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Protection Measures on Wind Turbines against Lightning Strikes

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Abstract. The major renewable energy sources can be considered wind, solar, hydro, biomass, geothermal and tidal. The adaptation of more renewables in European Union (EU) lowers the dependence on fossil fuels while energy production is getting more sustainable. Wind energy is the significant contributor on achieving the committed EU 2020 goals while the penetration of wind power plants follows an increasing trend in annual basis. Wind turbines of power plants are usually installed on high altitude areas where wind conditions have been proved that wind is sufficient for such projects. The installation altitude usually exceeds 1000m causing these structures vulnerable to lightning strikes. The lightning activity of an area has to be considered once a wind power plant is going to be installed. Additionally a wind turbine has to be designed and manufactured according to relevant IEC standards and special attention has to be given to the components which are most vulnerable like the blades and the nacelle. In the current paper will be discussed the effect and the potential disturbances that a lightning strike can cause to a wind turbine and also basic protection measures will be presented which allow the wind turbine to be effectively protected against lightning strikes.

Key words

Blade, grounding, lightning, LPZ, receptors, tip conductive area.

1. Introduction

Wind power plants (WPP) are installed on high altitude and isolated areas. The topography layout of such areas is exposed to lightning strikes. In case in such areas wind turbines are about to be installed, these will become the preferable point of attack for lightning strike. Thus, the smooth operation of wind turbines which are installed in the geographical polygon of such areas is about to be challenged during lightning storms. Polygon is the area that a wind farm is allowed to be constructed. The wind turbines are structures with total height that can exceed 100m and thus are required special protective measures in case of lightning strikes. The wind turbine lightning protection system (LPS) shall be reliable in order to be avoided major damages on vital components. LPS shall ensure uninterrupted power production and low maintenance costs thus higher availability of the wind turbines and income for the investor. The wind turbine protection measures are related with the most exposed parts which are the blades, the hub and the nacelle. Apart from these it is required lightning protection of other components like anemometers, tower (which usually acts as down conductor), while internally are required equipotential connections with all electrical components. The grounding system of the wind turbine foundation is one of the important parts of the lightning protection system since it dissipates the lightning current. In the current paper are presented basic ways for wind turbine protection against lightning strikes emphasizing to the grounding system which spreads the wind turbine lightning current and earth fault currents which are related with safety. For that specific reason of safety, grounding system shall be designed in such way in order to ensure that the step and touch voltages are within the allowed limits which are defined in the relevant standards.

2. Description of the problem

Wind turbines are usually installed in high altitude areas like the large majority of greek projects. The greek wind farms are usually installed at high altitude and mountainous areas and thus are vulnerable to lightning strikes. The lightning activity in Greece is depicted in Fig.1 [1]. In this map are depicted the isoceraunic levels and are mentioned the thunderstorm days per year. In western, eastern and central Greece are reported the higher numbers of thunderstorms per year. The activity is getting lower at southern areas. Due to the fact that wind turbines are structures of high height these become consequently the desired point for a lightning in case this is about to hit the specific areas. A severe lightning strike can cause damages to basic external components (blades, nacelle) or internal ones like generator and controllers. The problem of reliable protection of a wind turbine gets more complicated considering that both nacelle and blade can rotate depending on the wind speed and direction. Grounding system as mentioned before is also part of wind turbine LPS and has to be designed and constructed in a way that ensures equipment reliable operation and live beings safety. The areas where wind turbines are installed are of poor soil conditions since these are rocky and soil improvement is required in order to be secured compliance with international standards which require grounding impedance of less than 10Ω [2] and local ones [3].

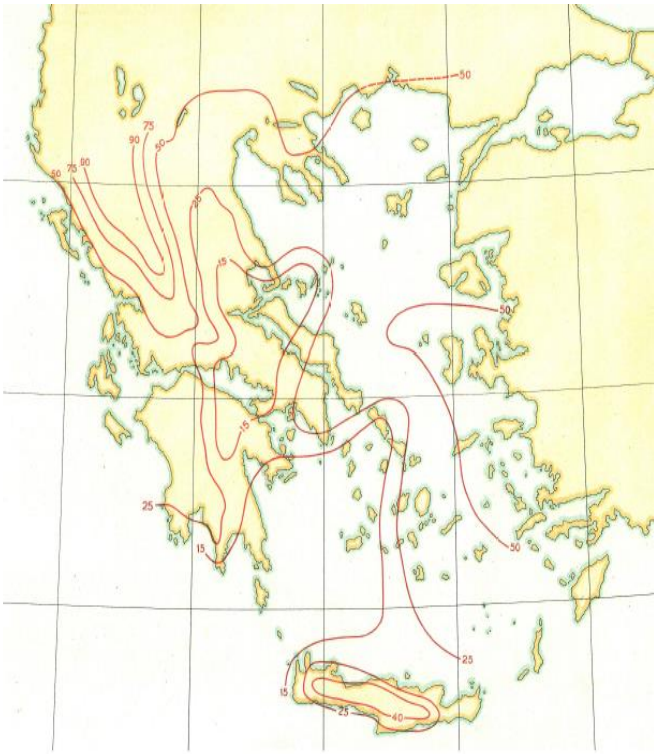

Fig. 1. Greek isoceraunic map [1].

3. Disturbances caused by lightning strikes

The presence of large scale wind farms is noticed since beginning of 2000. Wind turbine industry has made significant steps of product development leading to taller structures which can exceed even the 130m. The increase of wind turbine height causes these more vulnerable to lightning strikes especially for these that are installed at areas of high lightning activity. The disturbances that can be noticed are provided hereto.

A. Blade hits due to lightning strikes

The most exposed external component of a wind turbine is the blade which has also high probability to be affected by lightning. The problems that can be caused by lightning strikes are hits on blade surface as it is depicted in Fig.2 to severe blade damages. The consequences of a lightning hit depend on the lightning current characteristics (e.g. current peak value). The blade which is shown in Fig.2 is unaffected by lightning since the receptor has absorbed the lightning current.

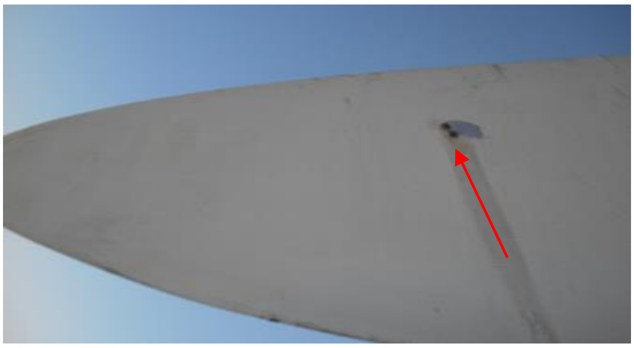

Fig. 2. Lightning hits on blade receptor.

B. Lightning hits on the nacelle

The nacelle and its components have less probability than the blade to be hit by lightning strike but there are reported lightning incidents. The most vulnerable components of the nacelle externally are the aviation light, the anemometer and the wind vane. In Fig.3 is shown the nacelle area that can be affected by a lightning strike and this backwards.

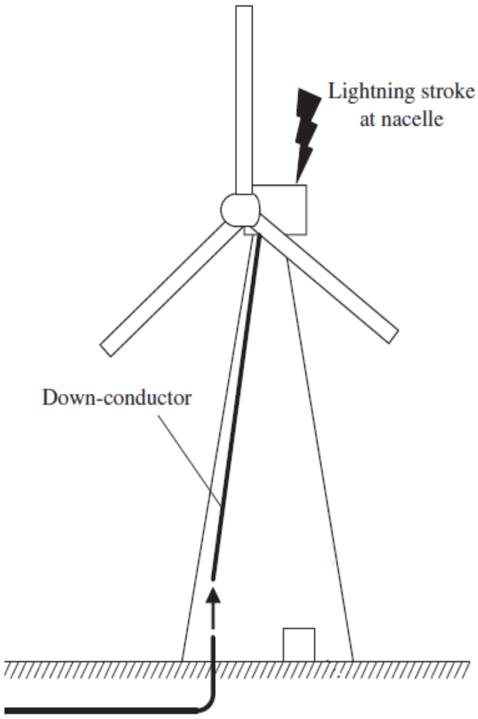

Fig. 3. Example of nacelle lightning strike on nacelle [3].

These components are exposed to lightnings and their operation is very important for the wind turbine smooth operation. The aviation light is required to be under continuous operation as per ICAO regulations [4]. The anemometer and wind vane are critical devices on the nacelle related with the reliable and safe operation of the wind turbine. The performance of the wind turbine depends on the measurement and feedback signal coming from the anemometer to the controller.

C. Disturbances on the electrical equipment

A lightning flash can cause irregularities apart from the external components to the internal also. The ones that can be affected are the ones installed in the nacelle of the wind turbines. For that purpose, it is required special protection measures like surge arrestors and equipotential connections as minimum for the generator, the transformer (if installed in the nacelle) and the gearbox if this exists. Special protection has to be provided to the electronic systems and controllers since are related with the wind turbine reliable operation. In case of a critical sensor failure it is possible the wind turbine to be stopped under emergency and on-site troubleshooting to be required in order to be put back in normal operation.

4. Wind turbines lightning protection measures

For the reliable protection of a wind turbine various factors shall be assessed and combination of protection measures is required. Once a wind turbine is hit by lightning it is of high importance the lightning current to be led to the earthing system in short time in order the effect to be minimized. The lightning protection measures which are presented hereto are based on IEC62305 [5-7] and IEC61400-24 [2] while are expected to be applied by the manufacturers. Protection of external components is based on air-termination, down conductor and grounding system. As internal equipment is considered the one installed inside the WT like generator, transformer, gearbox (if exists), controllers etc. Protection of wind turbines against lightnings is based on lightning protection zones (LPZ) concept as shown in Fig.4 [2]. This concept includes a reduction of the conducted and radiated interferences at boundaries down to agreed values.

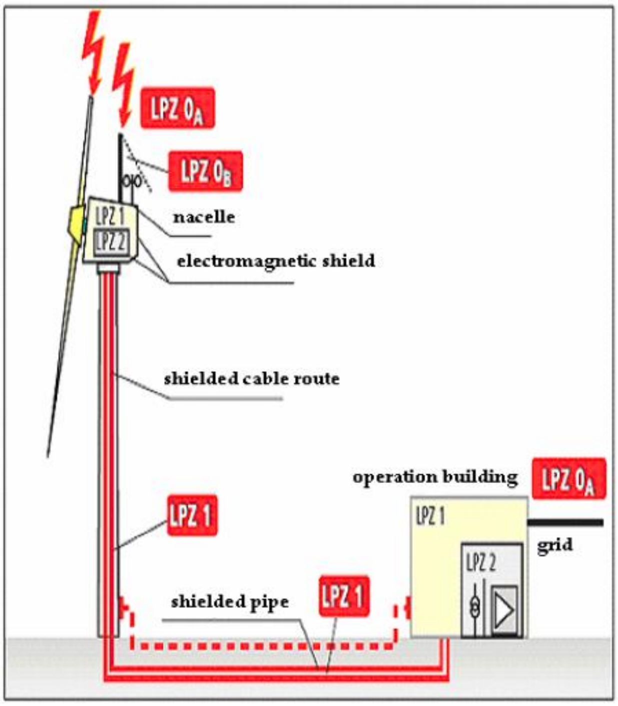

Fig. 4. Lightning Protection Zone concept [3].

A. Blade hits due to lightning strikes

Blades are the most vulnerable part of a wind turbine and most exposed one. Blade tip, depending on its position, can be the highest point of a wind turbine and therefore is at high risk during thunderstorms. The tip of the blade can be higher than 160m above ground level depending on the wind turbine model. A strike on the blade can cause blade damage and endanger personnel who may be inside the wind turbine. The current ways for blade protection is either through the installation of a steel receptor at the tip of the blade or with the construction of the tip with conductive material e.g. aluminium. In both cases there is a wire along the blade which connects the lightning protection components of the tip with the blade root. As regards to the blade design with receptors, considering that a blade has radius of minimum R=25m, the receptors are installed, depending on the design of the blade and to the wind turbine manufacturer, along the blade. The number of the receptors depends on the length of the blade. Example of receptor installation is shown in Fig.5 and the receptor concept in Fig.6. The blade consists of a conductive wire mounted inside the blade backbone (spar) which connects the receptors with the root of the blade and then with nacelle lightning protection system. This method provides protection of the blade since the possible direct lightning strike at the blade is led through the embedded cable to the root of the blade and the lightning current is injected in the nacelle equipotential bonding. Then, the lightning current is dissipated through the down conductors to the foundation grounding system which is the last point of the lightning protection system. By this way the lightning current is led to the earth in a controlled way [3]. Depending on the design of the blade there cases that the tip consists of an extended conductive area which is connected with the blade internal wire.

Fig. 5. Blade receptor.

Both designs have the same performance during lightning strikes while the capturing characteristics of receptors for both blade types (receptors and tip conductive area) do not differs so much based experiment held at the Shiobara Testing Yard of CRIEPI [8]. In Fig.7 is shown the way that the conductive part of the blade is constructed and the connecting wire with the root. The radius of the conductive material depends on the blade length and its design properties.

B. Protection of nacelle equipment

The impacts coming from lightning hit on a wind turbine are not only in the blades but also on the nacelle components. The exposed parts of the nacelle are the anemometer and the obstruction light. These are exposed to direct strikes. The protection of anemometer and aviation light is implemented with the use of lightning Franklin rod for the aviation light and conductive material for the anemometer. The connection with internal bonding of the nacelle is done with the use of flexible copper cable. In Fig.8 is shown the lightning protection system of both components.

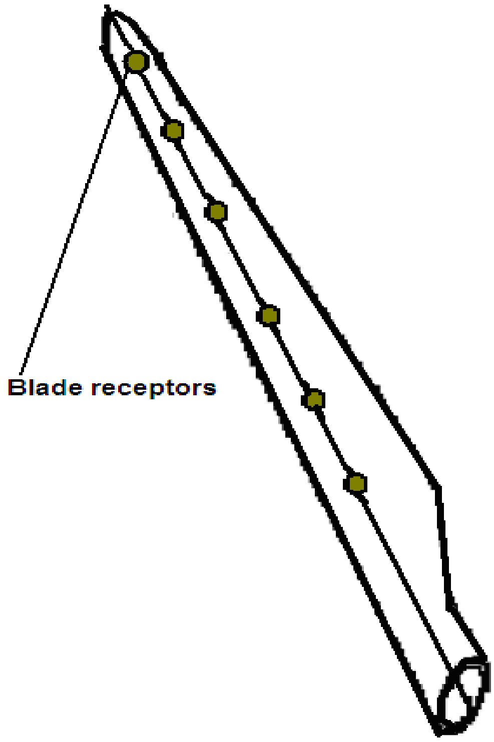

Fig. 6. Blade receptors and internal connection wire [3].

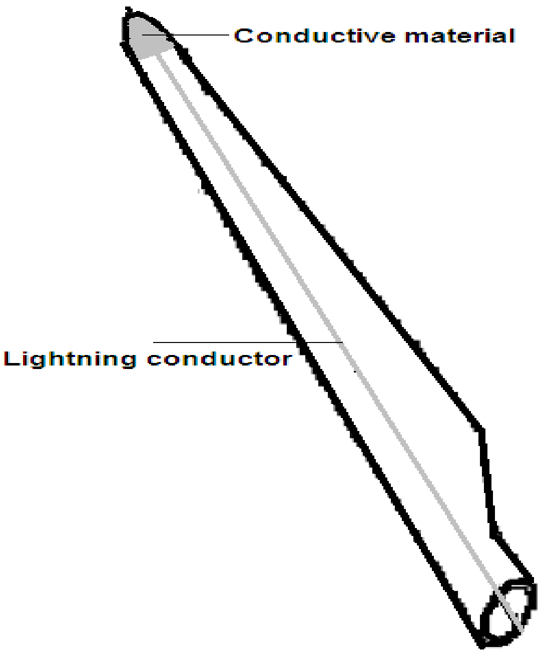

Fig. 7. Blade conductive area and internal connection wire.

Fig. 8. Anemometer and aviation light LPS.

Aviation light and anemometer are important components which are installed outside the nacelle. Inside the nacelle are installed the vital components of a wind turbine. The most important ones are the main shaft, the gearbox whenever exists, the generator, the power converter and the controller. The protection of the last will be presented to the following section. Based on the fact that the function of each component is vital for the reliable operation of the wind turbine it is essential the protection of these due to discharges caused by the lightning current. For this purpose there is equipotential connection of the components and there are mounted surge arresters in order to absorb the lightning current and to prevent discharges at an uncontrolled way internally in the nacelle. The lightning current that is inside the nacelle bonding at most of the wind turbine models is conducted to the tower via slip ring system on the yaw gear rim. Then cables or the tower itself depending the design can lead the lightning current to the earthing system.

C. Surge protection of wind turbine electronic devices

The operation of the wind turbine is based on continuous control devices, sensors and controllers which regulate the function of vital components like blades, nacelle orientation, electrical generator rotational speed etc. So it is essential to protect the electronic equipment against lightning incidents which may cause damage to them. The basic method is the use of equipotential bonding and overvoltage protection. This internal design assists on minimizing damages and/or interference of electrical-electronic components inside the nacelle and at the bottom of the wind turbine. Furthermore there are used surge arresters (varistors) which have high capacity to absorb the lightning current or to protect against overvoltages.

D. Foundation Grounding system

The foundation grounding system or earthing system as referred in technical literature is the last part of the wind turbine lightning protection system. It is considered as external protection measure. The grounding system is optimizing the dissipation of the lightning current into the ground and reducing step and touch voltages once it is properly designed. The last point is critical for human beings which are close to the wind turbine. The stationary earthing resistance should be in accordance with the IEC standards [2] and local requirements. In Greece the Greek Standardization Organization, ELOT, suggests 10Ω as maximum earthing resistance [3,9].

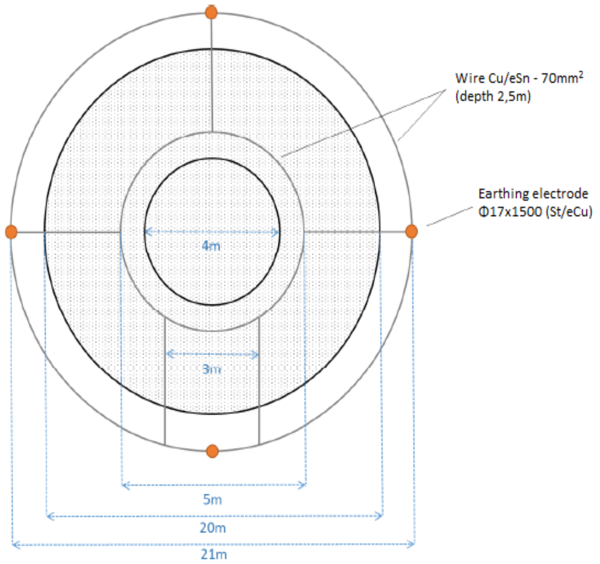

Fig. 9. Example of WTG foundation grounding (planview) [13].

The value of the ground resistance depends on the site and soil conditions. For that reason the rocky grounds need more complicated system compared to the soil with sand. Thus, the actual soil conditions can introduce the need of complicated grounding system. Wind turbine manufacturers require compliance of the foundation grounding systems with the relevant IEC or IEEE standards. A common acceptable solution for foundation grounding is the use of earthing electrodes usually constructed by copper with cross-section of 50mm^2 or aluminium with cross-section 75mm^2 or higher. The number and the length of the electrodes are based on studies regarding the earthing system total design. In case the earthing value is higher than 10Ω as per [3], additional measures are required. One way is the use of copper strip around the foundation. This strip can be mounted on the reinforcement of the foundation section so with the injection of the concrete there is a lower value. An overview drawing of a typical earthing system is shown in Fig.9 and a typical section plan in Fig.10. In order to be ensured the protection of personnel due to step and touch voltages it is required for each wind turbine specific study to be executed in order to be assessed the grounding system safety. Life beings can be under risk of step and touch voltages even when individual wind turbine grounding system is less than 2Ω [5]. Furthermore, the interconnection of all wind turbines grounding systems have a positive influence on the performance of the wind turbine that has been hit by lightning strike [10]. Interconnection of wind turbines grounding systems in a wind power leads to reduction of the current peak values [5]. Interconnected earthing systems contribute on the reduction of ground potential rise (GPR) of neighboring wind turbines [11]. Apart from these measures and depending on project specific soil conditions and the grounding study may be required an extra layer of grovel on each wind turbine foundation for safety purposes in case of earth fault currents.

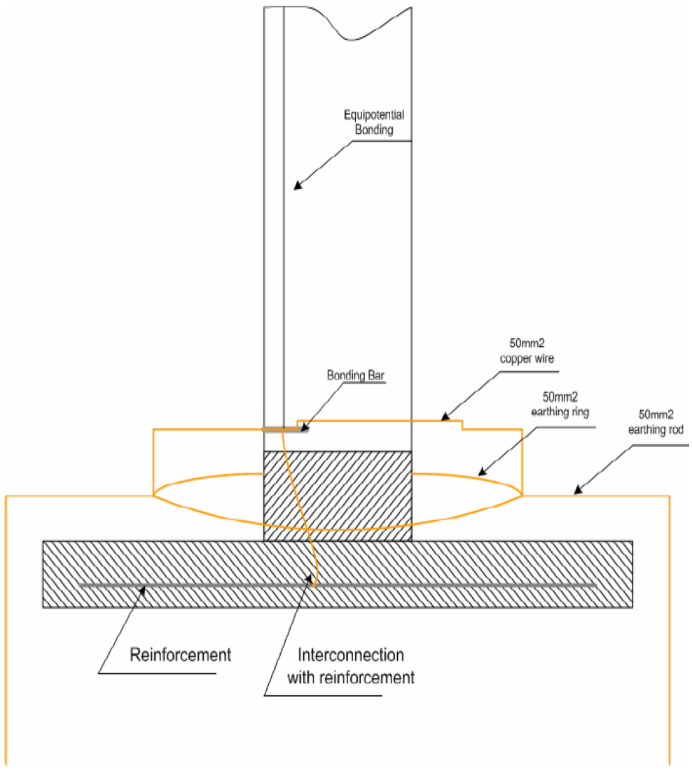

Fig. 10. Section plan of WTG foundation grounding [12].

The importance of grounding system for human beings is shown in Fig. 11 were are presented simulation results of the earthing system of Fig.9 [13]. In Fig. 11 are depicted two safety limits, one of medium risk and the other of high risk for the human beings that can face even fatalities. It is derived that for foundation resistivity of 300Ωm the higher is the lightning current the lower is the current that passes through human beings. This occurs since at high lightning currents that hit a wind turbine, soil ionisation is more present since the ionisation area is increasing and the current is dissipated at the surrounding ground. In the case of soil resistivity of 50Ωm and while the current is changing from 10kA to 30kA, the current that passes through the human body is increasing as well in contrast to the case of 300Ωm. This is due to the fact that at these cases of current increase, the change of equivalent soil ionisation radius is not affected significantly. During the change of current from 30kA to 100kA the currents are decreasing due to soil ionisation as occurred in the case of 50Ωm[13].

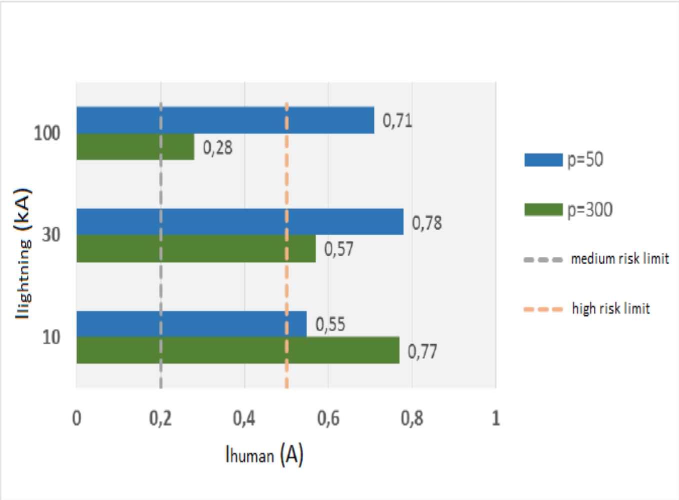

Fig. 11. Section plan of WTG foundation grounding [13].

5. Conclusion

Lightning strikes are characterized of stochastic performance and are mainly based on weather conditions and the topography of the surrounding area where the wind turbines of the wind power plant are installed. Wind turbines due to their total height, including the blade tip, and due to the reasons mentioned before are vulnerable to lightning strikes. The severity of the lightning strike can cause damages to the external components of a wind turbine like blades or to cause voltage rise which can destroy the electronic equipment. According to the current experience the reliable protection of a wind turbine against lightnings consists of combination of protection measures based on the LPZ concept [2]. The measures that have been presented in the current paper provide a reliable protection of wind turbines provided that the lightning parameters are within the range specified in IEC standard [3] and can be adapted in most wind power plants. These protection measures can be adapted on project basis in order to consider special site specific conditions like high lightning activity, lightning strikes which are not within the precautions of IEC.

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