Effects of Lightning on a Wind-Turbine & its Protection Techniques

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Abstract— This paper presents induced effect on structure of the wind-turbine due to lightning. Conventional lightning protection system is not 100 percent reliable to protect low voltage control circuits, communication devices, measurement devices inside wind-turbine. This paper gives some ideas for increasing reliability level of wind-turbine by applying various techniques like provision of individual back up protection path, shielding on wind-turbine's main components & good grounding system.

Key words: Equipotential Bonding and Over-Voltage Protection, Earth Resistance, Low Voltage Control Circuit

I. Introduction

Wind turbines are widely used as they are an environmental friendly way for energy production without emissions of greenhouse gases which are harmful gases for environment. Moreover the fuel used is wind which is free of cost & usually available for use. All above points explains the need of investment in wind field in energy production. This led to a rapid increase of the rated power of wind turbines increasing the size of the towers simultaneously. Due to this fact, these are vulnerable to lightning strikes that may cause damages to wind turbines of wind farms as they are usually located at isolated and high altitude areas. Taking into account that a large number of wind farms are constructed every year and considering the damages caused due to lightings, there is a need for lightning protection of the wind turbines. Since there is not, till now, an accurate and absolutely safe method is found to protect the wind turbines, they are vulnerable to lightning strikes.

The problems that are caused by lightning strikes are concluded in the following points [1]:

- High costs of repairing in case of damage and loss of energy production & so the revenue.
- Most exposed components (blades and nacelle cover) are made of composite materials.
- The blades and the nacelle rotate and change position during their function.
- Significant part of lightning current passes through or near to all wind turbine components.
- Electrically interconnected wind turbines in wind farms often placed at locations with poor grounding conditions meaning that there is a need for a reliable earth-termination system.

II. The Effects of Lightning on Structures & Establishing a Level of Risk

The high levels of energy, current, charge and rate of current rise associated with a lightning strike can result in a structure being severely damaged if struck. A key stage in determining the type of lightning protection system (LPS) required by a structure is the estimation of the lightning strike frequency. For each strike, the probability of thee energy/current/charge/rate of current rise exceeding a specific value can also be found mathematically.

The IEC standard detailing lightning protection of structures, IEC 1024, provides a method of calculating the lightning strike frequency to an object of no more than 60m height. This method is based on the calculation of an equivalent lightning collection area that is proportional to the size of the structure in question. Equation 1 shows the calculation needed to assess the annual number of downward propagating lightning strikes to a structure.

$$N_d = N_g A_e \ (\text{Year})^{-1} \quad \dots(1)$$

The ground flash density, Ng, a measure of the local lightning activity is multiplied with the equivalent collection area, Ae, of a specific structure to obtain the annual number of downward lightning strikes, Nd to that structure. The definition of equivalent area for an isolated structure in the IEC standard is:

'For isolated structures the equivalent collection area Ae, is the area enclosed within the border line obtained from the intersection between the ground surface and a straight line with 1/3 slope which passes the upper parts of the structure (touching it there) and rotating around it'.

The IEC standard is valid for structures not more than 60m in height. Considering modem wind turbines may have a hub height greater than 60m, this standard is inapplicable to such machines. The height is more than 60m meaning that needs special lightning protection system and additional measures. So, Lightning Protection Scheme (LPS) is very important for wind turbines.

Electrical Parameters and units	Effects	Endangered wind turbine components
Peak Current / A	Peak heating, Shock effects, Peak forces.	Blades, blade LPS, plant in nacelle, wiring.
Specific energy / J×(ohms)^-1	Total heating, Shock effects, forces	Blades, blade LPS, plant in nacelle, wiring.
Rate of current rise / A s^-1	Induced voltages on wiring by magnetic flux coupling, flashovers, shock effects.	Wind turbine control system and sensors, electrical sensors.
Charge transfer / C	Damage at arc attachment point or at other arc sites in current path.	Bearings, blades.

Table 1: Effects of lightning on a structure with particular application to a wind-turbine

Once a structure is struck by lightning, the various electrical components contained within a lightning strike will cause that structure to be damaged unless a suitable LPS is installed. The four electrical parameters commonly examined are the peak current, charge transfer, specific energy (action integral) and rate of current rise. The effects that these four specific electrical components of lightning have on a structure are detailed in Table along with particular reference to a wind turbine.

III. LIGHTNING DAMAGE STATISTICS

Generally, 4% to 8% of all wind turbines will suffer lightning damage every year & 7% to 10% of the wind turbine damage was to the rotor blades. This is important because the rotor accounts for 15% to 20% of the cost of a wind turbine and thus, damage to rotor blades is the most expensive type of lightning damage.

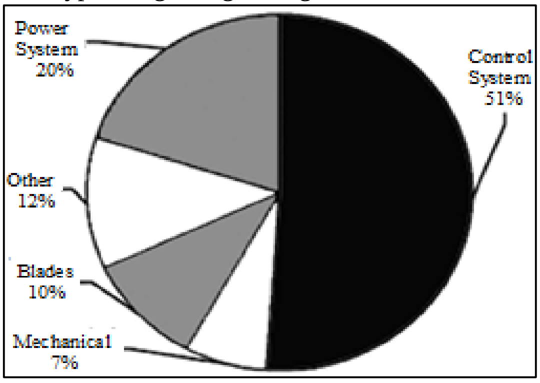

Fig. 1: Lightning Damage Statistics

It should be noted that most of the rotor damage reported was to older style blades manufactured out of non conducting fiber composite materials. Almost all modern turbine blades are constructed with build-in lightning protection in the form of conducting elements. This improved blade design has significantly reduced the amount of blade damage. One of the most significant statistics is that 50% to 70% of lightning faults are to the control and electrical systems and this damage accounts for at least twice as many days of "down time" as damage to rotors.

IV. TYPICAL WIND TURBINE INSTALLATION

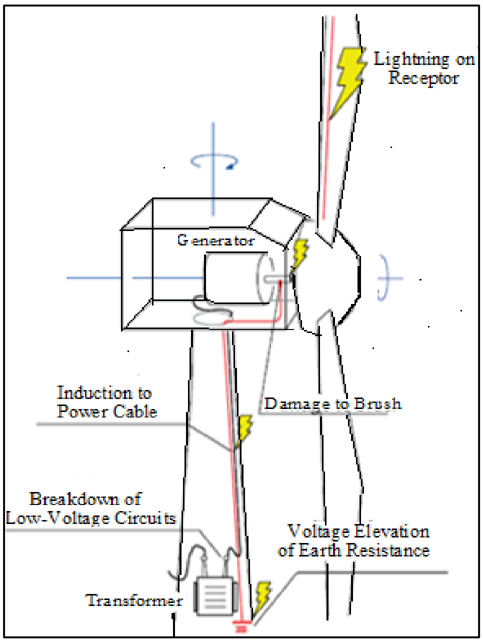

Fig. 2: Path of Lightning Current to Parts of Wind-Turbine

In a typical wind turbine, the blade drives a generator via a gearbox both of which are installed in the nacelle. In and around the nacelle devices such as anemometer wind direction, and speed/position/temperature sensors provide control data for the installation, and typically interface with signal conditioning units in the nacelle, and with control equipment in the tower or adjacent cabin. Once lightning strikes the wind turbine, assuming that it hits a receptor of one of the blades, a lightning current surge propagates through a down-conductor in the blade, a carbon brush or arc horn near the bearings, and the grounding conductor inside a wind tower (or, in another case, the current may flow through the conductive tower itself). The surge current flow inside the tower may create a large inductive current in low-voltage circuits such as control, measurement and communication devices. The low-voltage circuit in the wind turbine is easily broken by electromagnetic induction in such a situation[5]. The most frequent accident is dielectric breakdown on low-voltage circuits including electric and telecommunication equipment. In general, electrical and electronic equipment for wind power generation are set up close to or inside a wind tower.

V. ASPECTS OF CABLE ROUTING AND BONDING

For protection of systems the inductances associated with bonding are also very important. The current will distribute between whatever conductive paths are available through the structure to ground, and the current distribution is determined mostly by inductances of the available current paths. The designer should provide well defined routes for the current, using as much of the turbine and nacelle structure as possible. The alternative current paths installed (such as bonding straps) should be as low inductance as possible in order to provide most effective protection for equipment.

VI. AN INTEGRATED L.P.S FOR WIND-TURBINE

Lightning protection systems (LPS) can be divided into external and internal protection systems. External protection consists of air termination, down conductor and earth termination systems. Internal protection is considered by equipotential bonding and overvoltage protection[2]. The equipotential bonding and overvoltage protection are the most important measures in protection of the electronic and control systems of the wind turbine. As a wind turbine consists of many parts the lightning protection system should have protection zones which are shown in fig 3. The lightning protection zones concept includes a reduction of the conducted and radiated interferences at boundaries down to agreed values. For this reason, the object to be protected is subdivided into zones .The protection zones result from the structure of the wind turbine and shall consider the architecture of the structure. It is decisive that direct lightning parameters affecting lightning protection zone 0_A (fig 2) from outside are reduced by shielding measures and installation of surge protective devices to ensure that the electric and electronic systems and devices situated inside the wind turbine can be operated without interferences. The protection zones (LPZ) are usually three. The LPZ-0 concerns the protection against strike to the blade and the anemometer, the LPZ-1 the internal part of the wind turbine and the LPZ-2 the protection of the electronic equipment with electromagnetic shield.

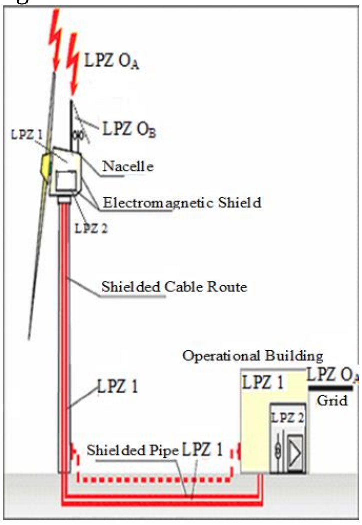

Fig. 3: Lightning Protection Zones of a Wind-Turbine

VII. EARTH TERMINATION SYSTEM

According IEC standards, the earthing resistance should be less than or equal to 10 ohm. The grounding system depends on the ground topography [4]. For grounding the wind turbines, the reinforcement of the towers should always be integrated. Installation of a foundation earthing electrode in the tower base, and, if existing, in the foundation of an operation building, should also be preferred in view of the corrosion risk of earth conductors. The grounding system of the tower bases and the operation buildings (if exist) are connected with an intermeshed earthing in order to get a grounding system with the largest surface possible. The extent to which additional potential controlling ring earthing electrodes must be arranged around the tower bases depends on the fact whether too high step and contact voltages must possibly be reduced to protect the operator in case of a lightning stroke.

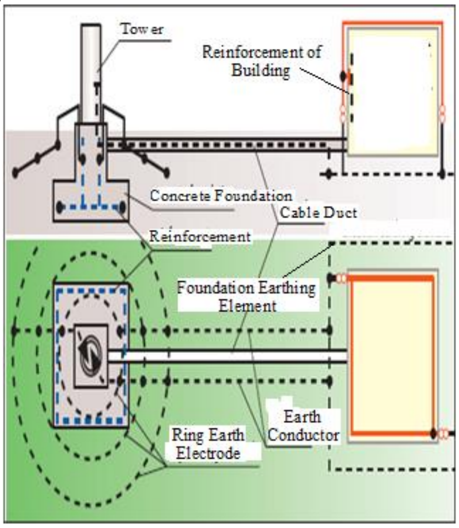

Fig. 4: Earth Termination System

VIII. TOTAL LIGHTNING PROTECTION SYSTEM

The presented lightning protection system based on protection of each part of the wind turbines (blades, nacelle) and the combination of them creates the total lightning protection system. The LPS, with exception of the blades, is seen in figure 5. Each part of the wind turbine both internal and external is connected with equipotential connections and eventually with the LPS. It is essential to protect against lightning or over-voltages except for the external parts (blades, nacelle, anemometer etc) the internal parts and especially the electronic and control systems [1]. These systems are responsible for the reliable function of the wind turbine. The only safe way to protect the internal parts is with equipotential connections as is seen below fig.5. So, there is an equipotential connection between top-processor and generator with down conductor, the tower and with the ground controller.

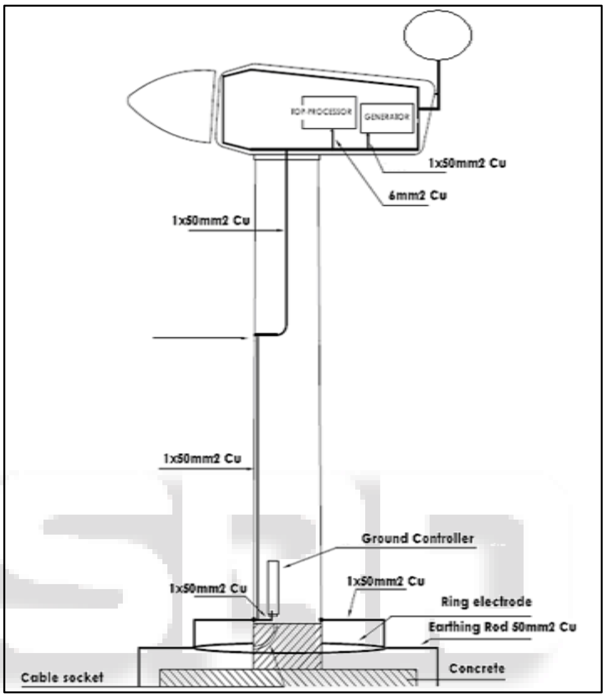

Fig. 5: Total Lightning Protection System

IX. CONCLUSION

Equipotential bonding, over voltage protection and good earth termination system is the 1st prerequisite for a reliable lightning protection of wind-turbine. A comprehensive lightning and surge protection is required in order to protect the wind turbine and ensuring continuous energy production without problems. Surge protective devices (Which are used in lightning protection scheme) should be chosen according to the operating characteristics of the electric and electronic systems. After the discharge, surge protective devices to be used in the power supply system must be capable of extinguishing safely the follow currents coming from mains afterwards. Beside the impulse current carrying capability, this is the second important aspect of design. Reliability level of lightning protection scheme can also be increased by providing back up protection paths.

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