UNIVERSITI PUTRA MALAYSIA

DAMAGE SEVERITY EVALUATION METHODS FOR BIOCOMPOSITE VERTICAL AXIS WIND TURBINE BLADES DUE TO LIGHTNING STRIKES

SITI ZUBAIDAH BINTI MAT DAUD

DAMAGE SEVERITY EVALUATION METHODS FOR BIOCOMPOSITE VERTICAL AXIS WIND TURBINE BLADES DUE TO LIGHTNING STRIKES

By

SITI ZUBAIDAH BINTI MAT DAUD

Thesis Submitted to the School of Graduate Studies, Universiti Putra Malaysia, in Fulfilment of the Requirements for the Degree of Doctor of Philosophy

October 2018

Abstract of thesis presented to the Senate of Universiti Putra Malaysia in fulfilment of the requirement for the degree of Doctor of Philosophy

DAMAGE SEVERITY EVALUATION METHODS FOR BIOCOMPOSITE VERTICAL AXIS WIND TURBINE BLADES DUE TO LIGHTNING STRIKES

By

SITI ZUBAIDAH BINTI MAT DAUD

October 2018

Chairman : Faizal Mustapha, PhD, PEng
Faculty : Engineering

In the wind turbine industry, damage occurs in many parts of the wind turbine, such as the tower, the gearbox, the shaft and the rotor blade etc., but the most common damage occurs in the rotor blade and the tower. More attention required on the structural health of the rotor blades since they play a significant role in the wind turbine system, accounting for 15-20% of the entire turbine cost and resulting in an expensive repair cost when damage occurs. The most common causes of rotor blade damage are wind gusts, heavy rainfall and lightning strikes. Over 30% is affected by thunderstorms or lightning strikes, 28.21% by heavy rainfall and 15.3% by strong winds. Wind turbines are susceptible to lightning strikes since their size is becoming larger and it is predictable that they will be more exposed to lightning strikes in the future. Therefore, this thesis focused on lightning strike behaviour with respect to rotor blades for both composite and biocomposite material. The literature review highlighted wind energy, lightning damage on rotor blades and the types of damage detection used. The main objective of this thesis is to determine the lightning strike behaviour with respect to biocomposite, hybrid and composite material. The study adopted two techniques: firstly, Failure Modes and Effect Analysis (FMEA) to recognise the failure modes and potential causes for blade damage, and secondly, the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) for assessing the potential causes that have been identified. It was found that the most dominant potential causes of blade damage is caused by lightning strike. Lightning tests were conducted for the coupon specimens and the blade specimens for both composite and biocomposite materials. The materials tested for coupon specimens are kenaf fibre, flax fibre and fibreglass with different configurations; without wire mesh, embedded wire mesh and outer-ply wire mesh in order to find the best configuration for wind turbine blade fabrication. The fibres were reinforced with a polyester (PE) matrix. Four types of damage detection were used to assess the severity of lightning damage on the composite and biocomposite blades, i.e. visual inspection, liquid dye-penetrant testing,

ultrasonic guided wave, and laser-based ultrasonic scan. Based on the NDT tests performed on the coupon specimens, the best configurations are either made of flax fibre or fibreglass with embedded wire mesh. Three different types of blade specimens; i.e. fibreglass, flax-fibreglass, flax were fabricated and subjected to lightning strike. It was found that the flax blade suffers the least lightning damage compared to the blade containing fibreglass. This means that, natural fibre can be a good alternative to synthetic fibre in wind turbine blade fabrication. All the techniques can detect the lightning damage in the overall tested materials and blade structural systems but, the most effective technique are ultrasonic laser-based scan because the damage size and location of the damage can be observed clearly.

Abstrak tesis yang dikemukakan kepada Senat Universiti Putra Malaysia sebagai memenuhi keperluan untuk ijazah Doktor Falsafah

KAEDAH PENILAIAN TAHAP KEROSAKAN BILAH BIOKOMPOSIT TURBIN ANGIN PAKSI MENEGAK (VAWT) DISEBABKAN OLEH PANAHAN KILAT

Oleh

SITI ZUBAIDAH BINTI MAT DAUD

Oktober 2018

Pengerusi : Faizal Mustapha, PhD, PEng
Fakulti : Kejuruteraan

Di dalam industri turbin angin, kerosakan berlaku di beberapa bahagian turbin angin, contohnya menara, kotak gear, aci dan bilah rotor, tetapi kerosakan yang paling biasa terjadi adalah kerosakan di bilah rotor dan di menara. Perhatian yang lebih dititikberatkan pada kesihatan struktur bilah rotor kerana ianya memainkan peranan yang penting dalam sistem turbin angin, yang merangkumi 15-20% dari jumlah keseluruhan kos turbin dan mengakibatkan kos pembaikan yang tinggi jika berlakunya kerosakan. Punca kerosakan bilah rotor yang paling biasa berlaku adalah disebabkan angin ribut, hujan lebat dan panahan kilat. Lebih dari 30% adalah disebabkan oleh ribut petir atau kilat, 28.21% oleh hujan lebat dan 15.3% disebabkan oleh angin kencang. Turbin angin yang terdedah kepada panahan kilat kerana saiz yang semakin besar dan dijangka ia akan lebih terdedah kepada panahan kilat pada masa akan datang. Oleh itu, tesis ini akan memberi tumpuan pada tingkah laku panahan kilat terhadap bilah rotor yang menggunakan bahan komposit dan biokomposit. Kajian literatur merangkumi tenaga angin, kerosakan yang berlaku disebabkan oleh panahan kilat pada bilah rotor dan jenis-jenis pengesanan kerosakan yang digunakan. Objektif utama tesis ini adalah untuk menentukan tingkah laku panahan kilat terhadap bahan biokomposit, hybrid dan komposit. Kajian ini mengaplikasi dua teknik iaitu; yang pertama, Mod Kegagalan dan Analisis Kesan (FMEA) untuk mengenalpasti mod kegagalan dan punca-punca yang mengakibatkan kerosakan bilah, dan kedua, Teknik untuk Pilihan Pesanan oleh Kesamaan kepada Penyelesaian Ideal (TOPSIS) untuk menilai potensi punca-punca kerosakan yang telah dikenalpasti. Ia didapati bahawa punca yang paling dominan yang akan mengakibatkan kerosakan bilah adalah disebabkan oleh panahan kilat. Ujian kilat telah dijalankan untuk spesimen kupon dan spesimen bilah untuk kedua-dua bahan komposit dan biokomposit. Bahan yang diuji adalah gentian kenaf, gentian flaks dan gentian kaca dengan konfigurasi yang berlainan; iaitu tanpa menggunakan dawai, dawai terbenam dan dawai luar-lapis untuk mencari konfigurasi yang terbaik untuk fabrikasi bilah turbin angin. Semua gentian yang digunakan telah

diperkukuh dengan polyester (PE) matriks. Empat jenis pengesanan kerosakan telah digunakan untuk menilai tahap kerosakan yang disebabkan oleh kilat pada bilah komposit dan biokomposit, iaitu pemeriksaan visual, ujian penanda pewarna cecair, gelombang berpandu ultrasonik, dan imbasan ultrasonik berasaskan laser. Berdasarkan ujian yang dilakukan ke atas spesimen kupon, konfigurasi yang terbaik adalah sama ada ia diperbuat daripada gentian flaks atau gentian kaca dengan menggunakan dawai terbenam. Tiga jenis spesimen bilah; iaitu gentian kaca, flaks-gentian kaca, flaks telah difabrikasi dan dikenakan panahan kilat. Didapati bahawa bilah flaks mengalami kerosakan kilat yang lebih rendah berbanding denagn bilah yang mengandungi gentian kaca. Ini bermakna, serat semula jadi boleh menjadi alternatif yang baik untuk serat sentetik dalam fabrikasi bilah turbin angin. Semua teknik yang digunakan boleh mengesan kerosakan yang disebabkan oleh panahan kilat untuk keseluruhan bahan yang diuji dan sistem struktur bilah tetapi, teknik yang paling berkesan adalah imbasan ultrasonik berasaskan laser kerana saiz dan lokasi kerosakan boleh diperhatikan dengan jelas.

ACKNOWLEDGEMENTS

Praised to Allah S.W.T. for His generous blessing, kindness, guidance and undying strength bestowed upon me to successfully complete my doctoral study.

My special appreciation and acknowledgement dedicated to my supervisor, Prof. Ir. Dr. Faizal Mustapha for his continuous support, invaluable guidance, patience and motivation throughout my period of completing the Ph.D. study. I would like to extend my appreciation to my supervisory committee, Dr. Mohamad Ridzwan Ishak, Prof. Ir. Mohd Khairol Anuar Mohd Ariffin and Dr. Zuraimy Adzis for their advices and assistance during this period of study.

Tokens of gratitude to my family members for their unconditional love and support. Special thanks to my dearest mother, Che Nab Che Man; my sister, and brothers for their patience, great sacrifice and always having faith in me. Thank you to my dear friends with their idea, support and always been by my side to survive all kind of challenges while completing this study. May Allah bless their kindness.

Last but not least, my sincere gratitude to Universiti Putra Malaysia for funding my study under the Geran Putra IPS (GP-IPS) [9479800] and Ministry of Education Malaysia for granting me MyPhD Scholarship under the MyBrain15 Program.

THANK YOU

This thesis was submitted to the Senate of Universiti Putra Malaysia and has been accepted as fulfilment of the requirement for the degree of Doctor of Philosophy. The members of the Supervisory Committee were as follows:

Faizal Mustapha, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Chairman)

Mohamad Ridzwan Ishak, PhD
Senior Lecturer
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Mohd Khairol Anuar Mohd Ariffin, PhD
Professor Ir.
Faculty of Engineering
Universiti Putra Malaysia
(Member)

Zuraimy Adzis, PhD
Senior Lecturer
High Voltage and High Current Institute (IVAT)
Universiti Teknologi Malaysia
(Member)

____
ROBIAH BINTI YUNUS, PhD
Professor and Dean
School of Graduate Studies
Universiti Putra Malaysia

Date:

Declaration by graduate student

I hereby confirm that:

- this thesis is my original work;
- quotations, illustrations and citations have been duly referenced;
- this thesis has not been submitted previously or concurrently for any other degree at any other institutions;
- intellectual property from the thesis and copyright of thesis are fully-owned by Universiti Putra Malaysia, as according to the Universiti Putra Malaysia (Research) Rules 2012;
- written permission must be obtained from supervisor and the office of Deputy Vice-Chancellor (Research and Innovation) before thesis is published (in the form of written, printed or in electronic form) including books, journals, modules, proceedings, popular writings, seminar papers, manuscripts, posters, reports, lecture notes, learning modules or any other materials as stated in the Universiti Putra Malaysia (Research) Rules 2012;
- there is no plagiarism or data falsification/fabrication in the thesis, and scholarly integrity is upheld as according to the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) and the Universiti Putra Malaysia (Research) Rules 2012. The thesis has undergone plagiarism detection software.

Signature: ________________________ Date: ____________________

Name and Matric No.: ____

Declaration by Members of Supervisory Committee

This is to confirm that:

- the research conducted and the writing of this thesis was under our supervision;
- supervision responsibilities as stated in the Universiti Putra Malaysia (Graduate Studies) Rules 2003 (Revision 2012-2013) are adhered to.

Signature: ______________________
Name of Chairman of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

Signature: ______________________
Name of Member of Supervisory Committee: ______________________

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

LIST OF ABBREVIATIONS

AE	Acoustic Emission
AHP	Analytical Hierarchy Process
AWAM	Anomalous Wave Amplitude Map
AWI	Acoustic Wavefield Imaging
AWPI	Anomalous Wave Propagation Imaging
CC	Closeness Coefficient
D	Detection
DEMATEL	Decision Making Trial and Evaluation Laboratory
ELECTRE	Elimination and Et Choice Translating Reality
ET	Eddy Current
FMEA	Failure Modes and Effect Analysis
FNIS	Fuzzy Negative Ideal Solution
FPIS	Fuzzy Positive Ideal Solution
HAWT	Horizontal Axis Wind Turbine
HV	High Voltage
LMS	Laser Mirror Scanner
MADM	Multi Attribute Decision Making
MT	Magnetic Particle
NDE	Non-Destructive Evaluation
NDT	Non-Destructive Testing
O	Occurrence
PE	Polyester
PROMETHEE	Preference Ranking Organisation Method for Enrichment Evaluation
PT	Penetrant Testing
PU	Polyurethane
PZT	Lead Zincornate Titanate
QL	Q-switched Laser System
RPN	Risk Priority Number
RT	Radiographic Testing
S	Severity
SHM	Structural Health Monitoring
TIR	Thermal Infrared
TOPSIS	Technique for Order Preference by Similarity to Ideal Solution
UPI	Ultrasonic Propagation Imaging
UT	Ultrasonic Testing
VAWT	Vertical Axis Wind Turbine
Vs	Versus
VT	Visual Testing
V_{PP}	Voltage Peak-to-Peak

CHAPTER 1

INTRODUCTION

1.1 Research Overview

The rising concerns over the depletion of fossil fuels have increased attention in developing renewable energy sources to overcome the crisis. Wind energy has become a strong contender for a renewable energy source because of its dependability, relative cost competitiveness and good infrastructure. In the wind industry, wind turbines can be categorised according to the turbine generator configuration, the turbine capacity, the airflow path relative to the turbine rotor, the generator-driving pattern, the power supply mode and the location of the turbine installation (Tong, 2010). Considering the direction of the turbine blade's rotational axis, the wind turbine has been classified into the Horizontal Axis Wind Turbine (HAWT) and the Vertical Axis Wind Turbine (VAWT) (Paraschivoiu, 2002; Park, Lee, Sabourin, & Park; Manwell et al., 2010; Adaramola, 2015). The VAWT has more advantages than the HAWT as it does not need to be pointed into the wind direction to be effective. Therefore, it can generate power in areas where the wind comes from a variety of directions and it can be installed much closer to each other. Although the wind turbine is considered to be the best solution for energy harvesting, there are still possibilities of exposure to damage. Damage can happen in any of the wind turbine blade's components, but the most mentioned types are blade and tower damage (Wind Turbine Accident Data to December 31st 2005). More attention has been focused on the structural health of the blades as these are the most critical components in wind turbine systems. In general, wind gusts, lightning strikes, heavy rainfall, or even bird collisions, are responsible for wind turbine blade damage (Li, Ho, Song, Ren, & Li, 2015). As the size of installed wind turbines is becoming rapidly larger nowadays, this will increase the possibilities of lightning damage for wind power plans. Since the rotor blades are the highest part of a wind turbine, they are more exposed to lightning strikes. Lightning can cause catastrophic failure of wind turbines, which may lead to high maintenance costs. Lightning damage occurrence can be visualised in Figure 1.1 and Figure 1.2. There are many damage detection techniques in existence for wind turbine blades (D. Li et al., 2015). One of the techniques used is non-destructive testing (NDT). This is an effective way of detecting damage in composites, and includes ultrasonic, x-ray, thermography and so on.

Figure 1. 1: Lightning strike on a turbine blade (D. Li et al., 2015)

Figure 1. 2: Lightning damage due to lightning strike (D. Li et al., 2015)

1.2 Problem Statement

Non-renewable energy, or conventional energy sources, i.e. from coal, oil and natural gas, are expected to deplete within the next century. Environmental concern has also increased during the 21st century due to their serious adverse effects on the environment in the form of greenhouse effects, air pollution and acid rain (Sahin, 2004; Leung and Yang, 2012; Kaygusuz, 2015). Since the prices of fossil fuels are not stable and are always increasing, this will also cause economic concern. Hence, it is very important to find the right solution so that electricity generation is less dependent on fossil fuel. Renewable energy comes from energy sources that are indigenous and essentially inexhaustible, and can help in reducing the dependency on fossil fuels (Joselin et al., 2007). There are a number of renewable energy sources exist, such as sunlight, wind, rain, tides, waves and geothermal heat. Among these sources, wind energy is a strong contender for renewable energy and is the fastest growing energy technology in the world; it offers technological maturity with good infrastructure (Leung and Yang, 2012). The use of wind energy is predicted to expand dramatically; the usage of it can reach 23% and it can become the second largest energy source compared to solar energy.

Damage can happen in any part of the wind turbine, but the most common types of damage are blade and tower damage. More attention should be paid to the structural health of the turbine blades because they account for 15 – 20 % of the entire turbine cost and play a crucial role in the wind turbine system (Babu and Reddy, 2006; Li et al., 2014). Blade damage is not only the most costly type of damage to repair, requiring a longer repair time, but it can also cause severe secondary damage towards the wind turbine system, which could lead to catastrophic failure (Larsen, Moeller & Sorensen, 2003; Sahin, 2004; Babu and Reddy, 2006). It can be a problem to increasing the introduction of the wind turbine. There are many aspects that lead to wind turbine blade damage as mentioned by researchers such as moisture absorption, fatigue, wind gusts, lightning strikes, internal stress, heavy rainfall, thunderstorms, human error, thermal stress, corrosion, bird strikes and more (Ghoshal et al., 2000; Sundaresan et al., 2002; Cotton et al., 2001; Ciang et al., 2008; Chou et al., 2013). It is important to find the most dominant causes of wind turbine blade damage. Being the best option for reliability analysis, Failure Modes and Effect Analysis (FMEA) can be used to evaluate the possible failure modes and its potential causes of wind turbine blade damage. In order to find the most dominant causes, a multi-attribute decision-making (MADM) such as Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) can be applied in selecting the potential causes of wind turbine blade damage.

Wind turbine blades are made of different kinds of material, including wood, steel, aluminium and composite (Sahin, 2004; Babu and Reddy, 2006). In the wind industry nowadays, the turbine blades are mostly fabricated of composite materials such as carbon fibre and glass fibre due to their good structural performance (Rachidi et al., 2008; Kong, Choi, & Park, 2011; Aymerich, 2012; Li et al., 2014). Since the usage of synthetic fibre as a reinforcing material for composites has increased, there has been growing global environmental concern because of its non-biodegradable properties. So, there is now a requirement for developing sustainable materials (Mohanty et al., 2000; Srinivasan et al., 2014; Bharath and Basavarajappa, 2015; Yan et al., 2014). The usage of natural fibres is expected to become a good alternative to synthetic fibres in the upcoming.

Blade damage will cause a high maintenance cost and require a longer repair time compared to others. So, there is a need to find effective ways or the best configuration to lessen the blade damage. The composite wind turbine blade damage can be evaluated using various non-destructive testing such as visual testing, acoustic emissions, C-scan, infrared thermography, laser ultrasonic (Drewry and Georgiou, 2007; Yun and Lim, 2013; Yang, He and Zhang, 2016), but the study of damage evaluation of biocomposite material is still at early stage. So, there is a need to find the effective ways to detect the damage in both composite and biocomposite blades.

In summary, below are the research questions formulated from the problem statement mentioned above, and these need to be answered by the end of this thesis;

1) What are the main dominant causes that lead to damage in VAWT blade?
2) Can natural fibre be a good alternative to synthetic fibre in wind turbine blade fabrication?
3) What is the best configuration to lessen the damage in VAWT blade?
4) What are the best techniques to evaluate damage severity in turbine blades?

1.3 Research Objectives

The general objective of this research is to study lightning strike behaviour with respect to biocomposite, hybrid and composite material. Therefore the specific objectives for this research are:

1. To define system-specific damage including types of damage and expected potential causes using FMEA and fuzzy TOPSIS
2. To evaluate the best configuration on the best design parameter for lightning damage protection using biocomposite and hybrid composite material
3. To assess the damage severity of lightning damage on a biocomposite and a composite blade using various NDT techniques

1.4 Research Scope and Limitation

This study is conducted in accordance with the following scope and limitations:

Scope:

1. The research covers the potential causes for wind turbine blade damage in the service environment and due to natural occurrence during the application of FMEA and fuzzy TOPSIS.
2. The FMEA are used to evaluate the possible blade damage and its potential causes and TOPSIS to select the most dominant potential causes.
3. The research covers the development of Vertical Axis Wind Turbine blades focusing on lightning protection and lightning damages.
4. The research covers the lightning test and non-destructive inspection from coupon size to the actual wind turbine blade specimen (Standard comply IEC 243-3, Madsen, Hansen, & Bertelsen, 2004).
5. The research scope covering only flax as biocomposite for the hybridization technique
6. Visual inspection are performed using an optical microscope as an optical aid to magnify the blade damage
7. Liquid dye-penetrant testing are performed using a portable penetrant kit to provide maximum contrast between the damage area and its background
8. Smart piezoelectric sensors of a circular disc type are bonded on the desired panels. The bonded sensors act as an actuator for interrogating and a receiver for data acquisitioning on the undamaged and damaged wind turbine blade specimens made from composite and bio composite materials.
9. Laser-based ultrasonic scanning are conducted to detect the surface damage, which the results are in terms of images processed by an Anomalous Wave Amplitude Map (AWAM)

Limitations:

1. The lightning test was conducted in a laboratory environment. Due to the performance limitation of the 20-stage Marx Impulse Generator, only the 4 stage of charging was used for coupon and blade test. The ranges of the voltages are around 40 kV to 120 kV.
2. The coupon size is 100 x 100 mm, with the thickness ranging from 1 to 3 mm.
3. The blade dimensions were 530 mm length, 148 mm width and 34 mm thickness.
4. Liquid dye-penetrant testing has a limitation with respect to coated or painted surfaces, the measurement of the damage size for the blade specimens were done manually.

1.5 Organisation of the thesis

This thesis comprises of five chapters covering the introduction, literature review, methodology, results and discussion (optimisation techniques, coupon test and blade test) and conclusions and recommendations. Chapter one presents the research overview and the problem statement, followed by the research objectives, scope and limitations, and the organisation of the thesis.

Chapter two presents the literature review of renewable energy focussing on wind energy. The types of wind turbine, its components and the materials used for wind turbine blades and the potential of biocomposite on turbine application have been reviewed. A brief review of Failure Modes and Effect Analysis (FMEA) is presented concerning how to analyse the possible failure modes in wind turbine components focussing on the turbine blade. Next, the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) is applied to determine the most risky potential causes of failure. The types of wind turbine blade damage and the damage causes are discussed in this chapter. In addition, the damage detection processes are presented, including visual inspection, liquid dye-penetrant, ultrasonic guided wave and laser-based ultrasonic scan.

Chapter three contains four stages of methodology. The first stage is applying Failure Modes and Effect Analysis (FMEA) and the fuzzy Technique for Order Preference by Similarity to Ideal Solution (TOPSIS) to find the critical damages types and potential causes occurring on the wind turbine blade. Specimen fabrication is done in stage two for both the coupon and turbine blade specimens. Stage three of the methodology is the lightning tests for the coupon, the turbine blade specimens and the Vertical Axis Wind Turbine (VAWT). The last stage is the damage detection process using visual inspection, liquid dye-penetrant testing, ultrasonic guided wave and laser-based ultrasonic scan.

The results and discussion are presented in three sections of Chapter four. The first section is about the FMEA and fuzzy TOPSIS for a wind turbine blade. Section two concerns damage detection with respect to lightning damage using non-destructive testing for the biocomposite and composite coupon specimens. Finally, section three discusses damage detection with respect to lightning damage using non-destructive testing for the biocomposite, hybrid composite and composite wind turbine blade specimens.

Chapter five concludes all the work carried out and presents the key contributions and recommendations for future study.

REFERENCES

Abreu, L. V. L., & Shahidehpour, M. (2006). Wind Energy and Power System Inertia, 1–6.

Ackermann, T., & So, L. (2000). Wind energy technology and current status : a review, *4*.

Ackermann, T., & So, L. (2002). An overview of wind energy-status 2002, *6*, 67–128.

Adaramola, M. (2015). *Wind Turbine Technology: Principles and Design*. CRC Press.

Akil, H., Omar, M., Mazuki, A., Safiee, S., Ishak, Z., & Abu Bakar, A. (2011). Kenaf fiber reinforced composites: A review. *Materials and Design, 32*(8-9), 4107-4121.

Al-Shemmeri, T. (2010). *Wind Turbines.* Bookboon.

Arabian-Hoseynabadi, H., Oraee, H., & Tavner, P. J. (2010). Failure Modes and Effects Analysis (FMEA) for wind turbines. *International Journal of Electrical Power & Energy Systems*, *32*(7), 817–824. https://doi.org/10.1016/j.ijepes.2010.01.019

Authors, F. (2016). Multidiscipline Modeling in Materials and Structures A comparative study of composite structures including carbon , glass and natural fibers.

Atta, T. (2013). *Vertical Axis Wind Turbine Parts*. Retrieved from Green Mechanic: www.green-mechanic.com/2013/03/vertical-axis-wind-turbine-parts.html

Aymerich, F. (2012, July). Composite materials for wind turbine blades: issues and challenges.

Babu, K. S., & Reddy, M. S. (2006). THE MATERIAL SELECTION FOR TYPICAL WIND TURBINE BLADES USING A MADM APPROACH & ANALYSIS OF BLADES, 1–12.

Barbier, E. (2002). Geothermal energy technology and current status: An overview. *Renewable and Sustainable Energy Reviews*, *6*(1–2), 3–65. https://doi.org/10.1016/S1364-0321(02)00002-3

Ben-Daya, M., Duffuaa, S. O., Raouf, A., Knezevic, J., & Ait-Kadi, D. (2009). *Handbook of Maintenance Management and Engineering.* Springer Science & Business Media.

Bharath, K. N., & Basavarajappa, S. (2016). Applications of biocomposite materials based on natural fibers from renewable resources: A review. *Science and Engineering of Composite Materials*, *23*(2), 123–133. https://doi.org/10.1515/secm-2014-0088

Blanchard, J. M. F. a., Sobey, a. J., & Blake, J. I. R. (2016). Multi-scale investigation into the mechanical behaviour of flax in yarn, cloth and laminate form. *Composites Part B: Engineering*, *84*, 228–235. https://doi.org/10.1016/j.compositesb.2015.08.086

Bongarde, U., & Shinde, V. (2014, March). Review on natural fiber reinforcement polymer composites. *International Journal of Engineering Science and Innovative Technology (IJESIT), 3*(2).

Brischetto, S. (2017). "A comparative study of composite structures reinforced with carbon, glass or natural fibers", Multidiscipline Modeling in Materials and Structures, Vol. 13 Issue: 2, pp.165-187, https://doi.org/10.1108/MMMS-12-2016-0061

Butler, R., & Woofenden, I. (2010). *Wind-Electric System Maintenance*. Retrieved from home power: https://www.homepower.com/articles/wind-power/equipment-products/wind-electric-system-maintenance?v=print
Carper, C. T. (2010). Design and Construction of Vertical Axis Wind Turbines using by SUBMITTED TO THE DEPARTMENT OF MECHANICAL ENGINEERING IN PARTIAL FULFILLMENT OF THE REQUIREMENTS OF THE DEGREE OF LGomns Professor of Mechanical Engineering Design and Construction of Vertica.
Chang, F.-K., & Kopsaftopoulos, F. (2015). *Structural Health Monitoring 2015: System Reliability for Verification and Implementation.* DEStech Publications, Inc.
Charlet, K., Jernot, J. P., Gomina, M., Bizet, L., & Bréard, J. (2010). Mechanical properties of flax fibers and of the derived unidirectional composites. *Journal of Composite Materials*, *44*(24), 2887–2896. https://doi.org/10.1177/0021998310369579
Chen, C. (2000). Extensions of the TOPSIS for group decision-making under fuzzy environment, *114*, 1–9.
Chia, C. C., Gan, C. S., & Mustapha, F. (2017). Local wavefield velocity imaging for damage evaluation. *AIP Conference Proceedings*, *1806*. https://doi.org/10.1063/1.4974569
Chou, J.-S., Chiu, C.-K., Huang, I.-K., & Chi, K.-N. (2013). Failure analysis of wind turbine blade under critical wind loads. *Engineering Failure Analysis*, *27*, 99–118. https://doi.org/10.1016/j.engfailanal.2012.08.002
Ciang, C. C., Lee, J., & Bang, H. (2008). Structural health monitoring for a wind turbine system : a review of damage detection methods, *122001*. https://doi.org/10.1088/0957-0233/19/12/122001
Cotton, I., Jenkins, N., & Pandiaraj, K. (2001). Lightning protection for wind turbine blades and bearings. *Wind Energy*, *4*(1), 23–37. https://doi.org/10.1002/we.44
Darrieus, T., & Laboratories, S. N. (2014). Vertical axis wind turbines ©.
Drewry, M.A, Georgiou, G.A. A review of NDT techniques for wind turbines. Insight 2007; 49: 137–141.
Dzitac, S., & Dzitac, I. (2016). Fuzzy TOPSIS : A General View, *91*(Itqm), 823–831. https://doi.org/10.1016/j.procs.2016.07.088
Elif, Ş., Can, Ş., Sharp, J. L., & Anctil, A. (2017). Factors impacting diverging paths of renewable energy : A review, (October 2016). https://doi.org/10.1016/j.rser.2017.06.042
Ellabban, O., Abu-rub, H., & Blaabjerg, F. (2014). Renewable energy resources : Current status , future prospects and their enabling technology. *Renewable and Sustainable Energy Reviews*, *39*, 748–764. https://doi.org/10.1016/j.rser.2014.07.113
Elsaid, A., Dawood, M., Seracino, R., & Bobko, C. P. (2011). Mechanical properties of kenaf fiber reinforced concrete. *Construction and Building Materials*.
Faruk, O., Bledzki, A. K., Fink, H.-P., & Sain, M. (2012, November). Biocomposites reinforced with natural fibers: 2000-2010. *Progress in Polymer Science, 37*(11), 1552-1596. doi:https://doi.org/10.1016/j.progpolymsci.2012.04.003
Foster, R., Ghassemi, M., & Cota, A. (2009). *Solar Energy: Renewable Energy and the Environment.* CRC Press.
Franck, R. R. (Ed.). (2005). *Bast and Other Plant Fibres.* CRC Press.

Gebert, E. (2012, May 4). *No answers yet on damaged turbine blades*. Retrieved from Times Bulletin: http://timesbulletin.com/Content/News/News/Article/No-answers-yet-on-damaged-turbine-blades/2/4/173338

Ghoshal, A., Sundaresan, M. J., Schulz, M. J., & Pai, P. F. (2000). Structural health monitoring techniques for wind turbine blades, *85*, 309–324.

Gumus, A. T. (2009). Expert Systems with Applications Evaluation of hazardous waste transportation firms by using a two step fuzzy-AHP and TOPSIS methodology. *Expert Systems With Applications*, *36*(2), 4067–4074. https://doi.org/10.1016/j.eswa.2008.03.013

Haigh, S., Garbagnati, E., Muljadi, E., Pedersen, A., Steinbigler H., & Wiesinger, J. (1997). Lightning protection for wind turbine installations. *Recommended practices for wind turbine testing and evaluation*

Hau, E. (2013). *Wind Turbines: Fundamentals, Technologies, Application, Economics.* Springer Science & Business Media.

Hellier, C. J. (2001). *Handbook of Nondestructive Evaluation.* McGraw Hill Professional.

Hemami, A. (2012). Wind Turbine Technology. Clifton Park, NY, USA:Cengage Learning.

Horizontal Axis Wind Turbine VS Vertical Axis Wind Turbine. (n.d.). Retrieved from Aeolos Wind Turbine: www.windturbinestar.com/hawt-vs-vawt.html

How 40mph winds wrecked this turbine: Photo shows two blades torn off and a third buckled under force of gale. (2013, September 4). Retrieved from Mail Online: http://www.dailymail.co.uk/news/article-2410938/How-40mph-winds-wrecked-turbine-Photo-shows-blades-torn-buckled-force-gale.html

Hwang, C. L., & Yoon, K. (1981). Multiple attribute decision making—Methods and applications. Heidelberg: Springer-Verlag.

International Atomic Energy Agency. (2001). Guidebook for the Fabrication of Non-Destructive Testing (NDT) Test Specimens. *Iaea-Tecdoc-Tcs-13*, (13).

Introduction to Nondestructive Testing. (n.d.). Retrieved from The American Society for Nondestructive Testing: https://www.asnt.org/MinorSiteSections/AboutASNT/Intro-to-NDT

Jha, A. R. (2011). *Wind Turbine Technology.* CRC Press.

John, M.J., Anandjiwala, R.D., & Thomas, S. (2014). Hybrid Composites, Carbon Fiber Compos. 201–209. doi:10.1016/B978-0-08-050073-7.50014-2.

Joselin Herbert, G. M., Iniyan, S., Sreevalsan, E., & Rajapandian, S. (2007). A review of wind energy technologies. *Renewable and Sustainable Energy Reviews*, *11*(6), 1117–1145. https://doi.org/10.1016/j.rser.2005.08.004

Joshi, S. ., Drzal, L. ., Mohanty, a. ., & Arora, S. (2004). Are natural fiber composites environmentally superior to glass fiber reinforced composites? *Composites Part A: Applied Science and Manufacturing*, *35*(3), 371–376. https://doi.org/10.1016/j.compositesa.2003.09.016

Jūngert, A. (2008). Damage Detection in Wind Turbine Blades using two Different Acoustic Techniques. *The e-Journal of Nondestructive Testing*.

Jureczko, M., Pawlak, M., & Mezyk, A. (2005). Optimisation of wind turbine blades. *J. Mater. Process. Technol, 167*(2), 463-471. doi:https://doi.org/10.1016/j.jmatprotec.2005.06.055

Kandachar, P., & Brouwer, R. (2002). Applications of Bio-Composite in Industrial Products. *Advanced Fibers, Plastics, Laminates and Composites*, 101-112.

Kaplanog, V., Durmus, Z. D. U., & Cenk, S. (2013). Expert Systems with Applications Integrating fuzzy DEMATEL and fuzzy hierarchical TOPSIS methods for truck selection, *40*, 899–907. https://doi.org/10.1016/j.eswa.2012.05.046

Katnam, K. B., Comer, A. J., Roy, D., da Silva, L. F. M., & Young, T. M. (2014). Composite Repair in Wind Turbine Blades: An Overview. *The Journal of Adhesion*, *91*(1–2), 113–139. https://doi.org/10.1080/00218464.2014.900449

Kaygusuz, K. (2015). Wind Power for a Clean and Sustainable Energy Future Wind Power for a Clean and Sustainable Energy Future, *7249*(October). https://doi.org/10.1080/15567240701620390

Kim, H., Halpin, J., & DeFrancisci, G. (2012). Impact Damage of Composite Structure. In K. P. al., *Long-Term Durability of Polymeric Matric Composites.* Springer Science + Business Media, LLC.

Klass, D. L. (1998). *Biomass for Renewble Energy, Fuels, and Chemicals.* Elsevier.

Kong, C., Choi, S., & Park, H. (2011). Investigation on Design for a 500 W Wind Turbine Composite Blade Considering Impact Damage. *Advanced Composite Materials, 20*(2), 105-123.

Kömürcü, M. I., & Akpinar, A. (2010). Hydropower energy versus other energy sources in Turkey. *Energy Sources, Part B: Economics, Planning and Policy*, *5*(2), 185–198. https://doi.org/10.1080/15567240802532627

Kuik, G. v., Ummels, B., & Hendriks, R. (2008). Perspectives on Wind Energy. In K. H. al., *Sustainable Energy Technologies: Options and Prospects* (pp. 75-97). Springer.

Kutlu, A. C. (2012). Expert Systems with Applications Fuzzy failure modes and effects analysis by using fuzzy TOPSIS-based fuzzy AHP, *39*, 61–67. https://doi.org/10.1016/j.eswa.2011.06.044

Larsen, Moeller, F., & Sorensen, T. (2003). New lightning qualification test procedure for large wind turbine blades. *International conference on lightning and static electricity.* Blackpool, UK.

Lee, C., Park, S., Lee, C., & Park, S. (2016). Flaw Imaging Technique for Plate-Like Structures Using Scanning Laser Source Actuation Flaw Imaging Technique for Plate-Like Structures Using Scanning Laser Source Actuation, (April 2014). https://doi.org/10.1155/2014/725030

Lee, J. R., Ciang Chia, C., Jin Shin, H., Park, C. Y., & Jin Yoon, D. (2011). Laser ultrasonic propagation imaging method in the frequency domain based on wavelet transformation. *Optics and Lasers in Engineering*, *49*(1), 167–175. https://doi.org/10.1016/j.optlaseng.2010.07.008

Lee, J. R., Ciang Chia, C., Park, C. Y., & Jeong, H. (2012). Laser ultrasonic anomalous wave propagation imaging method with adjacent wave subtraction: Algorithm. *Optics and Laser Technology*, *44*(5), 1507–1515. https://doi.org/10.1016/j.optlastec.2011.12.008

Leung, D. Y. C., & Yang, Y. (2012). Wind energy development and its environmental impact : A review. *Renewable and Sustainable Energy Reviews*, *16*(1), 1031–1039. https://doi.org/10.1016/j.rser.2011.09.024

Li, D., Ho, S.-C. M., Song, G., Ren, L., & Li, H. (2015). A review of damage detection methods for wind turbine blades. *Smart Materials and Structures*, *24*(3), 33001. https://doi.org/10.1088/0964-1726/24/3/033001

Li, X., Yang, Z., & Chen, X. (2014). Quantitative damage detection and sparse sensor array optimization of carbon fiber reinforced resin composite laminates for wind turbine blade structural health monitoring. *Sensors (Basel, Switzerland)*, *14*(4), 7312–7331. https://doi.org/10.3390/s140407312

Lightning Splits Blade in Australia. (2012, April 25). Retrieved from WX Guard Wind: https://wxguardwind.com/lightning-news/lightning-splits-blade-in-australia/

Madsen, S. F., Hansen, L. B., & Bertelsen, K. (2004). Breakdown tests of Glass Fibre Reinforced Polymers (GFRP) as part of Improved Lightning Protection of Wind Turbine Blades, (September), 19–22.

Manwell, J. F., McGowan, J. G., & Rogers, A. L. (2010). *Wind Energy Explained: Theory, Design and Application.* John Wiley & Sons.

Mishnaevsky, Jr. L., Branner, K., Petersen, H.N., Beauson, J., Mcgugan, M., & Sørensen, B.F. (2017). Materials for Wind Turbine Blades : An Overview. 1–24. doi:10.3390/ma10111285.

Mohanty, A. K., Misra, M., & Dreal, L. T. (2001). Surface modifications of natural fibres and peformance of the resulting biocomposite. *Composite Interfaces*, (January 2013), 313–343.

Mohanty, A. K., Misra, M., & Hinrichsen, G. (2000). Biofibres, biodegradable polymers and biocomposites: An overview. *Macromolecular Materials and Engineering*, *276–277*(1), 1–24. https://doi.org/10.1002/(SICI)1439-2054(20000301)276:1<1::AID-MAME1>3.0.CO;2-W

Mueller, M., & Wallace, R. (2008). Enabling science and technology for marine renewable energy. *Energy Policy*, *36*(12), 4376–4382. https://doi.org/10.1016/j.enpol.2008.09.035

Müssig, J., & Hughes, M. (2012). Reinforcements: fibres. In *Flax and Hemp fibres: a natural solution for the composite industry* (p. 40). European Confederation of Flax and Hemp.

Naidu, A. L., Jagadeesh, V., & Bahubalendruni, M. R. (2017). A Review on Chemical and Physical Properties of Natural Fiber Reinforced Composites. *International Journal of Advanced Research in Engineering and Technology (IJARET)*, pp. 58-68.

NDT Method Summary. (n.d.). Retrieved from NDT Resource Center: https://www.nde-ed.org/GeneralResources/MethodSummary/MethodSummary.htm

Paraschivoiu, I. (2002) Wind Turbine Design, with emphasis on Darrieus Concept, Polytechnic International Press.

Park, J., Lee, S., Sabourin, T., & Park, K. A Novel Vertical-Axis Wind Turbine for Distributed & Utility Deployment.

Peesapati, V. and Cotton, I. (2002). Lightning protection of wind turbines – a comparison of lightning data & IEC 61400-24

Peesapati, V., Cotton, I., Rashid, L.S., Brown, A., Jamshidi, P., & Hogg, P.J. Resolving performance conflicts in new wind turbine blade designs.

Pickering, K. L., Efendy, M. G. A., & Le, T. M. (2016). A review of recent developments in natural fibre composites and their mechanical performance. *Composites Part A: Applied Science and Manufacturing*, *83*, 98–112. https://doi.org/10.1016/j.compositesa.2015.08.038

Pil, L., Bensadoun, F., Pariset, J., & Verpoest, I. (2016). Why are designers fascinated by flax and hemp fibre composites? *Composites Part A: Applied Science and Manufacturing, 83*, 193-205.
Rachidi, F., M. Rubinstein, J. Montanyà, J. L. Bermudez, R. Rodriguez, G. Solà, and N. Korovkin (2008), Review of current issues in lightning protection of new generation wind turbine blades, IEEE Trans. Ind. Electron., 55(6), 2489–2496, doi:10.1109/TIE.2007.896443.
Raj, B., Jayakumar, T., & Thavasimuthu, M. (2002). *Practical Non-destructive Testing.* Woodhead Publishing.
Rose, J. L. (2002). A Baseline and Vision of Ultrasonic Guided Wave Inspection Potential. *Journal of Pressure Vessel Technology*, *124*(3), 273. https://doi.org/10.1115/1.1491272
Saba, N., Paridah, M., & Jawaid, M. (2015). Mechanical properties of kenaf fibre reinforced polymer composite: A review. *Construction and Building Materials*, 87-96.
Sahin, A. D. (2004). Progress and recent trends in wind energy, *30*, 501–543. https://doi.org/10.1016/j.pecs.2004.04.001
Shafiee, M., & Dinmohammadi, F. (2014). An FMEA-Based Risk Assessment Approach for Wind Turbine Systems: A Comparative Study of Onshore and Offshore. *Energies*, *7*(2), 619–642. https://doi.org/10.3390/en7020619
Shah, D. U., Schubel, P. J., & Clifford, M. J. (2013). Can flax replace E-glass in structural composites? A small wind turbine blade case study. *Composites Part B: Engineering*, *52*, 172–181. https://doi.org/10.1016/j.compositesb.2013.04.027
Shahariar, G. M. H. (2014). Design & Construction of a Vertical Axis Wind Turbine. *The 9th International Forum on Strategic Technology (IFOST), October 21-23, 2014, Cox's Bazar, Bangladesh*, 326–329. https://doi.org/10.1109/IFOST.2014.6991132
Sørensen, B. F., Jørgensen, E., Debel, C. P., Jensen, F. M., Jensen, H. M., Jacobsen, T. K., & Halling, K. M. (2004). *Improved design of large wind turbine blade of fibre composites based on studies of scale effects (Phase 1) - Summary Report* (Vol. 1390). https://doi.org/Risø-R-1390(EN)
Srinivas, K. (2017). A Review on Chemical and Mechanical Properties of Natural Fiber Reinforced Polymer Composites. *International Journal of Performability Engineering*, (June). https://doi.org/10.23940/ijpe.17.02.p8.189200
Srinivasan, V. S., Rajendra Boopathy, S., Sangeetha, D., & Vijaya Ramnath, B. (2014). Evaluation of mechanical and thermal properties of banana-flax based natural fibre composite. *Materials and Design*, *60*, 620–627. https://doi.org/10.1016/j.matdes.2014.03.014
Stamatis, D.H. (2003). Failure Mode and Effect Analysis: FMEA from Theory to Execution. ASQ Quality Press.
Sundaresan M. J., Schulz M. J. and Ghoshal A. (2002). Structural health monitoring static test of a wind turbine bladeǁ, Subcontract Report NREL/SR-500-28719, USA.
Taylor, P., Martin, H., Spano, G., Küster, J. F., Collu, M., & Kolios, A. J. (n.d.). Ships and Offshore Structures Application and extension of the TOPSIS method for the assessment of floating offshore wind turbine support structures, (March 2015), 37–41. https://doi.org/10.1080/17445302.2012.718957
Taylor, P., Samvedi, A., Jain, V., & Chan, F. T. S. (n.d.). Quantifying risks in a

supply chain through integration of fuzzy AHP and fuzzy TOPSIS, (March 2015), 37–41. https://doi.org/10.1080/00207543.2012.741330
Telang, N. M., & National Cooperative Highway Reserach Program. (2006). *Field Inspection of In-service FRP Bridge Decks, Issue 564.* Transportation Research Board.
Tong, W. (2010). Wind Power Generation and Wind Turbine Design. WIT Press
Thompson, D. O., & Chimenti, D. E. (1994). *Review of Progress in Quantitative Nondestructive Evaluation, Volume 13.* Springer Science & Business.
Twidell, J., & Weir, T. (2015). *Renewable Energy Resources.* Routledge.
Wang, Y.-J., & Lee, H.-S. (2007). Generalizing TOPSIS for fuzzy multiple-criteria group decision-making. *Computers & Mathematics with Applications*, *53*(11), 1762–1772. https://doi.org/10.1016/j.camwa.2006.08.037
Wang, Y.-M., & Elhag, T. M. S. (2006). Fuzzy TOPSIS method based on alpha level sets with an application to bridge risk assessment. *Expert Systems with Applications*, *31*(2), 309–319. https://doi.org/10.1016/j.eswa.2005.09.040
Wind Turbine Accident Data to December 31st 2005. (n.d.). Retrieved from Caithness Windfarm Information Forum 2005: http://www.caithnesswindfarms.co.uk/
Wind Turbine Blade Design, Flat or Curved. (n.d.). Retrieved from Alternative Energy Tutorials: http://www.alternative-energy-tutorials.com/energy-articles/wind-turbine-blade-design.html
Yan, L., Chouw, N., & Jayaraman, K. (2014). Flax fibre and its composites - A review. *Composites Part B: Engineering*, *56*, 296–317. https://doi.org/10.1016/j.compositesb.2013.08.014
Yang, R., He, Y., & Zhang, H. (2016). Progress and trends in nondestructive testing and evaluation for wind turbine composite blade. *Renewable and Sustainable Energy Reviews*, *60*, 1225–1250. https://doi.org/10.1016/j.rser.2016.02.026
Yuan, S. W. (2013). *Energy, Resources and Environment: Papers Presented at the First U.S.-China Conference on Energy, Resources and Environment, 7-12 November 1982, Beijing, China.* Elsevier.
Yun, D., & Lim, H. (2013). Study of the Damage Monitoring System on Wind Turbine Blades, 3549–3565.

BIODATA OF STUDENT

Siti Zubaidah Mat Daud was born in February 1990 in Machang, Kelantan, Malaysia. She obtained her Bachelor Degree in Product Design Engineering from Universiti Malaysia Perlis (UniMAP), Malaysia in 2012. She subsequently obtained her Master's degree in Innovation and Engineering Design from Universiti Putra Malaysia (UPM), Malaysia in 2014. In the same year, she was awarded MyPhD Scholarship Program from Kementerian Pendidikan Tinggi (KPT) to further her Ph.D. study in the Department of Aerospace Engineering, Faculty of Engineering, UPM.

LIST OF PUBLICATIONS

Journals

Siti Zubaidah Mat Daud, Faizal Mustapha and Zuraimy Adzis, "Lightning strike evaluation on composite and biocomposite vertical axis wind turbine blade using structural health moitoring approach," *Journal of Intelligent Material Systems and Structures* (https://doi.org/10.1177/1045389X17754259) (Q2 Journal) – Published

S.Z.M.Daud, F.Mustapha, Z.Adzis, M.R.Ishak, M.K.A.Mohd Ariffin, "Application of FMEA and fuzzy TOPSIS for Identifying Failure Modes and Potential Causes on A Wind Turbine Blade," *Renewable Energy* (Q1 Journal) – Submitted

Zuraimy Adzis, Siti Zubaidah Mat Daud, Faizal Mustapha, "Lightning test of composite and green biocomposite material for wind turbine blades," *Renewable Energy* (Q1 Journal) – Submitted

S.Z.M.Daud, F.Mustapha, Z.Adzis, M.R.Ishak, M.K.A.Mohd Ariffin, K.D.Mohd Aris, "Damage identification of composite and biocomposite wind turbine blade using ultrasonic guided wave," *Applied Sciences* (Q2 Journal) – Submitted

S.Z.M.Daud, F.Mustapha, Z.Adzis, C.C.Chia, C.S.Gan, "Damage identification of composite and biocomposite wind turbine blade using laser-based ultrasonic scan," *Optics & Laser Technology* (Q1 Journal) – Submitted

S.Z.M.Daud, F.Mustapha, Z.Adzis, C.C.Chia, C.S.Gan, "Damage detection of biocomposite plates using laser-based ultrasonic scan," *Optics & Laser Technology* (Q1 Journal) – Submitted

Proceeding

S.Z.M.Daud, F.Mustapha and Z.Adzis, "Structural Health Monitoring for Bio-composite Wind Turbine Blade due to Lightning Strike," *The Third International Conference on Advances in Structural Health Management and Composite Structures (ASHMCS 2016)*, CBNU, Jeonju, South Korea.

UNIVERSITI PUTRA MALAYSIA

STATUS CONFIRMATION FOR THESIS / PROJECT REPORT AND COPYRIGHT

ACADEMIC SESSION : ____________________

TITLE OF THESIS / PROJECT REPORT :

DAMAGE SEVERITY EVALUATION METHODS FOR BIOCOMPOSITE VERTICAL AXIS WIND TURBINE BLADES DUE TO LIGHTNING STRIKES

NAME OF STUDENT: SITI ZUBAIDAH BINTI MAT DAUD

I acknowledge that the copyright and other intellectual property in the thesis/project report belonged to Universiti Putra Malaysia and I agree to allow this thesis/project report to be placed at the library under the following terms:

1. This thesis/project report is the property of Universiti Putra Malaysia.
2. The library of Universiti Putra Malaysia has the right to make copies for educational purposes only.
3. The library of Universiti Putra Malaysia is allowed to make copies of this thesis for academic exchange.

I declare that this thesis is classified as :

*Please tick (√)

☐	**CONFIDENTIAL**	(Contain confidential information under Official Secret Act 1972).
☐	**RESTRICTED**	(Contains restricted information as specified by the organization/institution where research was done).
☐	**OPEN ACCESS**	I agree that my thesis/project report to be published as hard copy or online open access.

This thesis is submitted for :

☐	**PATENT**	Embargo from ____________ until ____________ (date) (date)

Approved by:

(Signature of Student)	(Signature of Chairman of Supervisory Committee)
New IC No/ Passport No.:	Name:
Date :	Date :

[Note : If the thesis is CONFIDENTIAL or RESTRICTED, please attach with the letter from the organization/institution with period and reasons for confidentially or restricted.]