IMPROVEMENT OF WIND TURBINE LIGHTNING RECEPTOR

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For my beloved mother and brothers.Ibrahim,Nashwan and Abdulhameed

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ABSTRACT

Lightning receptor is a device attached to a wind turbine blade that will attract and assist lightning current flow to the ground. However, lightning does not necessarily strike it, instead the other part of the wind turbine is still been stroked by lightning eventually leading to catastrophe damage of the wind turbine. This research is aimed to develop a needle-type receptor on a wind turbine blade for lightning protection system (LPS). Other than that, this project is aimed to study the practical parameters of lightning protection system, including the relation between receptor size and electric field strength. The receptors were designed by three different disk diameters of 0.2 m, 0.5 m and 0.8 m. In 0.2m receptor diameter, the comparison between the numbers and length of needles presents that 32 number of needles and 0.3m length of needles can attract a higher electrical field than others. Each disk diameter consists of different needles number and length. Finite Element Method (FEM) has used for this research, the proper dimensions and shapes of receptors simulated by suggesting the minimum and maximum electric field that accumulates around receptors. The simulation study plays an active role in understanding and designing the receptor of wind turbines for an effective lightning protection system (LPS), but it requires a validation under actual conditions.

ABSTRAK

Projek ini memberi tumpuan kepada kajian teori perlindungan kilat, pengetahuan dan asas. Pengetahuan petir awan ke bumi, sistem perlindungan kilat (LPS), hubungan medan elektrik, konfigurasi reseptor diterangkan. Projek ini bertujuan untuk mengkaji parameter praktikal LPS, termasuk hubungan antara saiz reseptor dan kekuatan medan elektrik. Selain itu, projek ini bertujuan untuk menguji tiga diameter reseptor yang berbeza iaitu 0.2m, 0.5m dan 0.8m dengan bilangan dan panjang jarum yang berlainan. Setervsnya ia jvga bertujuan untuk membangunkan reseptor turbin angin yang baru dengan nombor dan panjang jarum yang berbeza dan juga untuk mencadangkan parameter untuk diameter dan jarum reseptor. Kaedah Elemen Finite (FEM) telah digunakan untuk penyelidikan ini, dimensi dan bentuk reseptor yang betul disimulasikan dengan mencadangkan medan elektrik minimum dan maksimum yang berkumpul di sekitar reseptor. Kajian simulasi memainkan peranan aktif dalam memahami dan merancang reseptor turbin angin untuk sistem perlindungan kilat yang berkesan (LPS), tetapi memerlukan pengesahan dalam keadaan sebenar

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LIST OF SYMBOLS

ε_r	Relative Permittivity
m	Meter
σ	Sigma electrical conductivity

LIST OF ABBREVIATIONS

2D	2 Dimensional
LPS	Lightning Protection System
FEM	Finite Element Method
ESE	Early Streamer Emission
RE	Renewable Energy

CHAPTER 1

INTRODUCTION

1.1 Background of Study

Wind energy (or wind power) refers to the process of creating electricity using the wind or air flows that occur naturally in the earth's atmosphere. Modern wind turbines are used to capture kinetic energy from the wind and generate electricity. Typically standing at least 80 m (262 feet) tall, tubular steel towers support a hub with three attached blades and a "nacelle," which houses the shaft, gearbox, generator and controls. Wind measurements are collected, which direct the turbine to rotate and face the strongest wind, the angle or "pitch" of its blades is optimized to capture energy [1] . Wind turbines can be exposed to the effects of lightning strikes due to their high altitude and open rare location such as their typical installation in hilly off-shores and some other places that are established in which the wind speed is severe. Therefore, these locations are more vulnerable to lightning charges [2].

During the storm all negative charges start to develop downward leaders from branches and stop at around 200 m above the ground [3]. At that moment, all positive charges of the objects on the ground are emitted towards the negatively charged branches in the sky. One of the positively charged branches meets with one of the negative ones and this form of conductive channel is called "lightning". All the current inside the cloud flows to the ground through this channel and through the object which emitted the positively charged branch [4].

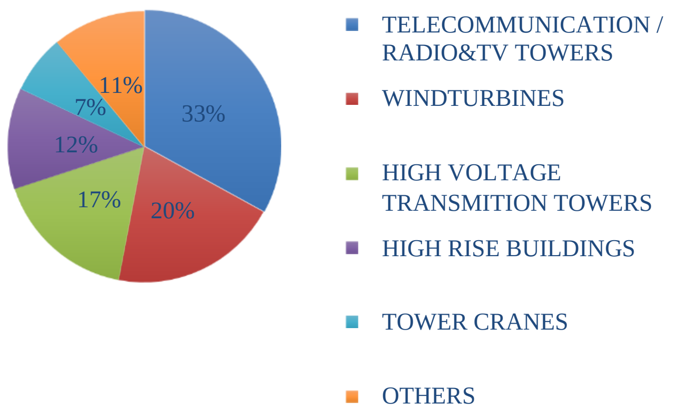

Figure 1.1: Lightning strike risk

Lightning is mostly observed in equatorial regions. Countries in this region experience extremely damaging results of lightning strikes which creates more than 50% of overall damage by natural disasters [5]. Moreover, with the industrial point of view as shown in Figure 1.1, telecommunication and radio-TV towers are the primary targets of lightning.

In recent years, the rate of lighting damages to the wind turbine plant has increased with the increase in number and size of wind farms [6]. However, wind turbines, transmission towers and tower cranes are also under serious risk of lightning damage. Essentially lightning damage to the blades of the turbine is exorbitantly expensive since the cost of repairing, fixing and replacement of the blade damage is high. Therefore, statistics indicate by insurance companies showed that the vast majority of lightning strikes blades occupy 75% of the total damages for wind turbine generators [7].

In addition, the increase in the size of the wind turbine which reached 200 m in 2017 to generate higher power leads to an increase in the size of the blades to be 50-60 m tall. This increase in size and length causes a high risk of lightning strike to the blades. Therefore, the lightning protection system (LPS) must be installed to prevent a lightning strike. Wind turbines are one of the primary targets for lightning strikes.

When lightning hits the wind turbine blade, the current flows through the LPS. The rod installed inside the blade to the earthing system gives damage to the components and parts on wind turbines especially blades. The study of this application area should start by understanding the relationship between lightning and charges dissipation on the wind turbine. Therefore, in this project, a new shape of receptor for LPS will be developed to investigate the effect of lightning towards the LPS [7][8].

1.2 Problem Statement

Over a few decades, researches on LPS are focused on modelling lightning attachment to wind turbines in complex locations or terrain has difficult problems [9]. However, studying the characteristics of receptors on blades is very challenging due to the relation among cloud charges, potentials, electrical fields and induced charges are difficult to be clarified during the discharge due to many lightning flashes occurs during sounding [8]. Many researchers had put their effort to overcome the problems. Nevertheless, LPS are very difficult to apply in practice. Due to the difficulty to understand and suggest the characteristics of lightning nature which can include several factors such as, different between seasons weather in summer and winter lightning characteristics, terrain orography, turbine blade material, turbine height and rotation speed [9] [8]. Therefore, a high voltage electrical simulation method will be more suitable for application. The receptor without needles is not affected by lightning same with the new shape as mentioned in the previous research.

Most of the other researchers in wind farms LPS still focused on the size and location of receptors to discharge lightning. The receptor though effective, also failed in so many instances as mentioned in the literature review [7-10]. According to the fundamental physics principles, all objects emit upward streamers. However, the sharper and smaller objects the faster and more emission compared to larger flat surfaces. Therefore, applying receptors with sharp tiny pins can prevent lightning attachment. It is on the contrary, the sharper the pin the higher electrical field. Therefore, ionization at the pin can easily occur electron avalanche which lead to emit initiate streamers that accommodate lightning attachment.

1.3 Objectives of the Study

(i) To develop a needle-type receptor on a wind turbine blade with different parameters of disk diameter, number of needles and length of needle using simulation approaches.

(ii) To analyze the electrical field distribution between traditional receptor and receptor with needles.

(iii) To propose a suitable configuration of needle-type receptor on a wind turbine blade.

1.4 Scope of Project

The scope of this project including:

(i) A horizontal wind turbine is the target for valuation, which is commonly used and known for its efficiency in various environments.

(ii) Using fiber reinforce carbon for blade material that wind turbines made of that is strong, light and to reduce the insulation properties.

(iii) A simulation tool is COMSOL Multiphysics.

(iv) This simulation uses an electrostatics physics interface with a stationary study.

CHAPTER 2

LITERATURE REVIEW

2.1 Overview

The capacity of wind turbine generations has been increasing to 12000kW in 2018 as shown in Figure 2.1. This development represents an increase in the size of wind turbines in order to keep up with the increasing volume of electrical power demand. The higher the turbine’s capacity, the greater the size of the turbine [7]; [11]. Therefore, many research on modelling the impact of lightning on wind turbines had been carried out to improve the wind turbine protection system performance.

In the case of huge wind turbines which reach 200m high, lighting protection becomes more important than that for small sizes. Replacement of damaged blades as shown in Figure 2.2 cost more due to the transportation of large blades and the replacement of it [7]; [11] .

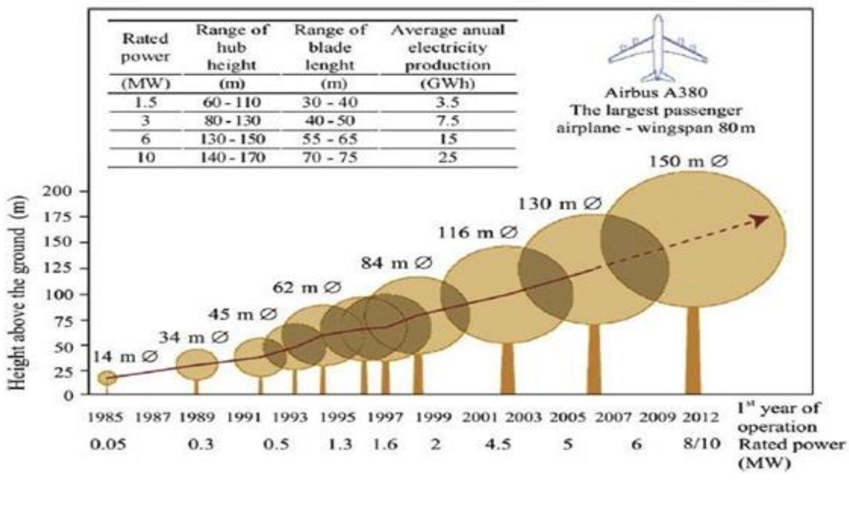

Figure 2.1: The rise of in rate of power and size of wind turbine[11]

Figure 2.2: Damage of wind turbine blades due to lightning[7]

Wind turbines usually are placed on high and isolated terrine with high resistive soil. Because of this high location, wind turbines often stroke by lightning [12]. In the European country, wind turbines are installed offshore, due to high wind speed. However, it is a very risky location for lightning to strike. One of the multi-faceted risk is the damage to the wind turbine due to the lightning strike. Blades are the most suspectable part of lightning damage [13].

The overall height of some modern wind turbines between 100 - 200m with the full size of the wind turbine blade is between 36 - 60m. Wind turbine blades material is composed of Epoxy-Based Glass Fiber Reinforced Plastics, to minimize the effect of lightning strike. Even though, blades can be burnt if struck by lightning[7] [10]. The literature review chapter will be focused on lightning wind turbine, wind turbine (LPS), lightning attachment location and lightning receptor as shown Figure 2.3.

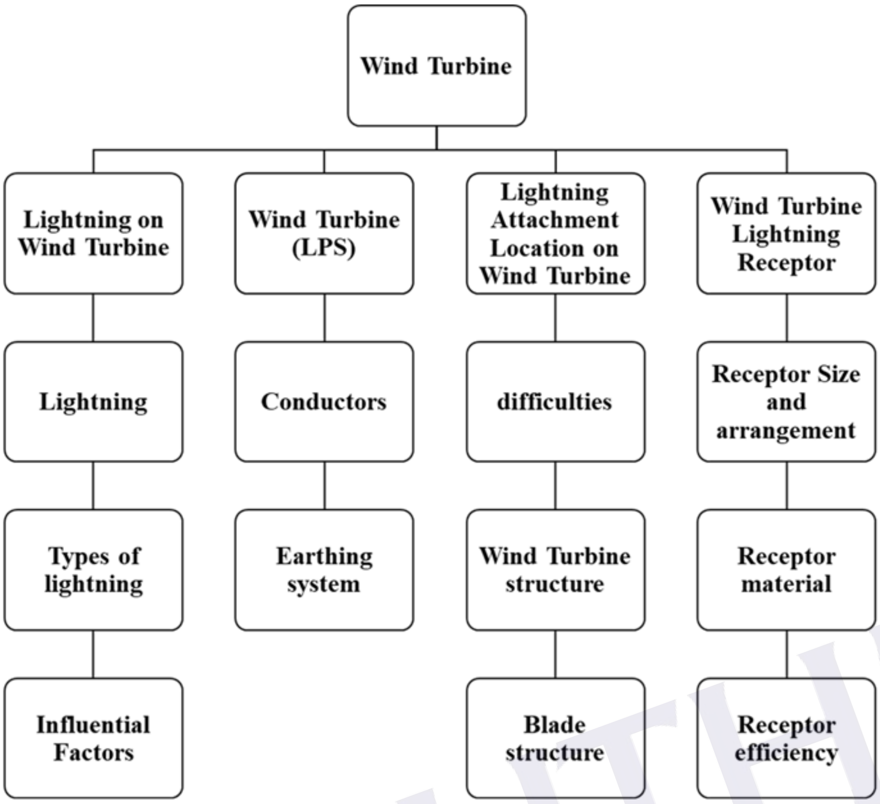

Figure 2.3: Literature Review Map

2.2 Lightning on Wind Turbine

Analyzing characteristics of lightning and how it occurs in the atmosphere has been simulated by digital programming simulation and real lighting simulation. When the electric field becomes very strong (on the order of tens of thousands of volts per inch), conditions are perfect for the air to begin breaking down. The electric field causes the surrounding air to become separated into positive ions and electrons the air is ionized. Keep in mind that the ionization does not mean that there is more negative charge (electrons) or more positive charge (positive atomic nuclei / positive ions) than before [14]. This ionization only means that the electrons and positive ions are farther apart than they were in their original molecular or atomic structure [4].

Discharge in the blocks cloud neutralizes only by 25-50% of the stored charge [8]. Here is the list of lightning type:

1. Intra to cloud: Occur between opposite charges within the thunderstorm cloud.

2. Cloud to cloud: Occur between opposite charges in the cloud and another cloud.

3. Cloud to ground: Occur between opposite charges in the cloud and on the ground.

4. Ground to cloud: Occur in the reverse direction.

Cloud to Ground lightning can neutralize some clouds charge 40 – 80 % in the upper charge region and 16 – 40 % of the cloud charges neutralized in lower charge region. Eventually, the electrons have been stripped from the molecular structure of the non-ionized air [8][14].

A 2D simulation from random lightning models using from several forms of cloud charge distribution was done. The impact of both negative and positive charge regions closest to the ground, the strength of the electric field becomes weak and the electrostatic in a thundercloud is obviously consumed when the discharge ends [15].

Cloud to Ground discharge cloud can cause complex charge transfer in thundercloud [13][8]. Cloud models are used to represent the ambient electrical field and results from that the electrical field intensity increases with the decreasing cloud height as shown in Figure 2.4-[10]. From figure 2.4 the length of each stepped leader has a length of 10 m passing in about 10^4 km/s, after that there is a rest about $30 - 90\ \mu s$, so the speed is developed approximately around 100 – 800 km/s. Upward and downward leaders are connected together by upward development with strong charge neutralization of the opposite polarity [3][10].

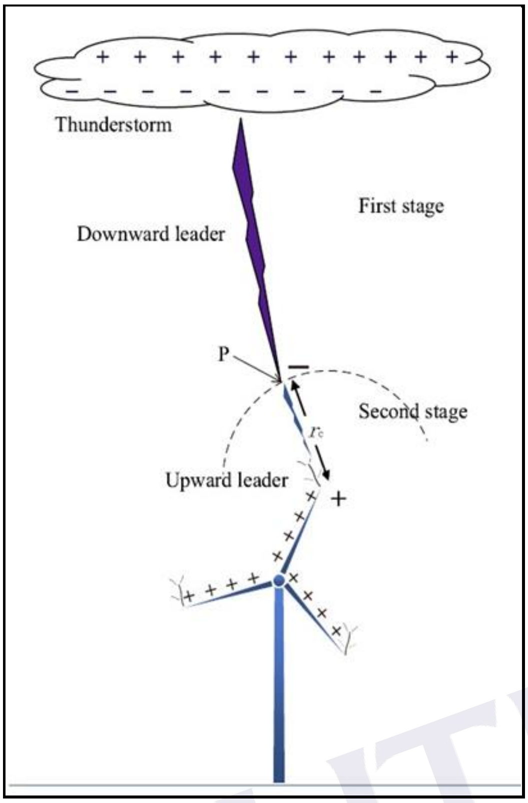

Figure 2.4: Leader development during lightning strikes wind turbine blade[10]

The humidity on the surface of the blade always increases the number of strikes [16]. The author mentioned that pollution with the conductive particles (moist, salt, dirt, humidity and water) can affect wind turbine blades by making it more conductive over time. Due to this, the rotation of wind turbine blades can affect interception efficiency. When the rotation angle increases the interception, efficiency is scientifically decreased by passing the lightning charge from one blade to the second one through the conductive pollution on the blades [11] [10].

Investigation of influence of pollution on blades, by spreading water mixed with salt and powdered clay[8] uses a high-voltage impulse generator for real lightning simulation to study the purpose of lighting damages of wind turbine blades. The author explain that the Sea of Japan has upward leaders with large energy of winter lightning, which damages wind turbine blades. Electrical charge in winter lightning can exceeds 300C, which is 10 times higher than in summer [11] [7].

2.3 Wind Turbines Lightning Protection System

Earthing system prevents blades from damage by dispersing and conduct the high frequency and high energy lightning current into the ground without causing any dangerous or electrodynamic effect. Electrodynamic is a branch of physics that deals with the effects arising from the interactions of electric currents with magnets, with other currents, or with themselves [1].

Several types of soil were improved to satisfy the ratio of the voltage distribution inside the soil. Wind turbines placed on high and isolated locations with high soil resistance. Each wind turbine has an earthing system consists of surge protection, conductors, grounding system and lightning receptor point. However, the optimum location of the wind turbine earthing system depends on the optimum rule of a component of the electrical field and the current density calculation inside the soil [12].

It is recommended to interconnect the earthing system of each wind turbine in the ground. This connection along with underground cables connects between turbines and other grid, to minimize the potential difference and reduce the chance of direct lightning flashes [1].

2.4 Lightning Attachment Location on Wind Turbine

Modelling lightning attachment to wind turbines in complex locations or terrain has difficult problems which include several factors such as, different between seasons weather in summer and winter lightning characteristics, direction of thunderstorm, terrain topography, turbine blade material, turbine height and rotation speed [16] . Boysian statistical learning and Gaussian process regression were applied on real lightning location systems data and predicted the number of lightning strikes. The effective height of the wind turbine located on a hilltop assumed to be hemispherical in shape [13]. Some of complex electrical and control systems of wind turbines have rotating composite blades up to 60m long and placed on up to more than 200 m high towers [1].

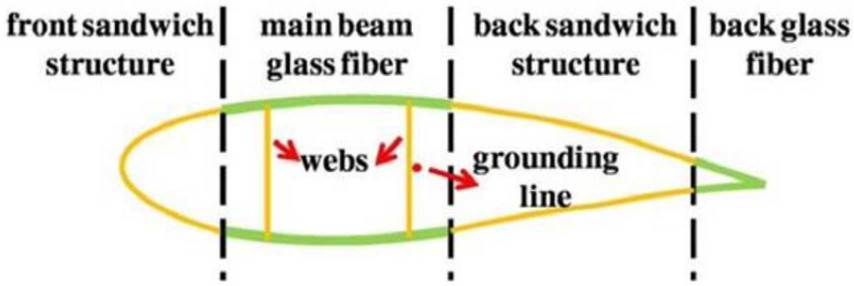

Figure 2.5: Blade Structure[16]

Therefore, statistic data by wind turbine companies showed that the vast majority of lightning strikes blades occupy 75% of the total damage of wind turbine generators [7]. Moreover, the back-sandwich position is the weakest area easy to be struck as shown in Figure 2.5. The tip of the blades is the most impacted part of the wind turbine hit by lightning [10]. Most of the lighting strikes the outermost 1m of the blade's tip, where the thickness of the blade between 2 - 10mm [11].

2.5 Wind Turbine Receptor

Various novel lightning protection procedures have been proved theoretically and some of them have been examined in the laboratory or by simulation method. However, none of these mentioned methods was applied due to their potential influence on the aerodynamics of the turbine [17][16]. The interception efficiency of wind turbine blades receptors during rotation are discussed [16][10]. The research on [18] [7] shows that lightning receptors that completely useful for lightning protection on wind turbines are not perfect due to the position of the protection receptors. This research exposes the weak areas on the blade which in turn contributes to offer steer for lightning protection design of blade materials and whole structure [19] [16].

By testing blades with high voltage impulse can elaborate on different factors such as:

Location for possible leader attachment points.
Optimize the location and number of protection devices.
Characteristics of protection devices [2] have applied a different number of receptors on the wind turbine blade with a different location.

The voltage distribution around the blade doesn't differ so much. Therefore, the best result was for two receptors in pairs on the blade's tip can be the most effective way of lightning protection of blades and is more economical than the other configurations. Receptors varies as a major role in distributing voltage on wind turbine blades by different configuration [2] Five different types of receptors are applied on LSP as shown in figure 2.6. According to the US wind energy lightning insurance, 23.4% of wind turbine damage due to the lightning [14]. Ordinarily, lightning strike protection devices are used by attaching a (e.g. copper or special tungsten alloy) receptors of the exterior side of wind turbine blades as shown in Figure 2.5.

These receptors are connected to the ground (e.g. high voltage cables), which are installed in the blade through the hole onside sandwich directly to the earthing system. The objection efficiency is strongly dependent on the quantity, size and spacing of receptors. The latest studies have shown that the blades are still not protected, although there is a lightning receptor installed on both sides of the blade. Up to now, very few experiments have been carried out to investigate the effects of simulation shape and size of the receptors [14].

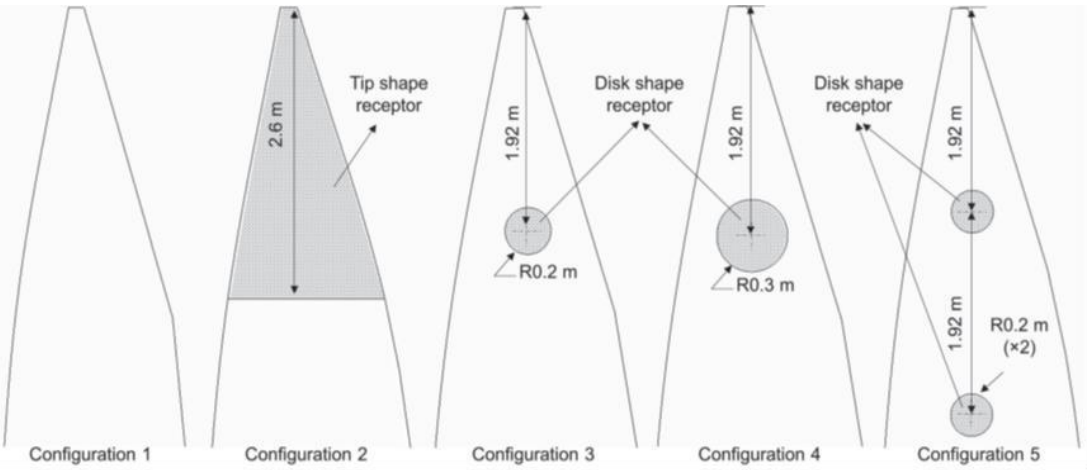

Figure 2.6: Five distinct arrangement of receptors[14]

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