FEASIBILITY STUDIES FOR OFFSHORE APPLICATION OF CROSS AXIS WIND TURBINE

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FACULTY OF ENGINEERING
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ABSTRACT

Situation such as low wind speed on the onshore has lead to the combination of Horizontal Axis Wind Turbine (HAWT) and Vertical Axis Wind Turbine (VAWT) to tackle the high turbulence and frequent wind direction as mentioned problem by introducing the Cross-Axis Wind Turbine (CAWT). Due to abundance of high speed wind at offshore, the CAWT foundation design was simulated using Computational Fluid Dynamics to shows the performance of CAWT at site. Monopiles was chosen as design of CAWT to analyze the behavior of CAWT. The design was based on code and conduct of practice either from Malaysia or International and as reference of the design. After the simulation was completed, the techno economics of CAWT at offshore was made and the result of investigation has found it is beneficial to be constructed. This CAWT is applicable in extensive range of services and creating significant opportunities to the country for the usage of wind energy and less dependent to the depleting fossil fuel. 16 MW can be extracted through CAWT application and 5 years of payback period if operational.

Keywords: Cross Axis Wind Turbine, Techno Economic, Offshore, Renewable Energy

ABSTRAK

Situasi seperti kelajuan angin rendah di darat telah membawa kepada gabungan Turbin Angin Mendatar (HAWT) dan Turbin Angin Paksi Menegak (VAWT) untuk menangani pergolakan yang tinggi dan arah angin yang kerap seperti masalah yang disebut dengan memperkenalkan Gabungan Turbin Angin Saluran (CAWT). Oleh kerana banyak angin berkelajuan tinggi di luar pesisir, reka bentuk asas CAWT disimulasikan menggunakan Analisis Dynamik Bendalir untuk menunjukkan prestasi CAWT di tapak. Monopil dipilih sebagai reka bentuk CAWT untuk menganalisis kelakuan CAWT. Reka bentuk ini adalah berdasarkan kepada kod dan piawai sama ada dari Malaysia atau Antarabangsa dan sebagai rujukan kepada reka bentuk. Selepas simulasi selesai, ekonomi tekno CAWT di luar pesisir telah dibuat dan keputusan siasatan mendapati ia bermanfaat untuk dibina. CAWT ini boleh digunakan dalam pelbagai perkhidmatan dan mewujudkan peluang-peluang penting ke negara ini untuk penggunaan tenaga angin dan kurang bergantung kepada bahan bakar fosil yang semakin berkurangan. 16 MW boleh diekstrak melalui aplikasi CAWT dan 5 tahun tempoh bayaran balik jika digunakan.

Kata kunci: Turbin Angin Saluran Axis, Techno Ekonomi, Luar Pesisir, Tenaga Diperbaharui

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TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

LIST OF SYMBOLS AND ABBREVIATIONS

CAWT	:	Cross Axis Wind Turbine
PTS	:	Petronas Technical Specification
DNV	:	Det Norske Veritas
FEA	:	Finite element analysis
H_s	:	Significant Wave Height
T_z	:	Zero Crossing Wave Period
T_p	:	Peak Wave Period
T_{ass}	:	Associated Wave Period for H_{max}
API	:	American Petroleum Institute
m	:	Mass
F	:	Applied force
PTS	:	Petronas Technical Specification
LCOE	:	Levelized Cost of Electricity
HAWT	:	Horizontal Axis Wind Turbine
VAWT	:	Vertical Axis Wind Turbine
OWT	:	Offshore Wind Turbine
GHG	:	Green House Gases
FEA	:	Finite Element Analysis
R&D	:	Research & Development
O&M	:	Operation & Maintenance
FLS	:	Fatigue Limit States
ULS	:	Ultimate Limit States
SLS	:	Serviceability Limit States
u	:	Design wind speed

z	:	Height above mean speed
C_p	:	Power Coefficient
t	:	Wall thickness
T	:	Torque
ρ_a	:	Density of air
V	:	Velocity
v	:	Volume
D	:	Diameter

LIST OF APPENDICES

CHAPTER 1: INTRODUCTION

Energy is fundamental element of a modern economy to become a developed country. As a functional nation to become progress, huge resources to be used for developing the country. Diminishing fossil fuel reserves and rise usage for demand of energy that lead to in speedy development of renewable energy sources to sustain the increase of usage demand. This Renewable Energy shall be utilized to ensure that the dependability of fossil fuel shall be reduce. Additionally, the fossil fuels will knowingly contribute to the release of Green House Gases (GHG) from the combustion of the fossil fuel to generate energy and raising the environment climate change. Thus, the new and renewable energies will become one of the main energy sources for the world. Currently, renewable energy contributes only 11% of the total global energy used.(Ong, 2010)

The mechanism of wind turbine is a devise to translate energy from the wind to generate electrical power. Mainly there are two (2) types of wind turbine, vertical axis wind turbine (VAWT) and horizontal axis wind turbine (HAWT) are commonly used in renewable energy. Both VAWT and HAWT are effective to generate electricity however, yaw mechanism and inability the rotor to start itself is a drawback for the system. Cross Axis Wind Turbine (CAWT) is mainly made up from the combination of HAWT and VAWT disadvantage while capable of maximizing the exploitation of the wind turbine nonetheless of the wind direction blowing and it is a self-starter.

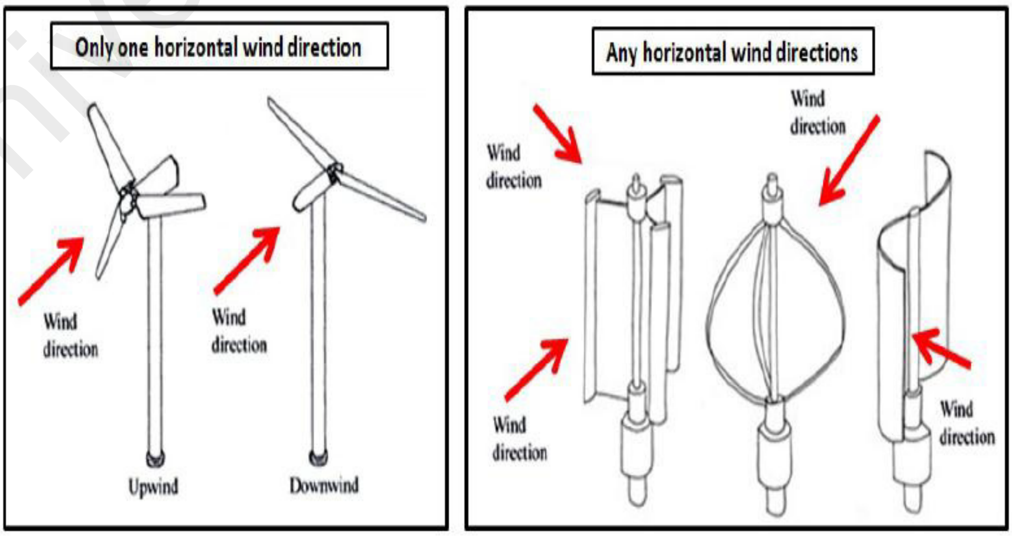


Figure 1.1 Comparison between HAWT & VAWT(Chong, 2017)

Offshore wind energy offers massive opportunities and potential in this energy industries. The mixture of the hydrodynamic loading from waves and current at marine environments, the aerodynamic effects of wind at sea side, structural dynamics of the support sub-structure and wind turbine, and the nonlinear effects of the controller of the mechanisms makes project of Offshore Wind Turbines (OWT) a very challenging project to materialize. Due to high winds speed and uncertain wind direction at the offshore environment, CAWT can extract wind energy irrespective of these downsides therefore enhancing the performance output.

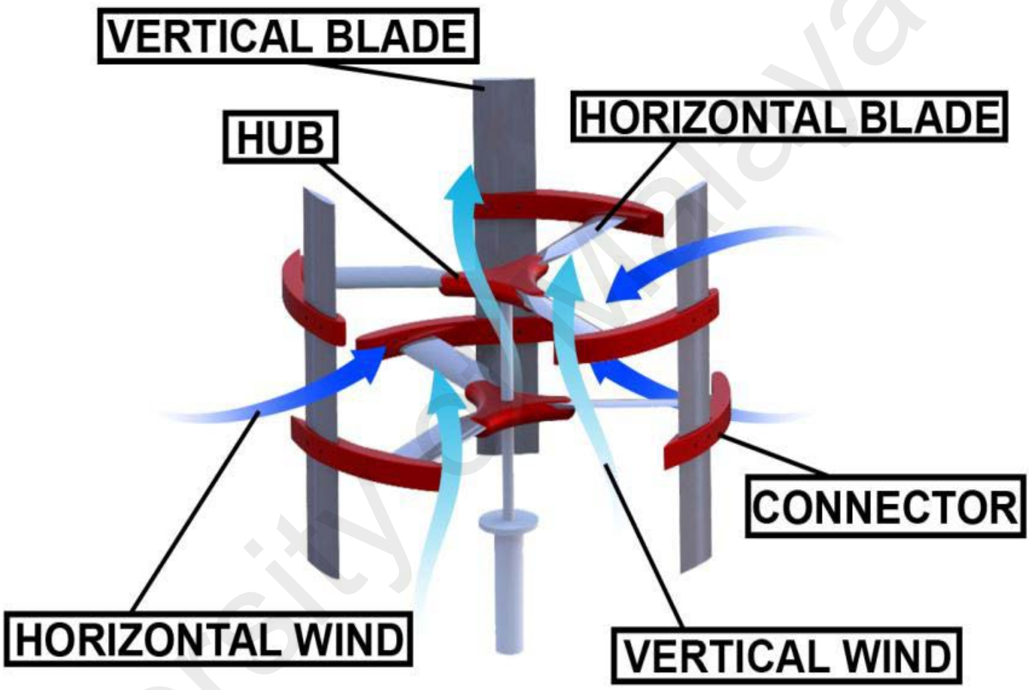


Figure 1.2 Arrangement of CAWT (Muzammila, 2017)

In the perceptive view structural design standpoint, numerous influences have to be considered in the design of Offshore Wind Turbine (OWT) support sub-structures and the structures, which are not available in onshore. Integrity of the structure designer shall be followed by rules and conduct. CAWT have a beneficial from harvesting energy at high speed and multi directional, many structure can be applied for these applications such as Tripod Jacket Leg, Four-Legged Jacket, Monopiles and others.

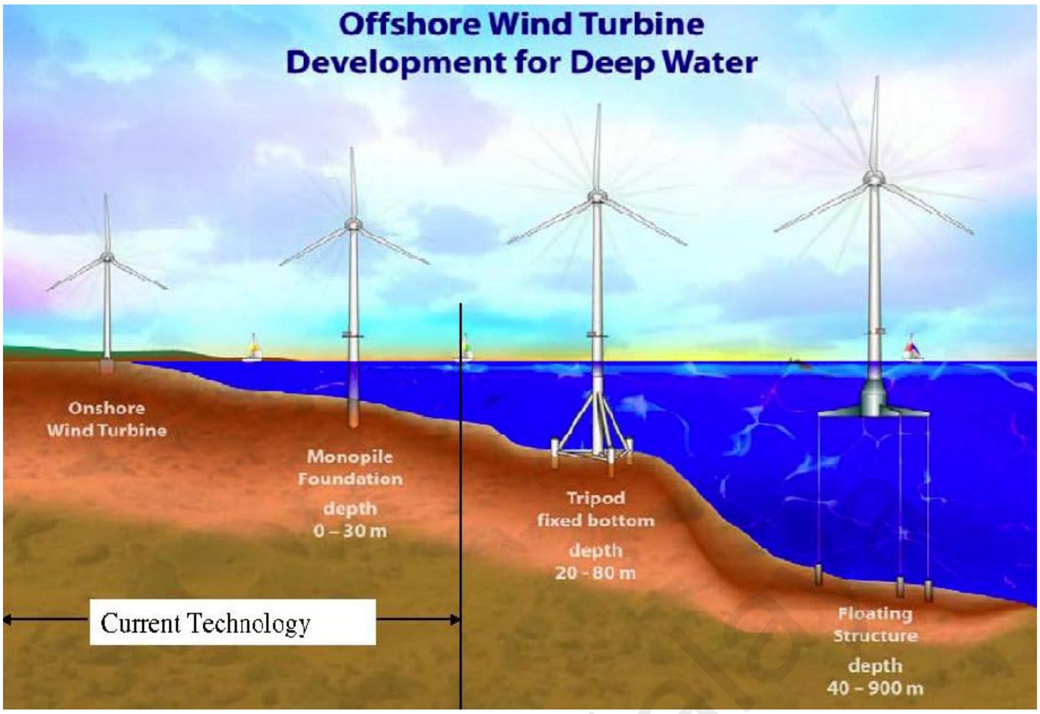


Figure 1.3 Types of Offshore Structure for Wind Turbine("Offshore Wind Turbine Foundations- Current & Future Prototypes," 2015)

Structural engineer design perspective, numerous factors have to be measured prior to design of Offshore Wind Turbine (OWT) support structures platform, which are missing from onshore studies. CAWT have a beneficial from harvesting energy at high speed and multi directional, many structure can be applied for these applications such as Tripod Jacket Leg, Four-Legged Jacket, Monopiles and others.

Techno economics is to determined either the CAWT project can be done within the budget from the project share holder. Techno economics have considered from the beginning of the project until the end of the projects. Most of the failure projects unexpectedly due to overrun of budget or underestimate the projects specification. Standard guideline shall be followed strictly for the project to successful. Material and manufacturing process is important in the project life-cycle for the success of the project.

Earning from the sales of the electricity produced from the offshore wind turbine should calculate and it is referred back to the initial cost of the project overall. In the

European country, carbon credits are established and use for their Green House Gasses effect. By generating and selling carbon credits is fluctuate in times and it is review over time the respective Nation.

Risk assessment is conducted to evaluate and emulate the less profitable project. This risk assessment done by teams of expert which directly advised the project share holder and back-up plan is needed if the initial investment project is jeopardize. Technical and economical is usually compare side by side to maximize the projects output. Other from risk assessment, there few risk to considered which are financial environmental, technical and social risk.

1.1 Problem Statement

i. CAWT has many potentials for industrial used but for offshore application, there is not many researches developed.

ii. There are many support design available and widely used in the industrial. Which are more suitable usage of CAWT at the offshore shall be studied on.

iii. By knowing the feasibility of the CAWT application, the economics of the CAWT shall be known to further the project.

1.2 Research Objectives

The objectives of this study can be outlined as the followings:

i. To design and analyze structure support Cross Axis Wind Turbine (CAWT) by using software. The structure of the CAWT shall be suitable for the foundation of the Malaysia seabed. Without proper analysis, failure of the CAWT are certain.

ii. To identify and analysis of maximum load to the structure support. The maximum load of the structure support shall be calculating to ensure CAWT can be operational functionally at offshore.

iii. Economics value to the Cross-Axis Wind Turbine (CAWT) in Malaysia. After completing the analysis of the material and load of CAWT, techno-economics to calculate either the application is worthwhile.

1.3 Scope of Work

i. To identify which sub structure is suitable for CAWT.

ii. To model and simulate the sub-structure CAWT in FEA simulation.

iii. To evaluate sub-structure application through simulation.

iv. To evaluate the economics value of CAWT for Malaysia.

CHAPTER 2: LITERATURE REVIEW

For the structure of the wind turbine for offshore application, Jackets is the foundation base of the support platform at offshore in oil and gas industries are called tripod or three (3) legged. The more commonly used in the oil gas platform is four (4) legged that come with pile foundation. The pile will support the four-legged platform. Both aerodynamic and hydrodynamic load forces is exposed for the Offshore Wind Turbine (OWT) during the operation. There are additional few analyses need to be done for the OWT such as the pushover analysis, lateral analysis, dynamic analysis and others. Pushover analysis is used as a tool to determine the ultimate capacity of structures under lateral loads, such as waves and earthquakes. (Abhinav, 2016)

Most of the OWT was based on the monopile structures. The soil of the seabed need to be considered for the OWT installation at the offshore. Fatigue analysis originally was not made into consideration for on the previous history. The behavior of the soil of the seabed is one of the criteria that most of the designer did not take into consideration. Most of the offshore structure require to withstand the project life cycle up to 20 years. The foundation of the seabed is relatively unknown and the soil condition is important features in the design. Support structures such as monopiles are often designed in a soft-stiff manner. Cyclic loading may cause collected pile movements and stiffening or softening of the soils around the pile which will be leading to differences in the foundation stiffness, thus changing the structural frequencies of the OWT. By the reasons provided, the structural frequencies closer to excitation frequencies, which would result in amplified dynamic amplification of the response, an heightening of fatigue damage, and a decrease in the proposed fatigue lifetime. Even though the offshore wind industry is relative new, a big scale of development requires more time to developed as it require to do testing and analysis to find optimum design for individual component. The technologies advances shall catch up due to lots of studies require to be done before progress in OWT can take places. During the initial or design phases, changes is commonly happen between the designer and engineer to the fundamentals projects of the Offshore Wind Turbine projects. As such, a typical ready-made of the previous project shall be the benchmarking to further study on the optimization of the projects in the future. Technologies advances over the year evaluating before final design is ready. The results of the analysis would be accurate when the wind turbine tower model behaves close to the actual model. Less accurate modeling of the tower leads to predicting incorrect response and improper estimation of the stresses.(Feyzollahzadeh, 2016). Later, it is significant to have a simplified design method that permits for fast design using only restricted site information and turbine information. That information and simplified version of design can be used during the tender plan and early design proposal of monopile foundations. Monopile foundation is analyzed and simulation to distribute all the forces and loads from the wave and wind load at offshore location. Analyzing of the monopiles load is transfer and to be checked from stress forces acting on the offshore wind turbine towards the seabed or foundation is found safe and not jeopardize the operation.

Many research and studies have been made on the many area for OWT. This including the capital cost of structure itself of the wind turbine, energy output or energy generation, integrity structural, supply networks, operation and maintenance, installation and transportation at offshore using barge is carefully evaluate to maximize the profitably of OWT. Most critical phase in the commissioning of offshore wind farm is the installation of wind turbine as the movement of the sea and whether at the point of installation is vital for the success of installation. Many coordination works require for these activities. Installation point includes transportation from the mainland to offshore to the wind farm park is done via barge and transportations analyses is made before journey embarked, Once the sub-structure is installed, next activity is piling and grouting of foundations into places so that the structure is secure properly. Finally, the installation of the turbine is made. Once the installation is complete, display cable installation within the farm and between OWT and the farm is set-up between parameters and integrate between one another.

Fatigue failure in offshore structures is commonly happen in oil and gas industries. If one is planned to do structures construction for renewable energy applications at the offshore environment can occur due to the extent of cyclic loadings which participation in service during the operations. Fatigue cracks shall progress if any pre-existing flaws which may be presented into structures through manufacturing process at the factory, transportation between factory to fabrication area and installation of the OWT at rough weather. Taking into consideration is the spreading of the strain energy release between the prominent ship and the fender guard structure is in place, three design principles can be distinguished which are the strength design, ductility design and shared-energy design. If no controlled on the fatigue crack, the problem can escalate into catastrophe or failure of the structures of the OWT when an unbalanced stage of the crack growth is reached. Consequently, imperfections or cracks in the offshore constructions require consistently inspected and observed to guarantee that the structures are fit for design purpose once installed at site. Another problem of the offshore environment is the structures construction are exposed to corrosion occurrences because the severe service maritime atmosphere and bring forward to momentous heights of harm to the structures and hence a decrease in operation life cycle of the CAWT. The erosion crack growth instruments and most feared among the operation and maintenance team as the crack enlarged under fatigue loading due to the synchronous interaction of the applied cyclic loads and the influence of the corrosive environment at offshore. (Institute Petroleum, 2014)

For the offshore wind technologies has a similarity from the onshore technologies with minor modifications to be made. Offshore wind flow has higher wind speed compare to the onshore. There are many difficulties need to be faced by the designer such as the waves and excessive wind. Safety of making the wind turbine for offshore use is the main priority. There are several standards and code to be follow and just recently was established. Offshore turbine technology bears striking similarity to that onshore with only minor modifications. The only significant difference is in the design of the foundations, which requires floating and/or other special foundations to account for underwater tower submergence. (Yogesh Kumar 2015). For example, of analysis require to take consideration is fatigue, stress, aerodynamic and structures analysis need to be done before moving to the next stage. Many software has developed to help designer to assists them.

Statistic have shown that more offshore wind farm has open for this RE use. China, Hong Kong, USA, UK and Germany are few Nations that are strived on this technology. The overall cost for making this offshore wind farm relatively high compare to the inland, through technologies advancement and large investment for Research & Development (R&D), this cost can be reduced further and become more competitive. Although the startup project cost of a wind turbine is high, the post-initial cost of electricity generation is lower than that of any other electricity generating system. In fact, this cost could even be significantly lower if installation takes place on a very large scale. (Yogesh Kumar a & Jin Woo Lee b, 2015).

Petronas Technical Specification (PTS) and American Petroleum Institute (API) was used for guidance on the developed of the CAWT application for the research. Petrolium Nasional Sdn Bhd (PETRONAS) was the operator and authority for the oil and gas in Malaysia. The relevant technical specification and data shall be followed to produce the

CAWT application at offshore. API is guideline used on the material selection and working stress design of the platform. API also a recommended practice based on other best and safe practice towards the newly design offshore area.

CHAPTER 3: METHODOLOGY

In order to perform structural analysis, there are few guidelines an engineer need to follow. First, the establishing the design data and collection data of the structure should be determined. Next, selection of pile dimension to be determined and wind load estimation and initial pile dimension to calculate the wave loads. Reference of the geotechnical of the foundation shall be reviewed prior to modelling of the monopiles.

Modelling of the monopiles to calculate the load stress of the structure is carried out on the conventional software, Solidworks and ANSYS. Next, economics of beneficial of the CAWT in offshore is calculated.

3.1 Design Basis

Malaysia is abundant of natural fossil fuel especially in Terengganu and Sarawak. Author has selected monopiles is being used for the research. Fatigue Limit States (FLS), Ultimate Limit States (ULS) and Serviceability Limit states (SLS) shall be design basis of monopiles. ULS is loss of structural resistance or interaction failure due to brittle feature of the material and FLS is cumulative damage due to repeated loads. SLS is to determine the deformations that the behavior changes in the distribution of loads between support rigid and monopiles.

This environmental load (ULS, FLS and SLS) to be determined prior to selection of piles to be used. Material selection of the monopiles can determined the value of the environmental load require to sustain.

Table 3.1: Steel Types

Steel Types	Grade	Allocated Members
Type I (Primary Member)	S355 M	Jacket Primay Members, Leg, Braces, Piles
Type II (Special)	S355 EMZ	Jacket Primary member with high stress concentration such truniion, padeyes, pile heads
Type III	275 DE	Jacket Secondary Member or miscellaneous bracket cable tray or pipe support.
Type IV	355 DE	Secondary Member where higher strength is required such as mudmat, caissons, J Tube or riser)

The table 1 shall be the guideline in selection of material of the monopiles.

3.1.1 Metocean

Metocean is combination of meteorology and oceanographic. Metocean is undertaking the estimate environmental conditions to in order to impact the choices for the project. PTS 112202 & DNV -OS- J101 have defined general information to be as guideline in the project.

Wind load act on the percentage area of CAWT above the water level in the offshore or Mean Sea Level, is an important apply to wind data. Then the time interval over which wind speeds is averaged as an whole. There are two types of averaging interval, gust or wind speed. Gust is referred to the averaging internal that will be less than one minute. wind speed can be classified as averaging interval is more than one minute. Based on Planning, Designing and Constructing Fixed Offshore Platforms, Working Stress Design (Institute Petroleum, 2014), Wind Profile Calculations from strong wind can be done:

$$u\,(z,t) = U\,(z) \times \left[1 - 0.41 \times I_u\,(z) \times \ln(\frac{t}{t_0})\right] \qquad (3.1)$$

Where:

u (z,t) design wind speed (m/s),

z height above mean sea level (m)

$t \leq t_o = 3600$ s

where the 1 hour mean speed U(z) (m/s) at level z (m) is given by:

$$u\,(z) = U_o \times \left[1 + C \times \ln(\frac{z}{10})\right] \qquad (3.2)$$

Where

$$C = 5.73 \times 10^{-2} \times (1 + 0.15U_0)^{\frac{1}{2}} \qquad (3.3)$$

And where the turbulence intensity $I_u(z)$ at level z (m) is given by:

$$I_u(z) = 0.06 \times (1 + 0.043 \times U_o) \times (\frac{z}{10})^{-0.22} \qquad (3.4)$$

Where U_0 (m/s) is the 1- hour mean speed at 10 m above sea level.

Below are standard data for offshore wind.

Table 3.2: Metocean Data

Peninsular Malaysia (Petronas, 2016)

Parameters	Units	1 Year Operating	100-year Storm
Wind			
1 Min Mean	m/s	20	29
3-sec Gust	m/s	22	33
Wave			
H_s	m	4.38	5.77
T_z	sec	6.91	8.06
T_p	sec	9.74	11.37
H_{max}	m	8.44	11.65
T_{ass}	sec	8.38	9.64
Ocean Current			
At Surface	m/s	1.24	1.67
At Mid Depth 0.58*D	m/s	0.98	1.33
At near seabed 0.01*D	m/s	0.27	0.36

Table 3.3: Metocean Data

Ballingian (Petronas, 2016)

Parameters	**Units**	**1 Year Operating**	**100-year Storm**
Wind			
1 Min Mean	m/s	24	27
3-sec Gust	m/s	26	42
Wave			
H_s	m	3.1	4.2
T_z	sec	7.0	7.5
T_p	sec	9.8	12.1
H_{max}	m	5.8	8.0
T_{ass}	sec	9.0	9.4
Ocean Current			
At Surface	m/s	0.8	1.5
At Mid Depth 0.58*D	m/s	0.7	1.2
At near seabed 0.01*D	m/s	0.2	0.3

3.1.2 Turbine Data

The kinetic energy of a stream of air can be calculated as:

$$E = \frac{1}{2}\, m\, V^2 \tag{3.5}$$

Where m is mass and V is velocity

Wind stream can be formulated at the wind rotor cross sectional area. The kinetic energy of the air stream can be expressed as at the turbine (Mathew, 2006):

$$E = \frac{1}{2}\, \rho_a v\, V^2 \tag{3.6}$$

Where $\rho_a$is the density of air and v is volume of air section available at rotor on the blade section. The air tract interface between the rotor over the unit time has a cross-sectional area is equal to the rotor (A_T). The thickness of the rotor is equal to the wind velocity (V), henceforth power can be expressed as :

$$P = \frac{1}{2}\, \rho_a A_T\, V^3 \tag{3.7}$$

Theoretical power accessible in the wind stream but turbine cannot harness the power totally from the wind. At the turbine area, wind stream shall pass and the kinetic energy is shifted between rotor and the gap air leaving the turbine removes other air away. Efficiency of the rotor is determined by the power output that transfer the wind rotor to take places. The power coefficient (C_p) written as:

$$C_p = \frac{2P_T}{\rho_a A_T\, V^3} \tag{3.8}$$

Where P_t is the power developed by the wind turbine. Many factors can impact the power coefficient such as blade arrangement, rotor blades and others. To obtain the maximum or optimum C_p these parameters to be tested with wide range of velocities. Formula of rotor torque (T) is:

$$T = \frac{1}{2}\, \rho_a A_T\, V^2\, R \tag{3.9}$$

Where R is the radius of the rotor.

At certain degree of wind speed, the power developed by the rotor is coexist between the rotor tip and wind.

3.2 Pile Design

3.2.1 Dimension

When sizing the pile foundation several factors need to be considered such as diameter, parameter, wall thickness, material strength and others to considered appropriate. The load applied to the capacity of piles referred on strength and deformation properties of the pile material. The design of the pile penetration intend to be keep adequate to developed tolerable capacity to resists the maximum calculated axial bearing and pullout loads from the installation during hammering of the piles.

3.2.2 Wall Thickness

The wall thickness value not be sufficient considered of stability during the installation or to avoid local and global effect of buckling. The pile wall thickness usually locality of the mudline or others is controlled by combined bending moment and axial load that results from the design loading environments of the monopiles.

According to API RP 2A, the D/t ratio of the entire length of piles shall be small relatively if possible to prevent local buckling at stress to the yield strength of the pile material. co minimum wall thickness can be calculate as per below(Institute, 2014):

$$t = 6.35 + \frac{D}{100} \tag{3.5}$$

Where

t is the wall thickness (mm)

D is the diameter (mm)

In selection of minimum pile material thickness, below are the normally used (Petronas, 2016):

Table 3.4: Suggested Nominal Thickness

Pile Diameter mm (in)	Nominal Wall Thickness mm (in)
610 (24	13 (1/2)
762 (30)	14 (9/16)
914 (36)	16 (5/8)
1067 (42)	17 (11/16)
1219 (48)	19 (3/4)
1524 (60)	22 (7/8)
1829 (72)	25 (1)
2134 (84)	28 (1.125)
2438 (96)	31 (1.25)
2743 (108)	34 (1.375)
3048 (120)	37 (1.50)

3.2.3 Length of Piles

During the installation of piles, the capability of the lift equipment of the installation barge is to considered the pile to be to lift up, lower down or in vertical position and stab the sections and pile driving hammer on the sections shall be considered when selection of piles length. These capabilities require to be check during installation of the piles. The stress developed in the pile lifting, static and dynamic stresses by the installation contractor due to hammer weight and operation also can success or failure during the installation of piles.

To avoid the premature failure in piles installation at sites, the following limit to the ultimate compressive capacity required of various pile size (Petronas, 2016):

Table 3.5: Limits of Ultimate Pile Capacity

Pile Diameter – inch (mm)	Ultimate Pile Capacity (MN)
30 (762)	4000 (17.8)
33 (914)	4700 (20.9)
42 (1067)	5500 (24.5)
48 (1219)	6300 (28.0)
54 (1372)	7000 (31.1)
60 (1524)	7800 (34.7)

Additional make up shall be considered problems of set up and restart during driving based upon available soil data at the time of design. Extra allowance to avoid any standby at offshore site is valuable is it calculated to cost.

3.2.4 Geotechnical load of the foundation

Malaysia seabed is varying between clay and sand depends on the location. For West Coast is marine clay and Sabah and Sarawak is sand.

To ensure no reduction in pile capacity, the zone of soils within two (2) * pile diameter of the center piles should be disturbed. Minimum center to center spacing pile and conductor can be calculate:

For piles in embedded in clay

$$S = 2D + x + d \tag{3.6}$$

For piles in embedded in sand

$$S = 2D + \ x + 4d \tag{3.7}$$

Where

S is minimum center to center spacing between a pile and conductor

D is pile diameter

D is conductor diameter

x is maximum deviation of a conductor during installation

Values for x can be taken as:

T < 90 m	X = 1 m
90m < T < 120 m	X = 2 m
T > 120 m	X = 3 m

3.2.5 Power Coefficient

Under constant acceleration, the kinetic energy of an entity having mass (m) and velocity (v) is equal to the work done (W) by displacing that object from rest to a distance s under a force (F). Rendering to Newton's Law:

$$F = ma \tag{3.8}$$

Hence

$$E = mas \tag{3.9}$$

Using the third equation of motion of Newton's Law:

$$v^2 = u^2 + 2as \tag{3.10}$$

Author get

$$a = \frac{(v^2 - u^2)}{2s} \tag{3.11}$$

Assume preliminary velocity of CAWT turbine is zero:

$$a = \frac{v^2}{2s} \tag{3.12}$$

Substituting in equation in 3.9, the kinetic energy of mass in motion is:

$$E = \frac{1}{2} m v^2 \tag{3.13}$$

Power extraction inside wind formulate in the rate change or energy:

$$P = \frac{dE}{dt} = \frac{1}{2} v^2 \frac{dm}{dt} \tag{3.14}$$

Flow rate mass equation:

$$\frac{dm}{dt} = \rho A \frac{dx}{dt} \tag{3.15}$$

Distance is given by the rate:

$$\frac{dm}{dt} = v \tag{3.16}$$

$$\frac{dm}{dt} = \rho A v \tag{3.17}$$

Hence from the equation 3.14, the power can be defined as

$$P = \frac{1}{2}\,\rho\,A\,v^3 \tag{3.18}$$

Bestowing to the Betz Limit or Bet'z Law concluded the highest theoretical power efficiency of any design of wind turbine is 0.59. The design philosophy shall be no further than 59% of the energy maintained by the wind that pull out by a wind turbine. Formula of power coefficient as

$$C_{pmax} = 0.59 \tag{3.19}$$

Limitation of wind turbines cannot function at this maximum boundary. The Cp value is exceptional to individually turbine category and is a purpose of wind speed that the turbine is operational. After integrate several engineering requirements of a wind turbine such as strength and durability in particular application, the real world limit is well below the Betz Limit values ranging from 0.35-0.45 are common even in the finest designed wind turbines. Taking consideration of other factors for completing the wind turbine system as whole such as the gearbox, tower, yaw system, nacelle, around 10% to 30% only the power of wind generation is actually converter into functioning energy. In conclusion, the power coefficient is summarized in equation (3.18) and the power extracted by the wind given by:

$$P = \frac{1}{2}\,\rho\,A\,v^3 C_p \tag{3.20}$$

3.3 Software

There are computer tools needed in order to generate the modelling structure and to conduct the analysis studies. Solid Works is used in order to generate the 3D model of the Cross-Axis Wind Turbine and Pile Design. The analysis studies were conducted by using ANSYS.

3.3.1 Solidworks 2017

Solidworks is 3D Computer Aided Design (CAD) software. It is used to generate 2D or 3D model and to analyse all type of mechanical component. Solid Works is a U.S-based developer and supplier for mechanical design automation software. This software is being widely used all over the world by engineers to analyze all type of mechanical component.

In this project, the 3D model of all the component and parts such as water pump and solar panel is generated by using Solid Works in order to conduct the analysis of the parts itself. Solid Works is used because it is easy-to-use and user-friendly software that manage to generate the desired drawing in matter of time. Solid Works software has achieved these goals because it helps engineers be more productive than before, while designing more pioneering goods that make engineer excel in their field.

3.3.2 Modelling

In modelling, it involves in generating a conceptual or graphical geometric of a structure. It also involves in defining the characteristics of the structure, as well as the behaviour in term of its physical properties such as material properties, load or force applied and support. Generally modelling contains a dependable set of philosophies for mathematical and computer modelling of 3D solids. All parameters and dimensions of the component need to be identified in order to generate the 3D model. The parameters refer to limitations whose values regulate the shape or geometry of the component. It can be either geometric or numeric parameters. Numeric parameters would be the line lengths or diameter of a circle. Geometric parameters refer to tangent concentric, horizontal or vertical.

3.3.3 Geometry

The solid model of the component can be generated in 2D or 3D graphical to represent the actual component. The dimension of the component is taken and be used in the drawing of the model. The geometry involves in creating the model are points, lines, surface, and volume of the component. There are also processes involved in creating the model such as extruded, extruded cut, revolved, fillet, and chamfer.

3.3.4 ANSYS

ANSYS is engineering simulation software with general purpose. ANSYS to simulate interactions of multi discipline in field work. ANSYS enables to simulation tests of the virtual working conditions. It also enables to simulation in virtual atmosphere before engineering models or products. ANSYS also can identify any flawless design in the simulation environment. ANYS can be link between the CAD and FEA.

3.3.5 Attributes

Attributes consists of the features of the 3D designer characteristic and the external influences which are applied to the model. There are several types of attribute in order to represent the particular type of behavior of the model such as load and support. ANSYS can download CAD data from Solidworks to build geometry. FEM which is required for computation is generated. ANSYS ability to experiment advanced simulation analysis swiftly, steadily and essentially by its diversity of contact procedures, time-based loading features and odd shape models.

ANSYS Workbench is a stage which combining simulation features and designed CAD systems with fully computerization and precision. The state of the art of ANSYS Workbench from the ANSYS solver algorithms within the software. Moreover, the modelling and simulation of ANSYS Workbench is confirmation and refining of the product in practical environment once established. Several features available inside ANSYS features are listed as follows:

- Material defines the behavior of the element used.
- Support specifies how the structure is constrained.
- Mesh describes the element type and discretization on the geometry.
- Loading specifies the load that is acting to the component.

3.3.6 Load Applying

Once the component is fully designed, it will be burden with the load such as gravity or pressure. Load is also the term of forces, deformations, and accelerations applied to the component. The load will cause stresses, deformations, and displacements in the component. The load is evaluated based on the published regulations or specifications. Each load case is solved separately and the results can be obtained separately according to the load case. Results can be combined together during the results viewing stage.

3.3.7 Meshing

Meshing is an fundamental part of the CAE simulation process. Once component or model is fully designed, it has a smooth geometry. Meshing features from ANSYS provide the flexibility or power by producing meshes that range via complexity of the model from pure hex to highly detailed hybrid. In meshing process, the component is defined on the form of nodes numbers and elements that will be used to represent the actual component. The mesh is giving direct effects in terms merging from meshing, accurateness of the modelling mesh and speed up the solution of the model. Additionally, time taken to create and mesh a model is often a important criteria of the modelling of to get results from a CAE solution. Therefore, the well design model and more refine meshing tools, the better output the solution given.

3.3.8 Results and Analysis of modelling parts

After the meshing process, simulation process is done in order to do the analysis of the component. The results are created by the solver in ANSYS software and it is automatically loaded for viewing. The results can be viewed after the component has gone through the simulation process. The results of the analysis consist of the yield strength, stress distribution, as well as the deformation of the component.

3.4 Generation Cost of Cross Axis Wind Turbine

Based on the energy trend resources in Malaysia, it is clearly the fossil fuel will be overtake of the renewable energy. CAWT can easily become dominant force to the wind energy industry if chances was given.

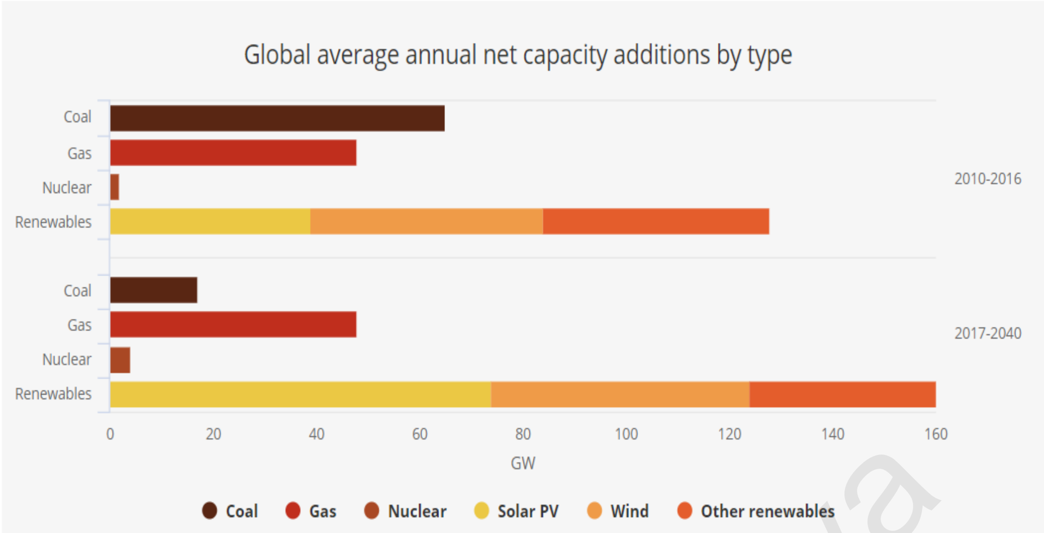


Figure 3.1 Global Average Annual Net Capacity by type ("World Energy Resources (Wind)," 2016)

Renewable energy as predicted will overtake the fossil fuel resources. Several costings shall be considered to developed the CAWT into fully functional wind energy are capital, variable, electricity cost and discounted rate. Wind farm park costs are apparently zero. This is the significant difference among electricity produced by wind power and other conservative electricity generation possibilities. For instance, in the natural gas power plant as high as 40–60% of the costs are linked to fuel and Operation & Manual (O&M), associated to about 10% for an onshore wind farm.

3.4.1 Capital Cost

Capital cost can be separated into four (4) groupings:

- Turbine price which compromise manufacture, blades, transformer, barge transportation to sites and installations.
- Grid connection charge including cables, connection and power evacuation system.
- Cost of civil works including site survey, foundation and buildings

- Other costing such as authorizing procedures, consultancy and licenses, Research and Development and monitoring.

Low labor cost has impacted several developing countries with industrial manufacturing capacity of producing wind turbine equipment, the intense of rivalry in a specific market or area of wind farm park, the negotiating influence of market dominant forces, government rules and regulation regarding the features of the wind turbine, the distance and modality of grid connection and the amount of the civil works has shown a degree of increase of capital cost of a wind turbine.

The wind turbine component is the solitary largest cost and trailed by the grid connection as shown in figure 3 below. The grid connection is associated to the circulation voltage grid ranging from 8-30 kV through step up or step-down voltage transformer. Nevertheless, in the new and modern approach of technologies for wind farms to be linked to the transmission network has result in larger costs for overall capital investment. Civil works may unlike from country to country. Some of the country have cheaper labor cost with many manpower to work on.

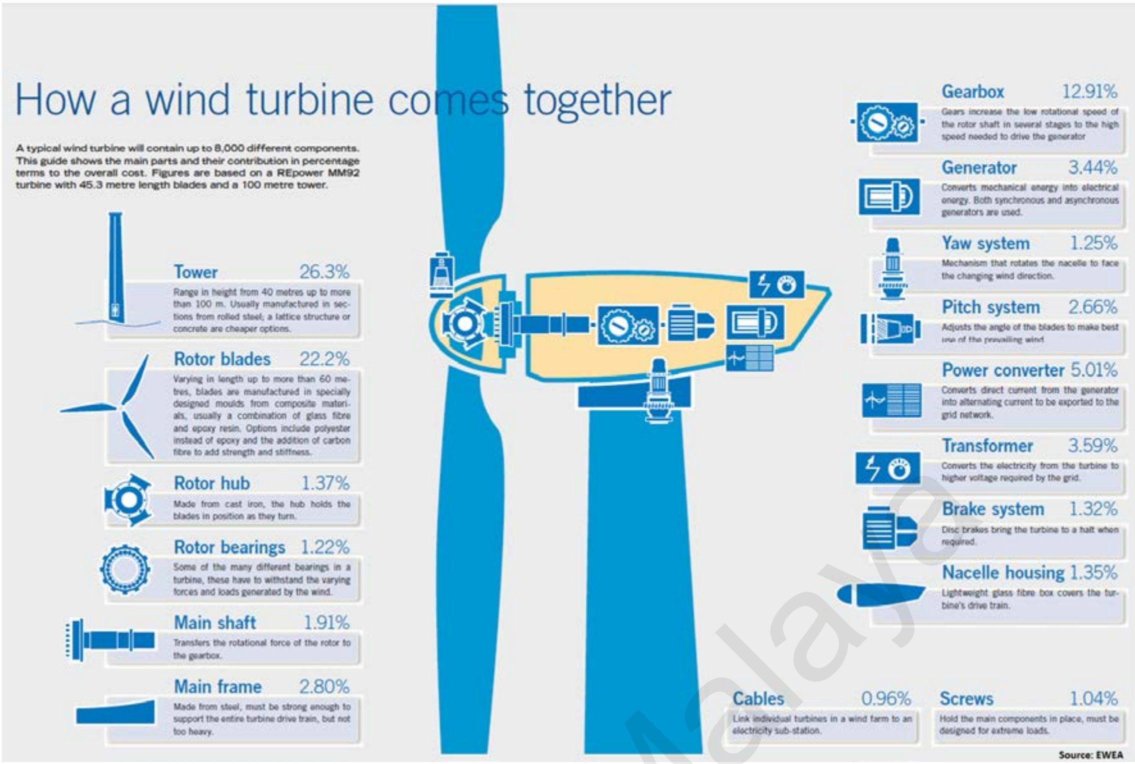


Figure 3.2 Breakdown of Wind Turbine components (Timvandendael, 2013)

Another factor to compute the capital cost are inclusive of R&D of specific wind farm park that it is potential to harvests the wind energy, tendering the specific location of land, health and safety of a public, taxes, rules and regulation, permits and licensing to operate the wind turbine. Institutional setting by the rulers of the government shall give priority in particular of public interest for the renewable energy have to be included in the cost.

3.4.2 Variable Cost

Wind turbines is similar to other engineering equipment that always require operation and maintenance (O&M) to ensure the safe and reliability of the equipment to perform at optimum level, which creates a considerable portion of the total annual costs. While the amount is considerably lower compare to fossil fuel electricity generating in the market. Some of the important factor to considered is the O&M spare parts and training, land and substation rental, insurances and taxes and management and administrative. Compare to capital cost, the variable cost is unknown to the users.

At the present time, some wind turbine constructors should give urgencies lower the variable costs and one of them is O&M. Many R&D shall be made to emerging new turbine designs that need less maintenance visits to site, which eventually indirect output is greater turbine productivity.

Wind turbines associate to the economies is measure defined as deteriorating investment per kW with increasing turbine capacity output. Favorable economics measure shall be include in the Operation & Maintenance frequent visit. Latest technologies including new, efficient and larger wind turbines have impacted the reduced of Operation and Maintenance requirements compare to the older installed at site, smaller turbine that can affect the capital cost overall.

3.4.3 Electricity Produced and Economic Lifetime

The specific location wind locally resource is definitely the critical vital influence affecting the cost-effectiveness of wind energy investments. This holy grail location also associated differences in the cost per kWh between nations and developments of the wind turbine generation of electricity and profitability by doing Renewable Energy in the first place. For example, of the crude oil, the hydrocarbon output is inoperable without a substantial sizes of oil field and this applied also to wind turbines generation are inoperable deprived of a powerful wind resource at sites. Wind turbine which depend on the size of the blades and features of the turbine are altered to ensemble the experiential airstream regime at site with extreme computer modeling and analysis, based on optimum topology and meteorology capacities obtain by many hours spend to obtain the as close as practically reasonable of data to compute.

By theoretical energy generation this can be done by wind turbine power curves and estimated wind regime at specific site or location. This power generation is compact by a number of features that can be applied. For example, the array losses, which happen due to wind turbines scrutiny between in a wind farm or blade fouling losses. Theoretical energy also can include the electrical losses between transformers and cabling due the temperature or weather. The most fear in O&M wind turbine downtime for schedule maintenance or technical failure. This unforeseen event can impact of 10 to 15% lower the energy calculation founded on the wind turbines power curves provided.

3.4.4 Offshore cost of wind energy

Offshore is harsh environment to work with. There are different scenarios regarding distance from between onshore and offshore embarking area, water depth to the sea bed, and grid construction connection or communication from offshore to the main land affect the cost overall of the offshore wind farm. Overall, the better energy production resulting from the better wind conditions at offshore than onshore situation does not compensate for the higher preliminary capital O&M costs. However, offshore wind power more expensive than onshore wind power. Several key restrictions need to be considered for offshore wind energy projects.

The foundations or specific area of wind farm are noticeably more expensive compare to onshore. The costs is highly correlating between height water depth and the chosen construction and installation method. The foundations soil or metocean of specific site need to run the study and analysis to ensure no mistake no room for errors. The construction and installation method shall be carefully analyzed and developed compare to onshore projects to ensure the effectiveness of the wind turbine to operate. Indirectly, this has impact on both cost and reliability but with continuous efforts and investment made in R&D can lower down the costs.

O&M costs at offshore are significantly higher compare to onshore projects. Several factors to be factored in such as higher cost of transport since need to transport all the equipment to site via special arrangement of barge as well as frequencies of site access.

Another factor is due to wave and weather conditions are the main causes. By having well-organized O&M strategy and periodic inspection plan is extremely significant for reducing the costs down. Detailed planning has to being made to avoid any increase in cost unintentionally. Electrical and instrumentation connections between the turbines, and between the farm and the onshore grid, generate substantial additional costs compared to onshore wind projects.

Environmental analyses tend to be more stringent due to impact on the society and environment. Moreover, Research and Development (R&D) programs by related government agency to monitor impact and consequences of animal habitat in the ocean. With more initiative and incentive given, more offshore wind turbine projects to be developed with reduction in cost and complexity of the wind turbine. Any potential suitor or investor has faces higher risks of investment which can relate into higher interest rates and premiums to cover the cost.

To become realization of the wind farm and to fulfill the dreams of offshore wind park to become realism, several issues to be tackle. For instance, the National and local policies that decide either the wind energy development shall bear the entire cost of the grid connection and upgrade the current civils work. An assessment shall be made on the impact of the environment to avoid any issues related to the environment. Extensive studies on the taxes and fund loan should be made beforehand if the offshore wind farm to be established. Balance roles and responsibilities between project developer and the government shall be established to avoid complication later. Long term development and cost predisposition of wind energy investment shall be reviewed by an expert as these new available technologies improvement from time to time. This advancement of new technologies should be correlate between the energy or taxation policies where the offshore wind farm to be operate and established.

3.4.5 Levelized Cost of Electricity

The Levelized Cost Of Electricity, (LCOE) terms of electrical energy production that expressed by the current value of the price to produced electrical energy in cents /kW.hr considering the economic life of the offshore wind farm (Mathew, 2006). This cost shall incurred in the construction of the wind turbine, installation of the wind turbine at specific location, operation harvesting the wind turbine energy and maintenance of wind turbine itself. 20 years is operation planned of a lifetime to generate electricity. The equation as per below:

$$LCOE = \frac{(CapE \times FCR) + OpEx}{(AEP_{net}/1000)} \tag{3.20}$$

Where

LCOE = Levelized cost of energy ($ / Megawatt-Hour (MWH))

FCR = Fixed Charge Rate

CapEx = Capital expenditures ($/Kilowatt (kW))

AEP net = net average annual energy production (MWH/megawatt MW / year yr)

OpEx = Operation expenditures ($/kw/yr)

In Malaysia, Sustainable Energy Development Authority (SEDA) is the constitutional body that administrative and managed the execution of the Feed-In-Tariff (FiT) mechanism. However, for the wind energy, there is no tariff that could be applied for this study. FiT in Malaysia includes the following Solar (PV), Biogas, Biomass, geothermal and small hydro.

FiT DASHBOARD

FiT Rates | RE Quota | RE Capacity | RE Generation

Solar PV (Community)
Solar PV (Individual)
Solar PV (Non-individual (≤ 500 kW))
Solar PV (Non-individual (> 500 kW))

Biogas
Biogas (Landfill / Agri Waste)

Biomass
Biomass (Solid Waste)

Small Hydro

Geothermal

FiT Rates for Solar PV (Community) (21 years from FiT Commencement Date)

Description of Qualifying Renewable Energy Installation	FiT Rates (RM per kWh)
(a) Basic FiT rates having installed capacity of :	01-JAN-2018 ▼
(i) up to and including 4kW	0.6682
(ii) above 4kW and up to and including 24kW	0.6519
(iii) above 24kW and up to and including 72kW	0.4435
(b) Bonus FiT rates having the following criteria (one or more) :	
(i) use as installation in buildings or building structures	+0.1256
(ii) use as building materials	+0.0848
(iii) use of locally manufactured or assembled solar PV modules	+0.0500
(iv) use of locally manufactured or assembled solar inverters	+0.0500

Figure 3.3 FiT Rate in Malaysia(Kementerian Tenaga)

Investor can be interested if another option is given for investor to invest in the renewable energy. Another alternative beside the FiT is the carbon credits or emission certificate can be imposed into the energy industries. The taxes and incentive can attract more stakeholder to invest in the renewable energy if better rate is given from the government.

CHAPTER 4: RESULT AND DISCUSSION

4.1 Simulation

From the above data requisition of the material of pile, Solidworks software are being used to find the optimal pile selection for CAWT. Once the selection of pile is complete, techno-economic analysis is done.

4.1.1 Steel Selection

The pile selection is referred to table 3.1 where type I is recommended steel compare to type II. Difference type I and II was through the Through Thickness Properties (TTP) and "Z" direction of load in transverse direction is known. S355N was chosen to be the selected as it abundance availability in the market and it commonly used for jacket construction for offshore.

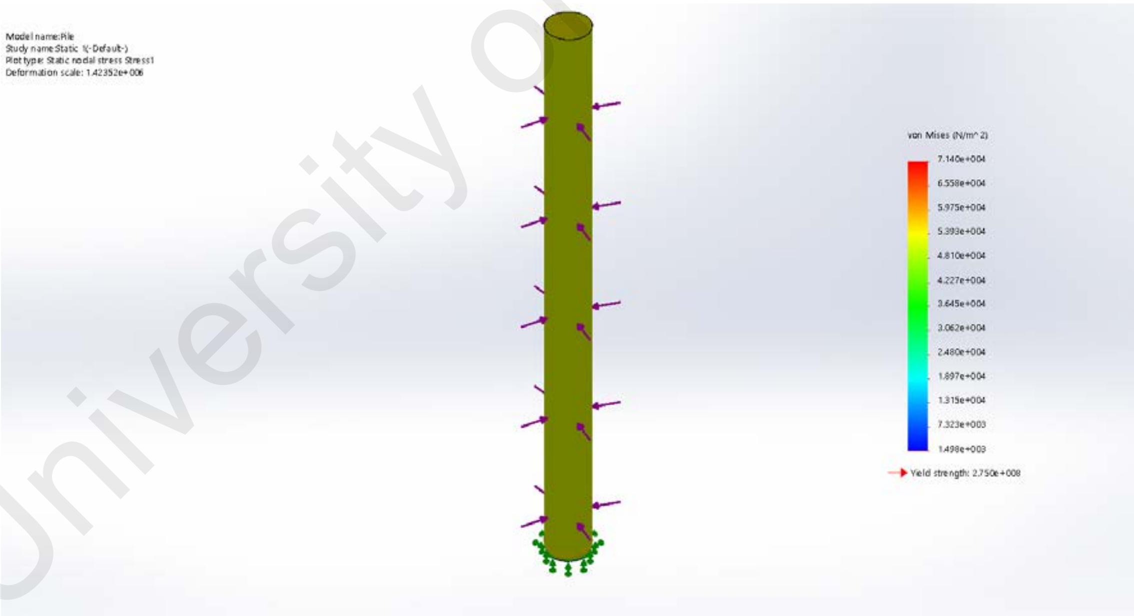


Figure 4.1 30" of 20mm thickness stress deformation

From the result from Solidworks, 7.14 N/m^2 the maximum value of the stress developed at the pile design.

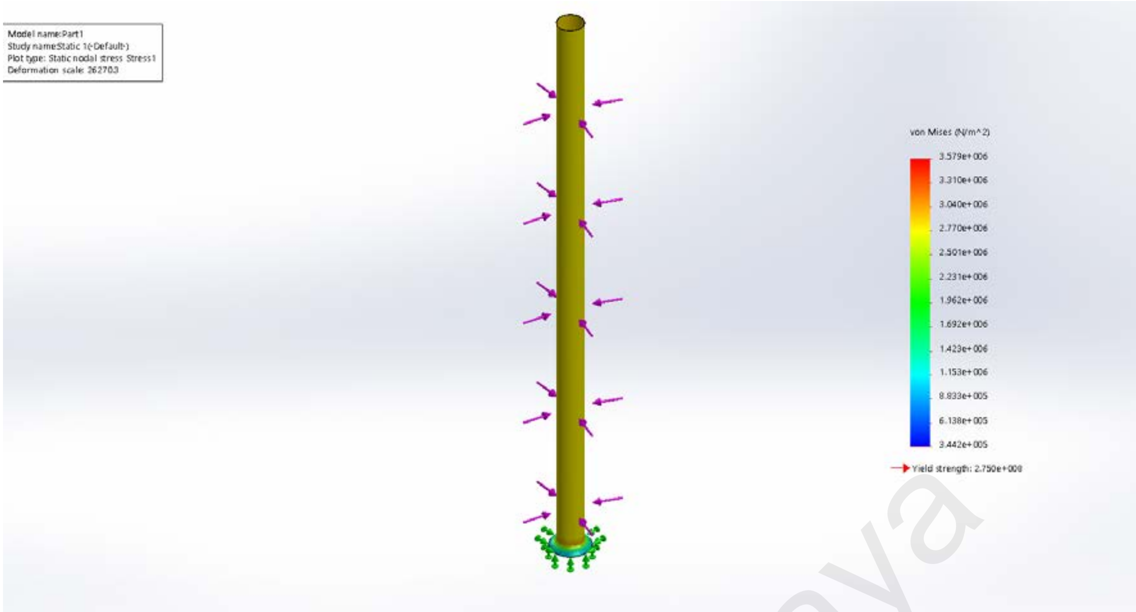


Figure 4.2 30” of 14mm thickness stress deformation

From the result from Solidworks, 3.6 N/m^2 the maximum value of the stress developed at the pile design.

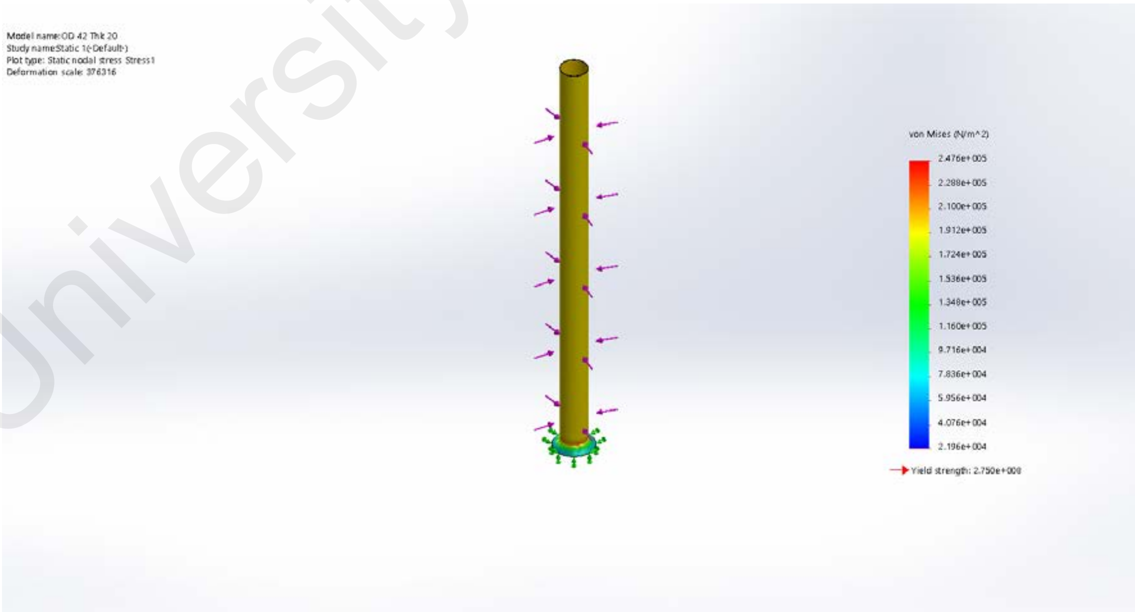


Figure 4.3 42” of 20 mm thickness stress deformation

From the result from Solidworks, 2.5 N/m^2 the maximum value of the stress developed at the pile design.

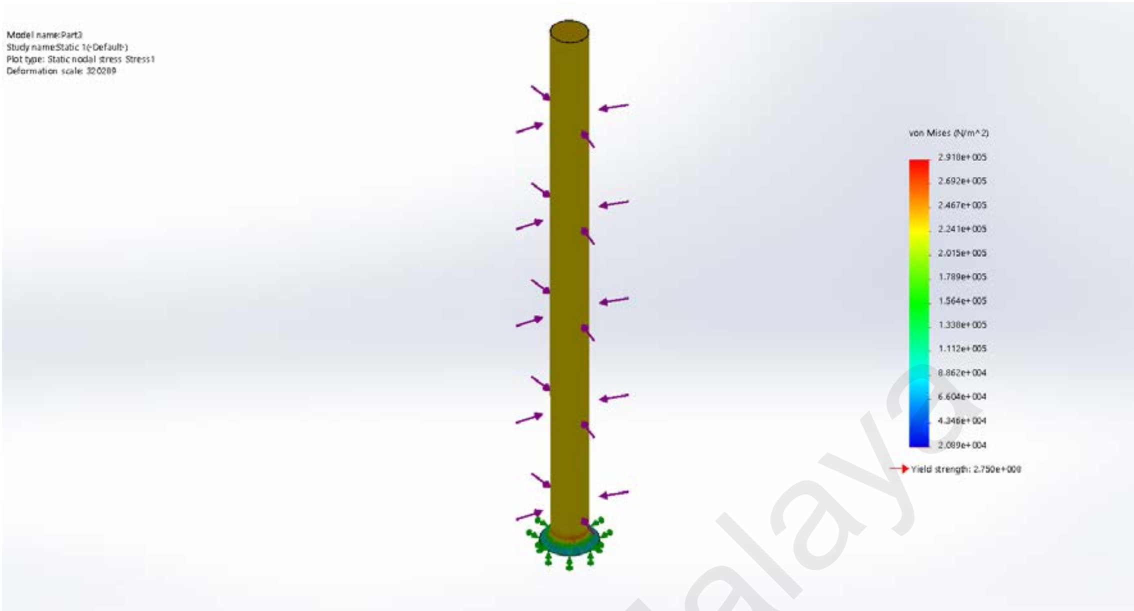
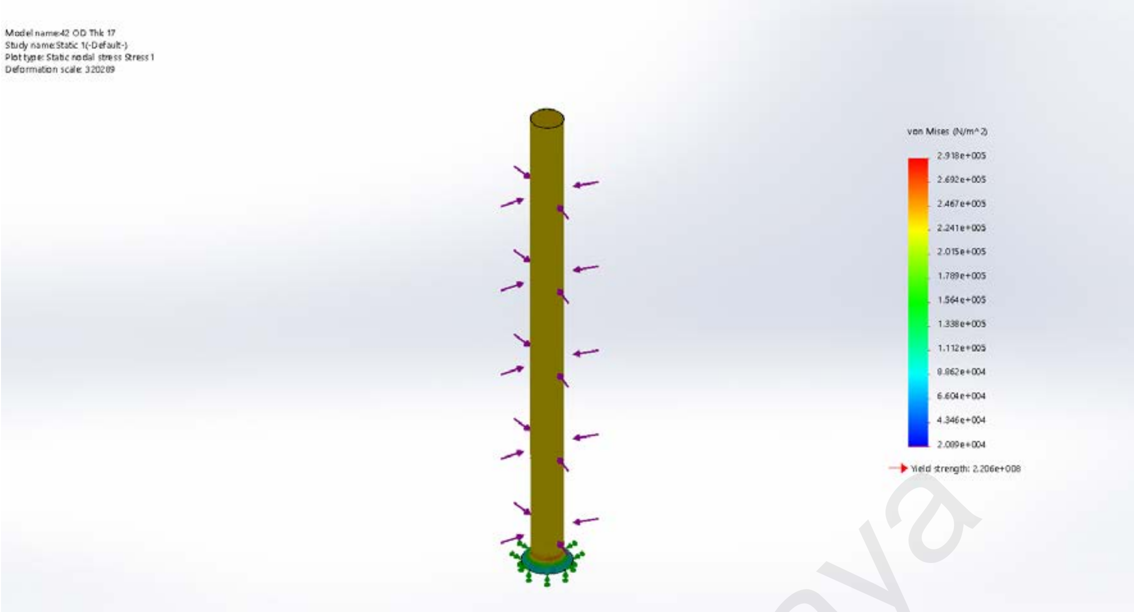


Figure 4.4 42” of 17 mm thickness stress deformation

From the result from Solidworks, 2.9 N/m^2 the maximum value of the stress developed at the pile design.

For the material of S355N is compare with A572 Gr 50 material on the stress deformation. A570 has similar mechanical properties with S355N but different in chemical properties such as Mn, Si, Cu and N at values 1.35%,.40,0,0 respectively compare to 16, 55 max, 55 max, 012.



Figure

Figure 4.5 A572 42" of 17 mm thickness stress deformation

From the result from Solidworks, 2.9 N/m^2 the maximum value of the stress developed at the pile design.

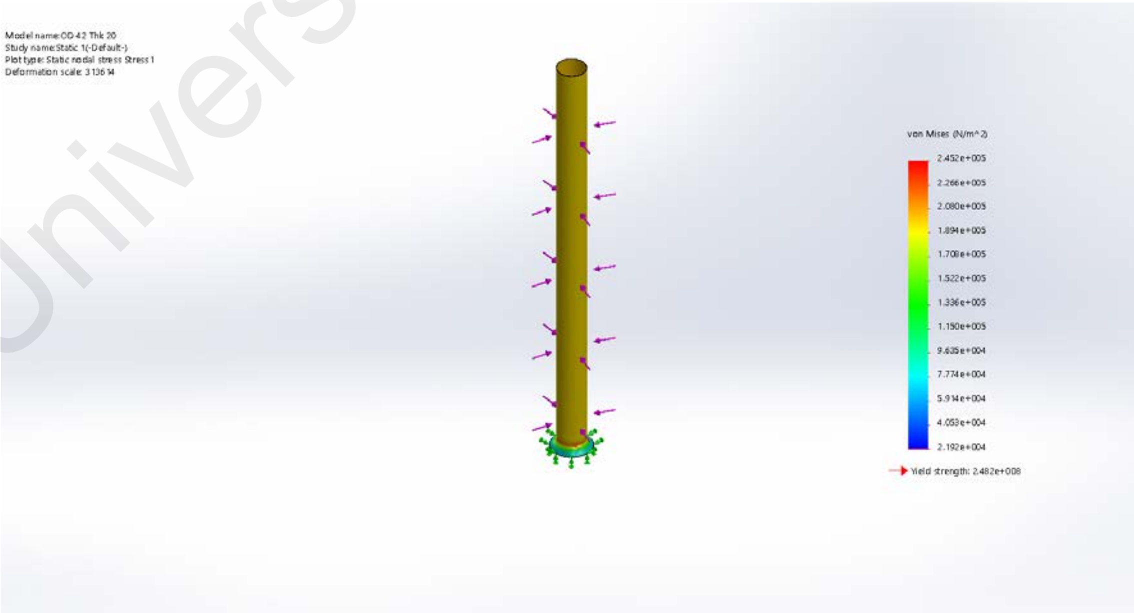


Figure 4.6 A572 42" of 20mm thickness stress deformation

From the result from Solidworks, 2.45 N/m^2 the maximum value of the stress developed at the pile design.

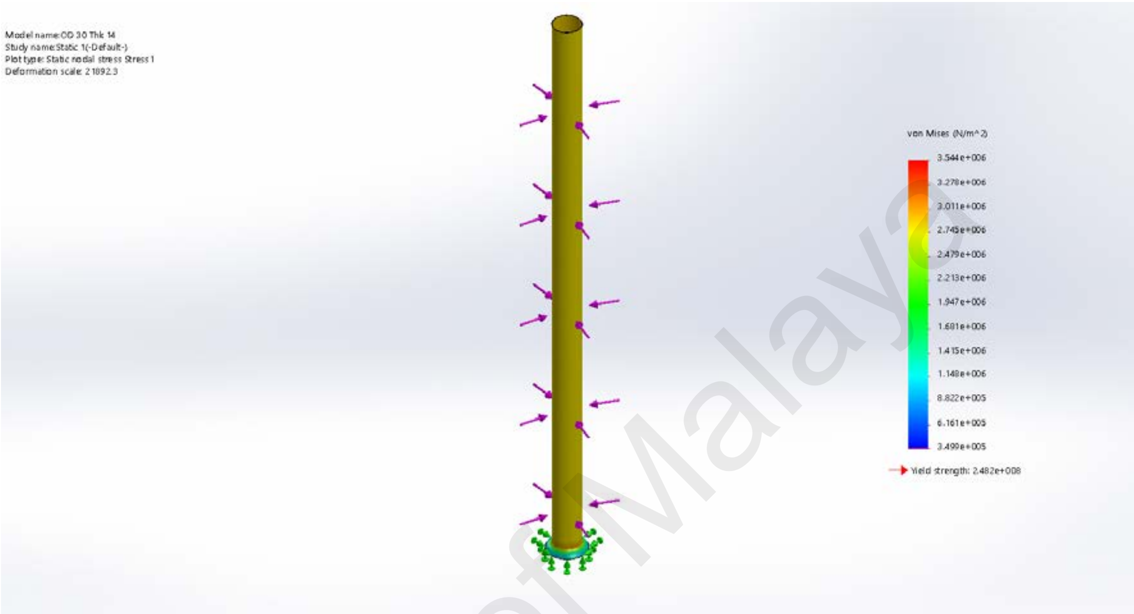


Figure 4.7 A572 30" of 14 mm stress deformation

From the result from Solidworks, 3.5 N/m^2 the maximum value of the stress developed at the pile design.

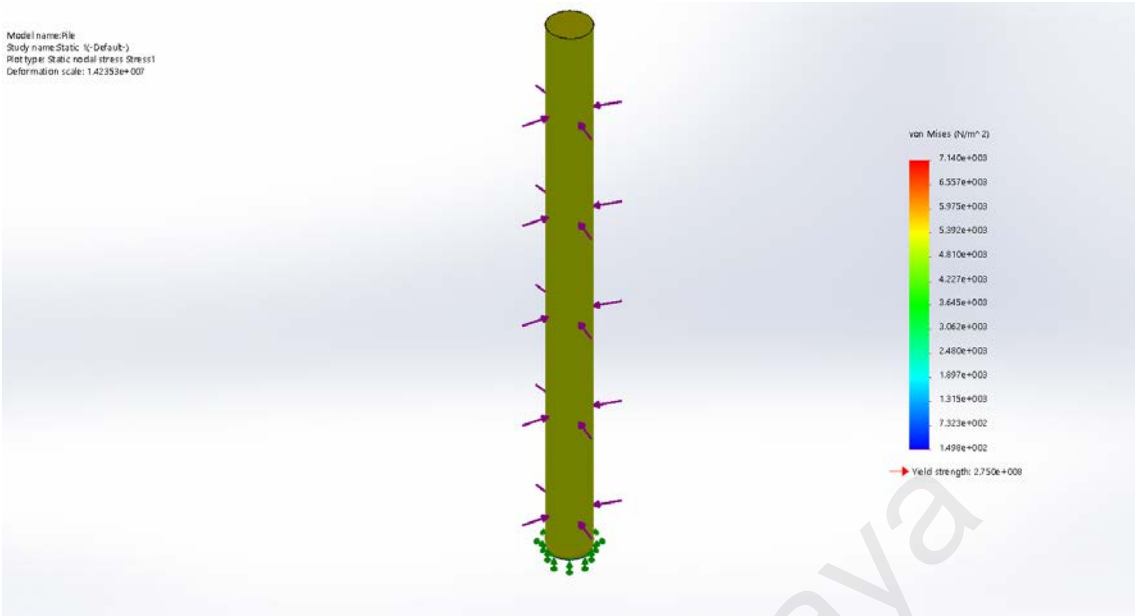


Figure 14.8 A572 30" of 20 mm stress deformation

From the result from Solidworks, 7.1 N/m^2 the maximum value of the stress developed at the pile design.

Table 4.1 Summary of Maximum Deformation and Yield Strength

Type	**Maximum Deformation (N/m^2)**	**Yield Strength (N/m^2)**
S355N, 30”, Thk 20 mm	7.1	2.75
S355N, 30”, Thk 14mm	3.6	2.75
S355N, 40”, Thk 20mm	2.5	2.75
S355N, 40”, Thk 17mm	2.9	2.75
A572, 30”, Thk 20 mm	3.5	2.48
A572, 30”, Thk 14mm	7.14	2.75
A572, 40”, Thk 20mm	2.9	2.2
A572, 40”, Thk 17mm	2.45	2.48

From the above results, author can conclude that a higher thickness has more deformation compare to less thickness of material. The pile has additional mark up or transition piece for extra allowances.

4.1.2 Cross Axis Wind Turbine Simulation at Offshore wind

Offshore wind is extreme and high speed compare to the onshore wind. The wind speed can be reaching up to 20 m/s on the bad weather. Table 3.2 was referred to for the ANSYS simulation.

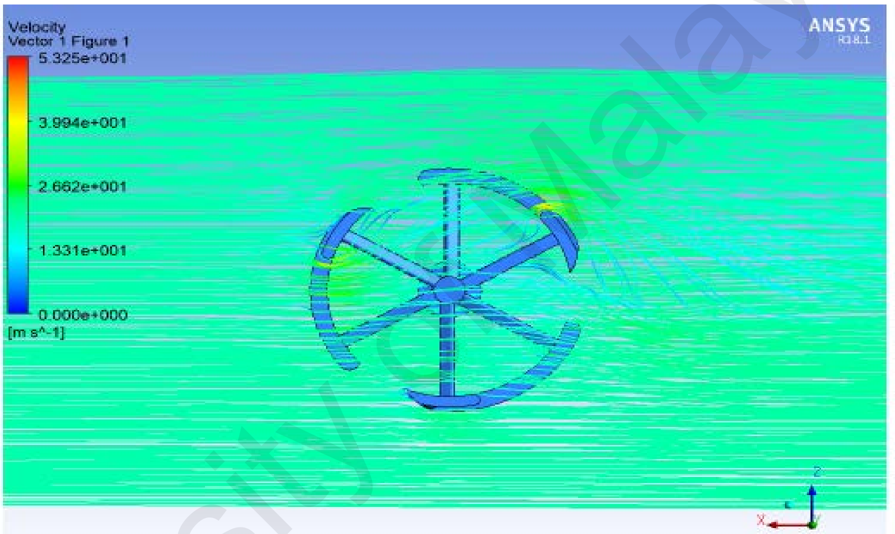


Figure 4.9 20m/s wind speed wind speed behavior CAWT

From the above simulation, CAWT experience up to 53 m/s high velocity at the tip of the blade and make the turbine spin faster.

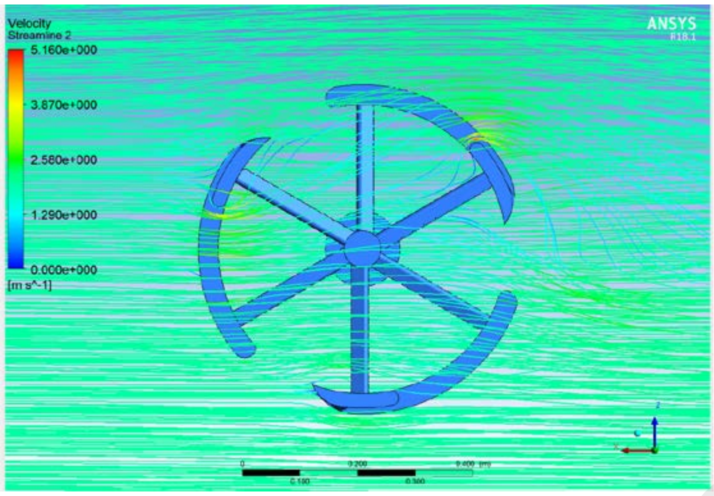


Figure 4.10 2m/s wind speed behavior CAWT

From the above simulation applied in the ANSYS software, the velocity generated was high enough to generate the electricity even with the initial speed was at 2 m/s.

However of the blade of CAWT spin faster without control, it can cause hazardous and potential to become fire to the rotor and gearbox if no control is given to the system.

4.2 Cross Axis Wind Turbine Techno Economics

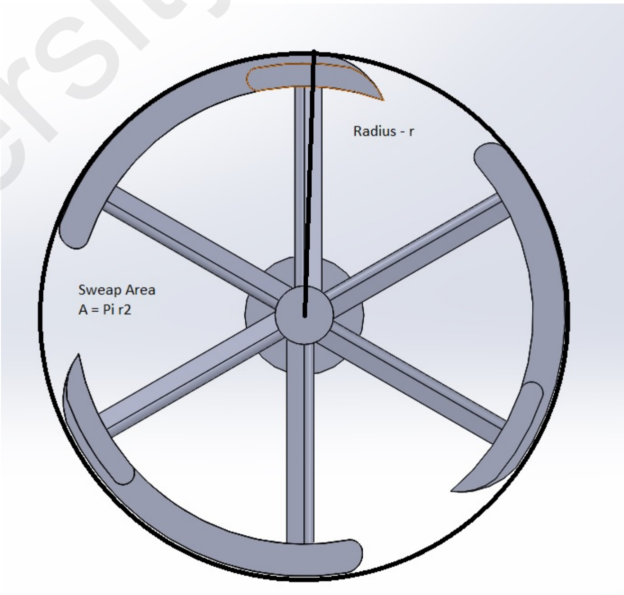


Figure 4.11 Sweep Area CAWT

The length of radius the CAWT length of turbine blades is used to calculate the sweep area using the equation as below:

$$A = \pi r^2 \tag{4.1}$$

Table 4.2 Data Assumption

Blade Length, l	52 m
Wind Speed, v	20 m/s
Air Density, ρ	1.23 kg/m³
Power Coefficient, C_p	0.4

CAWT length blade radius is known and can be inserted to calculate the sweep area into equation 4.1:

$$l = r = 52\, m \tag{4.2}$$

$$A = \pi r^2 \tag{4.3}$$

$$= \pi \times 52 \tag{4.4}$$

$$= 8495 m^2 \tag{4.5}$$

Next author calculate power converted from the wind into the rotational energy using the equation 3.20 :

$$P = \frac{1}{2} \rho A v^3 C_p \tag{4.6}$$

$$= \frac{1}{2} \times 1.23 \times 8495 \times 20^3 \times 0.4 \tag{4.7}$$

$$= 16.72\, MW \tag{4.8}$$

From the mathematical model calculation above, the expected power produce by CAWT is 16.72 MW at offshore.

The estimation price of electricity by generating from wind power shall cover the following aspects:

- Economic depreciation value of the invested into the environment

- Interest payment of the loan amount
- The operation and maintenance cost
- Taxes paid government authorities
- Government incentive and tax credit for project shareholder
- If standby mode, usage of electricity produced to be paid
- Energy storage or power bank component if any
- Due to abundance of wind energy hence the cost is free or free

To calculate the payback period of the investment can be calculated as:

$$n = -\frac{\ln\left(1 - \frac{I\ C_I}{B_A - mCI}\right)}{\ln(1 + I)} \quad (4.9)$$

Do assume the $10,000,000 as a capital investment cost to developed a 16 MW installed capacity. The specific site has a capacity factor of 0.35. An annual operation of the system and maintenance of wind turbine is schedule at cost of 2% of the initial investment and 5% real rate of discount. Undertake the project life cycle of the offshore wind turbine is 25 years and local electricity price is set to $0.05/kWh. Yearly electricity making is projected as below:

$$E_I = 8760\ P_R\ CF \quad (4.10)$$

Where PR is rated capacity and CF is capacity factor.

$$E_I = 8760\ \times 0.35\ \times 16000 = 49056000\ kWh \quad (4.11)$$

Using the electricity power rate, the annual return rate from the electricity sales occurred can be applied.

$$B_A = 49056000\ \times 0.05\ = \$2{,}452{,}800 \quad (4.11)$$

Pay back period can be calculated using the formula 4.9.

$$n = -\frac{\ln\left(1 - \frac{0.05 \times 10000000}{2452800 - 0.02 \times 10000000}\right)}{\ln(1 + 0.05)} = 5.2\ years \tag{4.12}$$

After doing the calculation for the pay back period, it can have said that after 5 years, the electricity sales have become profit to the company.

CHAPTER 5: CONCLUSIONS AND RECOMMENDATION

5.1 Conclusions

After doing the analysis and simulation of the monopiles and techno economics of CAWT, it can come to conclusion that CAWT has lot beneficial in the energy industries in Malaysia. Even the initial capital investment is high but the return is even higher. The CAWT can exists both in onshore and offshore environment as can gain advantage from low speed wind. The depleting sources of fossil fuel and green initiative by Malaysia government should be an advantage to the CAWT to take this opportunity to has serious impact in the energy industries.

With minimum support to be used to cater the high wind speed of CAWT has a big advantage to be used at offshore. No noise and aesthetic appearance shall be an issue for the residential as the site is far away from residential area. Wind energy is another alternative beside the solar PV as the FiT is established in Malaysia.

CAWT at offshore environments is exposed with corrosion as the sea water contain salt and it will rapidly increase the attack of corrosion. To minimize the corrosion attack is to installed the anode and marine-growth-preventer at the monopiles. Another alternative is to applied painting with special coating to increase the life of the sub-structure.

Initial capital investment shall be calculated with more supplier data is provided such as the gearbox, rotor, electricals and instrumentation cost are known to make the CAWT more realistic project to become reality. The high wind speed at offshore environment shall be taken full advantages for investor to invest in the CAWT progress to become commercialize and beneficial to the Nation.

5.2 Recommendation for future works

An optimization is always better ways to improve as general. There are some modifications can be done to improve this project in the future:

1. A guide base or wind tunnel of the CAWT to ensure maximum flow of the wind going towards the CAWT.
2. With better software and computer hardware, more accurate analysis can be done.
3. Wind energy should be in the renewable energy policies in Malaysia since Malaysia climate and environment has plenty to offer.
4. The decommissioning of old platform from the oil and gas industries should be taken as an opportunity to CAWT to demonstrate the effectiveness of wind energy.
5. Risk Assessment towards the environmental and social impact need to be set-up before project commencement.
6. Good wind tunnel in laboratory to test a scale down CAWT with offshore environment atmosphere setting to ensure the CAWT can be commercialize for public use.

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