shielding wires, magnetic shields and SPD determine lightning protection zones (LPZ), details information refer to IEC 62305-1 clause 8.3.

For wind turbines, typical LPZ methods applied to ensure that components, for example blade parts, machinery, electrical systems or control systems, can withstand the effects of the magnetic and electrical fields, as well as the full or partial lightning current that may enter the zone in which the components are placed.



Tower

A tubular steel tower, as predominantly used for large wind turbines, usually fulfil the dimensions required for down conductors stated in IEC 62305-3 and can be considered an almost perfect electromagnetic shield Faraday cage, as it is electromagnetically almost closed both at the interface to the nacelle and at ground level, so in most cases the internal of the tower can be defined as LPZ1 or LPZ2.

Nacelle

Nacelles with GFRP cover or similar should be provided with a lightning air-termination system and down conductors forming a cage around the nacelle. In most cases, no matter the GFRP meshes width and materials, LPZ1 is suitable to define.

Operating building/cabinet

The operating building or cabinet with shielding effect shall be divided into LPZ1, if the distribution cabinet is installed inside the tower , it can be divided into LPZ 2.

Hub

The hub can be divided into LPZ1 zone due to its good shielding performance, and the pitch system always installed in this zone. As the pitch system takes power from the slip ring of generator and the wires passes through LPZ1/2 zone), Type 2 SPD is generally applied.

TYPICAL REQUIREMENTS FOR WIND TURBINES

HARMONIC OSCILLATION

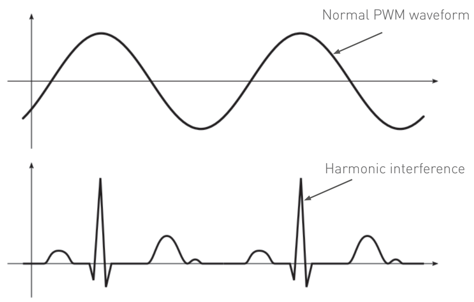
The generator side of convertor(usually in tower base) output pulse width modulation (PWM) connected to the generator(usually in nacelle) through a long cable normally more than 100 meters. Due to the distribution characteristics like distributed inductance and coupling capacitance from the long cable, the over-voltage will generate high frequency damped oscillation at the rotor side of the generator (e.g. in the figure below).

Double-fed induction a synchronous generator (DFIG) harmonic oscillation mainly exist in two position:
- The generator side of convertor
- The rotor side of generator

As EN 50539-22 describes at the rotor side of generator for DFIG, typical repetitive transients superimposed on the operating voltages could reach 2.95kV(L-L), and dV/dt of repetitive transients superimposed on normal operating voltage is 1.4kV/μs, so SPD with varistor will activate frequently by this disturbance and certainly will reduce the expectation of SPD life. If we choose higher U_c to cover the peak value the harmonic interference, the U_p of SPD may exceed the rated impulse withstand voltage of generator.

CITEL have developed several dedicated SPD type for the application of harmonic oscillation, based on CITEL highenergy gas tube to realize good tolerance performance on the harmonic oscillation, the related product like DU33S-1000G/WD and DAC50S-31-760-2600DC applied to the generator and convertor respectively.

Typical harmonic interference from PWM



THE EQUIPMENT&SYSTEM IMMUNITY LEVELS

For AC ports(230V/400V) and DC ports(50V) suggests refer to IEC 61400-4-5 and IEC 60664-1, for telecommunication ports should refer to ITU-T K.21, K.20 and IEC 61400-4-5.

The equipment to be protected, the immunity of which has to be determined by applying the methods in accordance with IEC 61000-4-5.

The protective effect of the SPDs has to be determined with test procedures in accordance with IEC 61643-11.

HIGH VOLTAGE RIDE THROUGH CAPACITY (HVRT)

Wind turbines should have the fault voltage ride through capability which contains low voltage ride through and high voltage ride through capability, HVRT is a typical TOV which will exert on the SPD in DFIG&PMSG generator, and it may pose a threat to the safe operation of semiconductor devices at the rotor side of the convertor, which may lead to crowbar action frequently or even burn the convertor.

CITEL SPD conform to HVRT requirements for wind turbines

NO.	Operating Voltage	HVRT requirements	CITEL SPD type	SPD parameter	Conclusion
1	400/690Vac	400*1.1=440Vac continuous	DAC50S-30-530	U_c=530Vac continuous	Satisfied
2		400*1.3=520Vac 500ms		U_T=700Vac withstand	Satisfied
3		400*1.1=440Vac continuous	DAC50S-31-760-2600DC	U_c=800Vac continuous	Satisfied
4		400*1.3=520Vac 500ms		U_T=2200Vac 5s withstand	Satisfied
5	230/400Vac	230*1.1=253Vac continuous	DAC50S-40-440	U_c=440Vac continuous	Satisfied
6		230*1.3=299Vac 500ms		U_T=580Vac 5s withstand	Satisfied

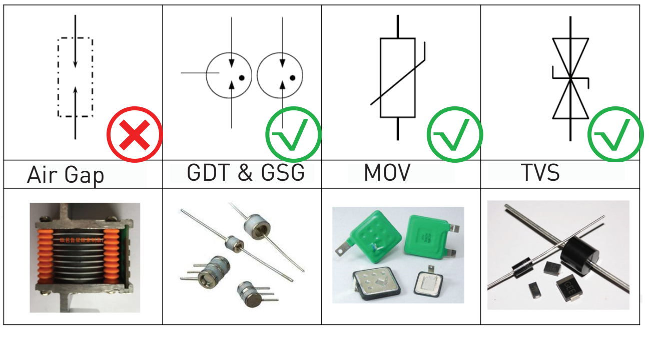
ENVIRONMENTAL STRESSES

SPDs shall withstand the environmental stresses conform to the installation place such as:

- Ambient temperature
- Humidity
- Corrosive atmosphere
  - -Offshore salt-mist test
- Vibration and mechanical shock:
  - -Frequency: 0,1 Hz to 10 Hz;
  - -Acceleration: 0,5 m/s^2.

Follow the consideration of environment of offshore and high attitude wind turbines, GB/T 51308-2019 and GB/T 37921-2019 have described open air gap type SPD is not permitted used in offshore wind turbines as the effect of the humidity and saltmist environment.

Open air gap type SPD should not applied to offshore wind turbines



SPD KEY PARAMETERS' REQUIRE-MENTS

U_c

For most application,select the proper vaue for U_c should conform to IEC 61643-12 depends on power supply systems (TT,TN,IT) and U_{ref}, but for wind turbines application, two more points should be considered:

- U_c should be selected to sustain the stress of repetitive transients superimposed on the operating voltages.
- For offshore wind turbines,as the high cost for mainte-nance, SPD need to withstand high TOV but not change into the safe failure mode,so higher U_c is required.

U_p

According to IEC 60664-1, a electrical equipment have defined the value of recommended rated impulse withstand voltage U_w, so the U_p for selected SPD must not exceed the U_w as IEC 60664-1 shows in F.1.

U_w=2.5kV is suggested for 400/690Vac power supply systems while for 230/400Vac system, U_w=1.5kV is required to protect the electrical and electronic equipments.

In case for generator and converter application, as most time using the "3+1" combination SPD to match the har-monic oscillation, as a consequence, U_p is always higher than the U_w as the GDT effect by front-wave discharge voltage(low energy).

I_{imp} and I_n

A possible way to increase the service lifetime of SPDs in the case of a high number of lightning attachments is to select SPDs with higher discharge current and impulse current parameters than given in IEC 60364-5-53 as below.

Discharge and impulse current levels for TN systems given in IEC 60364-5-53

SPD Class I- I_{imp}(10/350)
12.5kA for each mode of protection
SPD Class II- I_n(8/20)
5kA for each mode of protection

Circuits connected to equipment located inpro-tective zone LPZ0$_B$ might be regarded as partic-ularly exposed circuits, in such cases, it is rec-ommended that SPDs within wind turbines fulfil the requirements as below.

Exposed circuits requirements for TN systems given in IEC 60364-5-53

SPD Class I- I_{imp}(10/350)
25kA for each mode of protection
SPD Class II- I_n(8/20)
15kA for each mode of protection

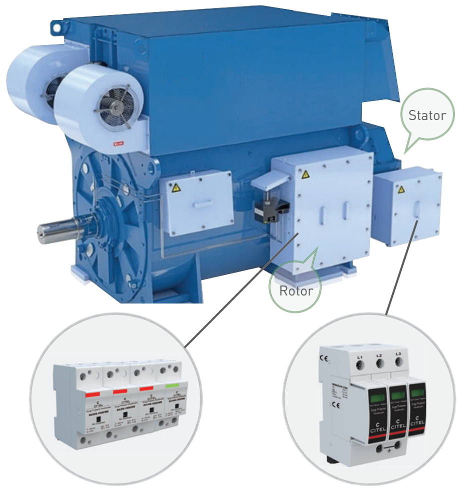
RECOMMENDED SPD SELECTION RULES

GENERATOR

The generator always located in nacelle, double fed induction generator (DFIG) are the most common type, but with the development of permanent magnet technology, permanent magnet synchronous generator (PMSG) takes up an increasing proportion. The DFIG excitation power accepted on rotor side, and the power output is always on stator side. The operating voltage is usually 400/690Vac.

For DFIG rotor side 400/690Vac system, U_c=1000V is recommended to realize the high voltage tolerance and TOV withstand level to prevent harmonic oscillation, which will accelerate the aging of SPD and affect its service life. Typically solution is using "3+1" combination based on high energy gas tube technology, at least U_t=2.2 kV should be declared to prevent the varistor operate frequently within the unstable voltage, so the rotor windings of generator can be protected when spike voltage comes. DU33S-1000G/WD equipped with three varistor module plus one "GSG" module to applied to rotor side application.

For DFIG stator side, following the stator voltage, typically U_c=660V or 760V is required to protect 400/690Vac power systems, DAC50S-30-760 with locking feature for better vibration withstand, and U_p=3.5 kV is suitable for rated impulse withstand voltage according to IEC 60664-1. For PMSG stator side pretection should refer to the DFIG rotor side requirements.



DU33S-1000G/WD

Protection for rotor winding of generator with "3+1" combination

DAC50S-30-760

Protection for stator side of generator with new DAC range

CONVERTOR

The convertor cabinet is generally located at base of tower, operating voltage is generally 690Vac but now 1140Vac or even more higher voltage is common for new offshore wind turbines with higher unit capacity. The PMSG wind turbines converter has a larger capacity (typically 120% rated capacity is required), while DFIG generally has a 25% rated capacity, convertor protection is generally divided into rotor side and power grid side.

For rotor side 400/690Vac systems of convertor, the fluctuation voltage is usually caused by PWM current control, so higher U_c and TOV withstand capacity is required. As the isolation effect for the power grid convertor, type 2 SPD with "3+1" combination is typical solution for TN-C system, DAC50S-30-760-2600DC is dedicated designed for rotor side of convertor, compact design(72mm) and with extremely high energy gas tube ensure fine protection.

For power grid side of convertor, it depends on the real situation on the scene, some case high-duty type SPD is required for LEMP happen frequently area, and even I_{imp} is required if customers have not install primary SPD in operating building or cabinet which is always outside of the tower, but typically type 2 SPD follow IEC 60364-4-44 I_n=15kA is enough. DAC50S-30-530 with locking feature for better vibration withstand, and U_p=2.5kV is enough to protect sensitive equipments like IGBTs as IEC 60664-1 requires.

DAC50S-30-760-2600DC

Protection for rotor side of convertor with "3+1" combination

DAC50S-30-530

Protection for power grid side of convertor with "3+1" combination

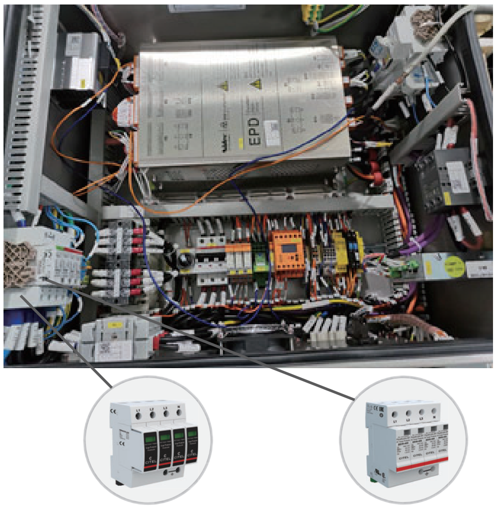
RECOMMENDED SPD SELECTION RULES

PITCH SYSTEM

Pitch system is generally installed in hub, with 230/400Vac operating voltage, communication systems usually contain Profibus, Can and RS485 systems. Due to the hub have good shielding effect, and take power from slip ring in the nacelle, so wires is usually installed in LPZ1 or higher shielding protection zone, type2 is applied to pitch system.

As the power driver and the communication wires is sensitive with the LEMP, so coordination with upstream SPD should be considered and U_p below 1.5kV is recommended. DAC50S-40-320 is recommended for pitch power TN system to withstand the vibration and perfect protection effect.

Signaling lines between the pitch(hub) and main control system(nacelle) usually in LPZ 1, U_c depends on operating voltage like U_n=24dc, DLA/DLU range have covered wide U_n scope, and suitable for LPZ0B to LPZ2 or higher zone application.



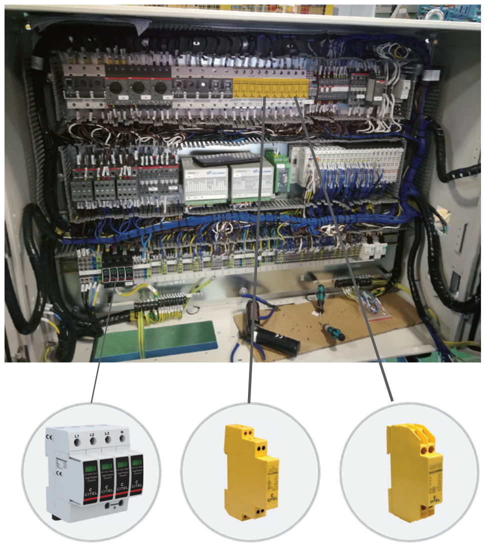
DAC50S-40-320 DS44S-440

Protection for pitch system

MAIN CONTROL SYSTEM

The main control cabinet is generally located in the nacelle and serves as the power supply and exchange information with equipment. It contains power supply and signalling system, and the operating voltage is generally 230/400Vac, both three-phase and single-phase power supply systems is existed.

The meteorological equipment (anemometer) supplied by the main control system is generally located in $LPZ0_B$, and the shielding cables passes through LPZ1. Main control system have lots of IT systems for signaling processing, converter, actuators are communicating with main control network by long shielding cables, LEMP caused by indirect lightning strike refer to IEC 61643-21. DLA/DLU range is applied to 1&2 pairs, common and differential mode is suitable, with hot-plugging and with two reliable grounding ways to discharge current, risk can be accepted even if the cables pass $LPZ0_B$ like meteorology station area as these ranges I_{imp} could reach to I_{imp}=5kA.



DAC50S-40-320 DLA Range control system DLU Range control system

Protection for main control system

OPERATING BUILDING/CABINET

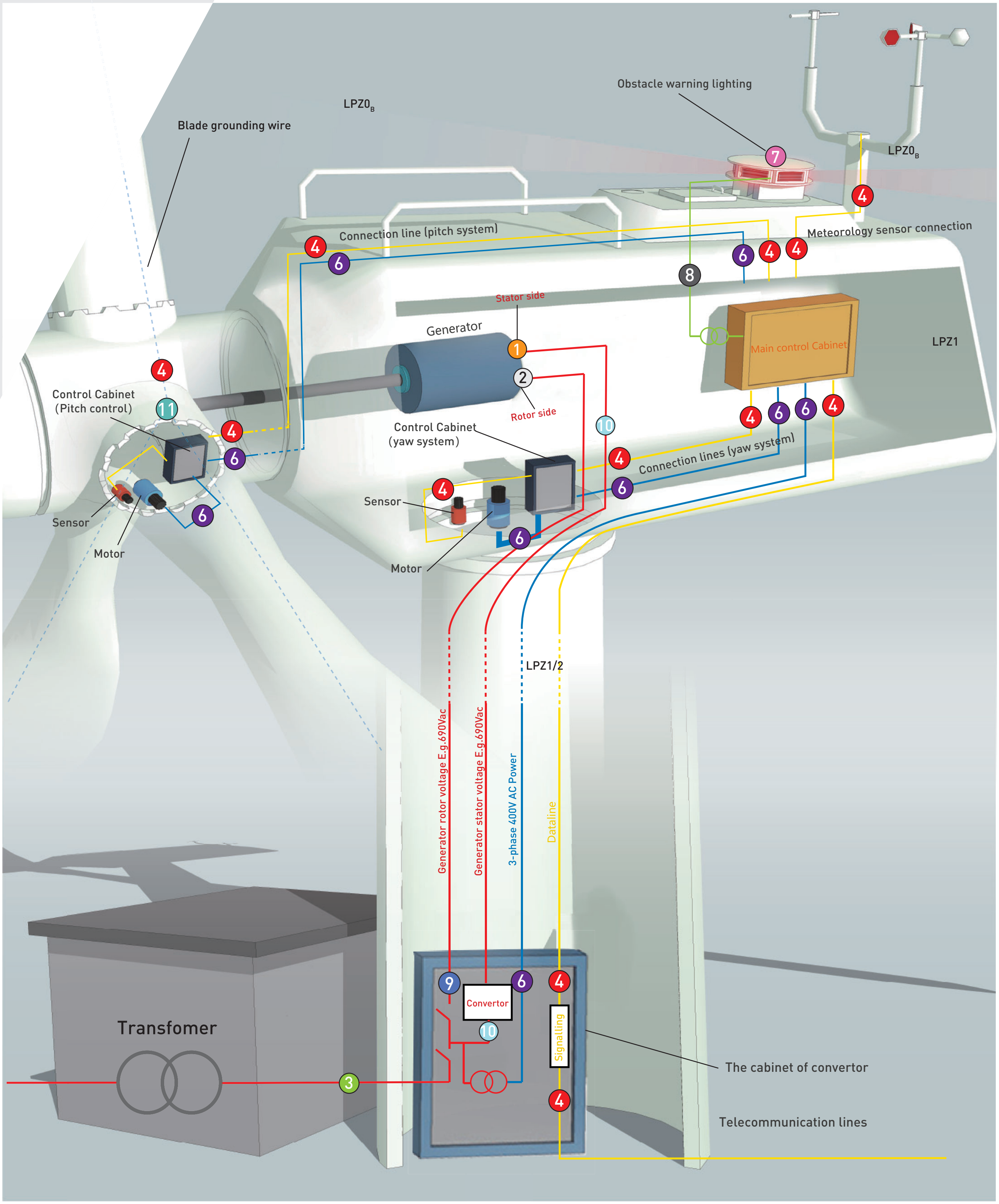
The operating building/cabinet is generally located outside the tower (some cases inside the tower). The primary side of the transformer is generally equipped with a high-voltage lightning arrester, and the secondary side voltage is mostly install type1 SPD with I_{imp} parameter due to the lightning direct risk of external wires and other ancillary facilities,I_{imp} value should conform to IEC 61400-24 and IEC 60364-4-44.

DS253VG-690/WD with four "varistor+GDT" module to realize good performance on lower U_p and better coordination with downstream SPD in the tower by using CITEL dedicated "VG technology", furthermore, none leakage current and high TOV withstand performance can well match 400/690Vac TN-C system.

DS253VG-690/WD DS150E-480

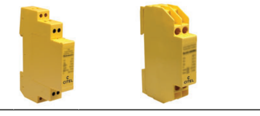
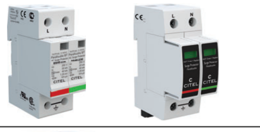
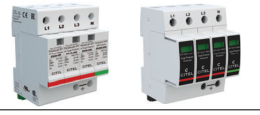
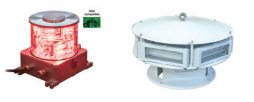
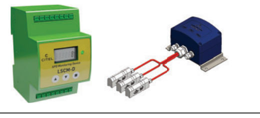
Protection for operating building/cabinet

SURGE PROTECTION FOR DOUBLE-FED INDUCTION ASYNCHRONOUS GENERATOR(DFIG)



CITEL

CITEL SPD SOLUTION FOR WIND TURBINES

NO.	Equipment to be protected	CITEL solution	Picture	I_{imp}/I_n by pole	Characteristics
1	Generator: stator side Convertor: rotor and grid side	DU33S-1000/WD DS41S-1000		I_n: 15kA/20kA	$U_c \geq$ 1000Vac High TOV withstand
2	Generator: rotor side Convertor: rotor side	DU33S-1000G/WD DS43S-690/100G		I_n: 15kA	High energy GSG technology $U_c \geq$ 1000Vac Apply to harmonic oscillation
3	Operating building/cabinet Convertor:grid side	DS253VG-690/WD DS150E-480		I_{imp}: 25kA/15kA	High exposure area High energy MOV/GSG tech.
4	Main control system Pitch system Convertor	DLA Range DLU Range		I_{imp}/I_n: 5kA	CM/DM mode Protection 1/2 pairs Apply to $LPE0_B$-2 or higher zone
5	Pitch system Main control system Convertor	DS42S-320/G DAC50VGS-11-320		I_n: 20kA	VG Technology(DAC50VG) $U_p \leq$1.5kV Locking feature for DAC
6	Main control system Pitch system	DS44S-400/G DAC50S-31-440		I_n: 20kA	TT power supply system High TOV withstand Locking feature for DAC
7	Top of nacelle	Obsta Obstacle warning lighting		/	Long life High surge withstand
8	Main control system Meteorology power supply	DS230-48DC DDC30S-20-65		I_n: 15kA	48Vdc system Extreme low U_p Locking feature for DDC
9	Convertor: rotor side	DAC50S-31-760-2600DC		I_n: 20kA	Apply to harmonic oscillation Locking feature Compact design (72mm)
10	Convertor: power grid side	DAC50S-30-660 DS73RS-600/YG		I_n: 20kA/30kA	High TOV withstand High discharge capacity Locking feature for DAC
11	Pitch system in the hub	LSCM LSC-B		I_{max}/I_{imp}: 100kA/50kA	Smart lightning current detection 24Vdc/230Vac optional