Improving the Life service of Aluminium scandium Tidal Turbine Blades Using Variable PMF

Eisa A. Almeshaiei[a] Benedict Nazioki[b]. Lubanah Ahmad[c]

[a]*Associate Professor, Collage of Technological Studies,*
Public Authority for Applied Education and Training, Mail: ea.meshaieie@paet edu.kw.
[b]*MSc , School of sustainability Sciences, Tottori University, Japan.*
[c]*Jordan University of Science and Technology, Mechanical engineering department*

Abstract: The energy of tides can be used in generating huge amounts of electricity if it is harvested efficiently. Tidal turbines had become more efficient and dependent, they are designed to resist extremely tough environmental and operating conditions. Unfortunately, fatigue failure is commonly results in mechanical fracture of the turbine. Researchers suggest studying it to be able of predicting the turbine life cycles before fatigue failure take place. This paper investigated the fatigue life of a tidal turbine, which operates under certain conditions. The fatigue life predictions had been achieved mathematically using Rainflow algorithm. A mathematical model had been established to describe the fatigue mechanism. The study assumed that, the blade is manufactured from 0.4wt % Scandium-reinforced aluminium alloy. This alloy decided to be affected by pulsed magnetic field (PMF) with different voltages. Three different voltages had been considered in the study, which are 0, 100 and 180 volt. It was investigated that, increasing voltage of the pulsed magnetic field applied on the studied alloy resulted in refining its structure and enhancing its mechanical properties. Obtained results for all the studied PMF cases showed that, increasing the blade thickness is investigated to increase its fatigue life significantly. However, the highest performance had been achieved by the blade made of 0.4wt % Scandium-reinforced aluminium alloy when it is affected by a PMF (180 v). The study considered studying the effect of the operating hours on the turbine, which had been achieved by repeating the study for different operating hours (8, 16 and 24). Obtained results showed that, increasing operating hours of a tidal turbine would result in a significant shortage in its fatigue life.

Keyword: Tidal turbine, Pulsed magnetic field, Aluminium alloys, Fatigue, Rainflow algorithm, Matlab.

1. INTRODUCTION

As a result of the ever rising population, escalating demand for energy, changing climatic patterns together with peak oil, major efforts have been directed to finding alternative sources of energy to reduce over reliance on fossil fuels. Renewable sources of energy such as wind energy and solar energy are commonly known and applied due to the availability of their technologies as well as their availability in the global market. Also, many potential sources of renewable energy are still going through a series of development so as to satisfy a section of future power demands. Many countries advocate for this research by setting standards and objectives for diversification of these energy sources by approving and promising to direct a larger section of their energy uses to renewable sources. Generally, electricity can generated from mainly three different sources that had represented in the following flowchart figure 1. Researchers had paid a major interest tidal energy due to its very high potentials that allow assuring satisfying high percentage of the electrical power generation rate of the globe. Conventionally, tidal turbines have been greatly employed in Europe and in North America [1].

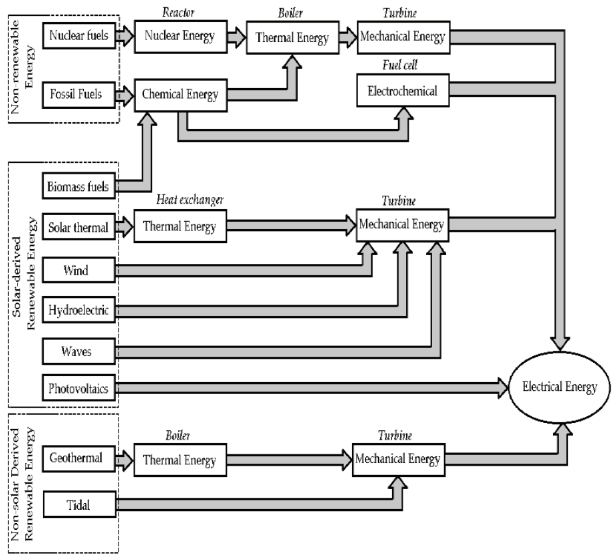

Figure 1. Major forms of energy in the world [1].

Tidal energy turbines employs this mechanism to produce power. When the elevation height of a tidal wave is high or when the velocity of the tide is high, a corresponding high amount of tidal power is harvested. seasonal fluctuations of tides causes a continuous dissipation of mechanical power in the earth to moon interaction system because it pumps water via natural boundaries next to the coastlines together with the viscous dissipation along the seedbed when the flow is not laminar (high turbulent intensity). The following figure 2 represents a clearer vision of the seasonal fluctuations of the tides and their effect on the tidal power output [2].

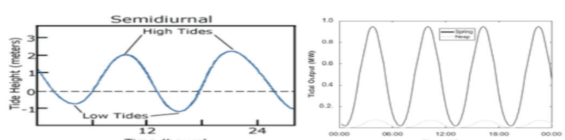

Figure 2. Seasonal variations in the tidal output over a time period [2].

Tidal energy is a type of clean energy that is relied upon. Tidal barrages, deep-sea tidal turbines such as wind turbines that are propelled by the sea together with the many different machines used to harvest under-sea currents are still under development. Slight changes have been observed in the local tides, this is due to La Rance barrage as well as environmental effects although it is negligible [3].

It is predicted that, at Bay of Fundy, power plants harnessing tidal energy could reduce the existing local tides by around 15 centimetres. The disadvantages of generating tidal energy is that a huge wall commonly referred to as a dam may be necessary constructed to ease the flow of water via the generators, this is poses a great danger for animals and plants living in this surrounding. This may not seem a lot when one puts into consideration the natural variations (caused by natural phenomenon such as wind) could possibly alter the tide levels by several metres. Tidal power project is a long term means of generating electricity [4].

Alazmi prepped a study about the feasibility of tidal farm in state of Kuwait according to statistical data for tidal, also he use CFD simulation to analyse the forces drag and lift then he calculated the output power. He evaluated the performance for two different locations , where the suggested tidal farm contains 50 turbines [5].

In fact, tidal energy can be predicted more accurately comparing with either solar or wind energies. As the flowing fluid (seawater) can be assumed as being incompressible, which results in reducing complexity of Naveir stokes model that can be solved only numerically. However, the performance of a tidal turbine cannot be predicted easily, as it requires understanding the most effective parameters according to its operation, efficiency, safety and lifespan. A tidal turbine is expensive, it is designed to be able of serving for such a lifespan that is highly desired to be increased as possible as it could be. However, simulation studies of tidal turbines are still complex due to the seasonal variation in turbulence intensity of the flow (main source of fatigue), which results in reducing the accuracy of these type of studies [6]. Researchers suggested using mathematical models to represent these fluctuating forces to be able of achieving a higher accuracy. Rainflow algorithm is a mathematical method that allows dealing with huge data by separating them into ranges and cycles, which eases studying their effect on such a blade (or more) installed in the studied turbine [7].

2. LITERATURE REVIEW

The seasonal fluctuations of wave heights and the related tidal currents are created as a result of gravitational attraction of both the sun and moon in relation to the position of the earth. Amount of tide at a geographical location depends on the constantly changing locations of both the moon and the sun in relation to the earth, impacts caused due to earth rotation, the location of seawater as well as the coastlines. Since the tides are formed as a result of tidal forces generated because of the gravitational interaction of the moon and the sun as well as earth's rotation, the inexhaustible nature of tidal energy makes it be categorized as a renewable source of energy. The interactive gravitational forces of the moon, the earth and the moon generates the sequential rising and lowering of ocean water labels around the globe, this as a result causes tide waves. Due to the less distance of the moon to the earth as compared to that of the sun, the moon exerts twice the force that the sun would have exerted. Therefore, the tide uniquely follows the moon at the course of its rotation while creating a diurnal tide and ebb cycles anywhere on the surface of the ocean. Energy loss has resulted in a gradual slowdown in earth's rotation in the several years estimated to be 4.5 billion years as from the big bang. In the past 620 million years, the duration of rotation has risen from a period of 21.9 hours to the current 24 hours; within this time, planet earth has lost around 17% of its total rotational energy. As much as tidal energy takes the surplus energy away from the system, escalating the slow down rate, the impact would have been observed over the large span of years, therefore the energy loses are negligible. Consequently, tidal energy forms one of the most sustainable and dependent renewable energy source [5].

3. TIDAL TURBINE OPERATION

Tidal turbines are identical to wind turbines but they are designed to serve under tougher environmental conditions. as seawater is 832 times denser than air and consequently tidal turbine rotors are much smaller than wind turbine rotors and therefore can be deployed much closer together and still generate equivalent amounts of electricity. As seawater is hundreds of times denser than air, such turbines have the potential to generate much more energy than can be produced by wind turbines of similar size. there are different types of tidal turbines that are operate based on the same concept, which tends to convert the flow energy into mechanical power that can be used in generating electricity. The following figure 3 shows a schematic representation of an operating tidal turbine. Seawater is to be allowed to flow over the blade to convert the flow energy (pressure and kinetic energy of the fluid) into mechanical torque that rotates the blade by a rotational speed. This generated mechanical power (torque x rotational speed) is to be transformed to an electric generator to generated electrical power that can be connected to the grid, stored in such batteries or consumed directly [8].

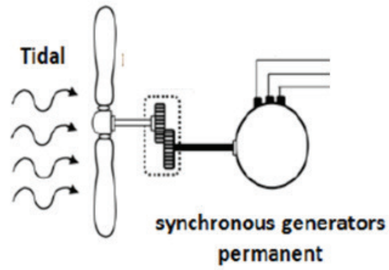

Figure 3. Schematic representation of a tidal turbine [8].

In fact, tidal turbine design, manufacture, installation, operation and maintenance are not simple as it seems to be. As each installed component highly effects on the performance to be achieved by a turbine. The following schematic diagram figure 4 shows a tidal turbine installed by a controller that tends to visualize the performance of the turbine in order to predict or expect the possible failure based on data recorded in the ECU of the controller. Other modern tidal turbines transmit the mechanical power depending on modern power transmission systems aiming to reduce the friction losses resulted from metal to metal contact between gears. Data acquisition systems are highly benefifcial in monitoring the performance of the turbine that helps in predicting its failure before occurrence resulting in applying a proper maintenance technique [9].

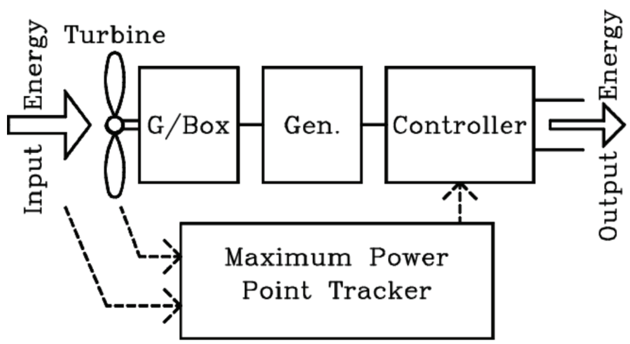

Figure 4. Operating components installed in a tidal turbine [9].

4. FATIGUE

Sources of fatigue

A tidal turbine is designed to generate electricity by converting tidal energy under seabed, which is estimated as being one of the toughest environmental conditions. Fatigue failure of a tidal turbine blade is highly common and results in reducing the electrical power generation rate of the turbine leading to reduce its dependency and economic benefits. Fatigue stress generated due to applying oscillating forces, which represented in the following figure 5. This oscillating force may be completely reversed (a), the mean stress is not zero (b) or the zero to tensional stress fatigue stress (c). Applying any of these oscillating forces is predicted to result in applying a fatigue stress on the material leading to a mechanical fracture to be occurred after certain number of loading cycles. This number of loading cycles highly dependent on the material properties as well as other parameters such as the maximum and minimum value of the applied force, the geometry of the structure and other such conditions as corrosion, impacts, etc. [10]

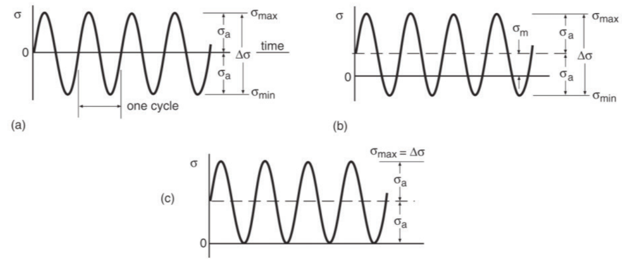

Figure 5. The most common fatigue stress sources [10].

Fatigue failure in a tidal turbine is common and considered being very important to be predicted during the design stage of the turbine. A fatigue stress applied on a tidal turbine blade due to the seasonal variation in the turbulence intensity and wave heights over the year resulting in affecting by a periodic hydrodynamic forces on the blade. Fatigue failure will occur for any material and under any operating conditions but for different loading cycles. In other words, for the same oscillating force applied on the same structures that are made from different materials; the material characterized by the lowest mechanical properties is predicted to be failed firstly. All operating tidal turbines are affected by fatigue stresses due to the seasonal variation in the hydrodynamic forces. But the fatigue failure is subjected to the blade material, thickness, operating conditions and the environmental conditions. The following figure 6 represents recorded wave heights in such a geographical location over five months and it is clear that; a significant variation in the wave heights is recorded that refers to the fatigue stress generation on such a turbine serve in this location. This wavelength seasonal change predicted to result in a variation in the flow velocity and turbulence intensity as well, which represented in figure 7 for the same period (5 months). Hence, considering fatigue stress is vital to assure the tidal turbine safety as well as assuring achieving smooth operation and high energy conversion efficiency [11].

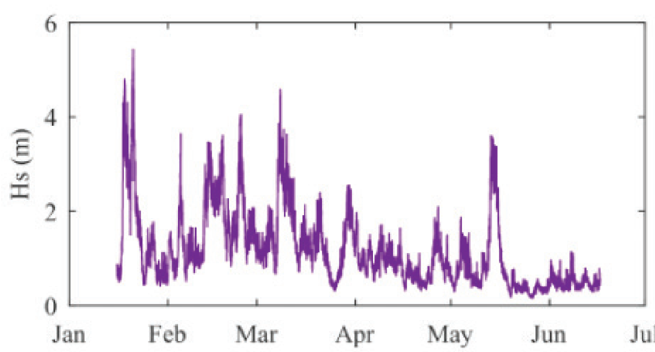

Figure 6. Oscillation in the wave height over five months [11].

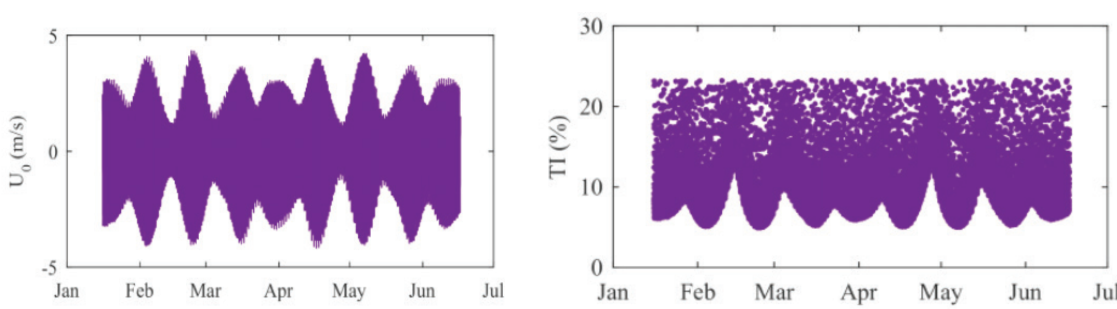

Figure 7. Oscillation in the seawater flow velocity and turbulence intensity over five months [11].

5. NEGATIVE CONSEQUENCES OF FATIGUE

Fatigue stress is mainly studied to be able of predicting the material ability of resisting it for certain operating period, which is commonly indicates the lifespan of the designed tidal turbine in case no unexpected collisions had been occurred. Fatigue mechanism is complex and require attaining a detailed comprehension of the microstructure of the material to be able of determining its stages. When a cyclic load is applied on such a structure it starts to be affected by a fatigue stress that is resulted in stressing the structure and resulting in deflecting it until reaching the elastic zone of the material (no permanent displacement is expected to take place). In case of the cyclic load continues, micro cracks are expected to be generated resulting in increasing the material surface roughness. In fact, the aforementioned consequence is estimated to lead to a significant reduction in the energy conversion efficiency. However, this is not the worst case as these cracks start to propagate resulting in a wider cracks and generating weak points of the structure. These weak points are estimated to form the main source of failure that is occurred when the fatigue stress applied on the material reaches a certain number of cycles. The following figure 8 represents these stages on the S-N diagram, which varies from a material to another [12].

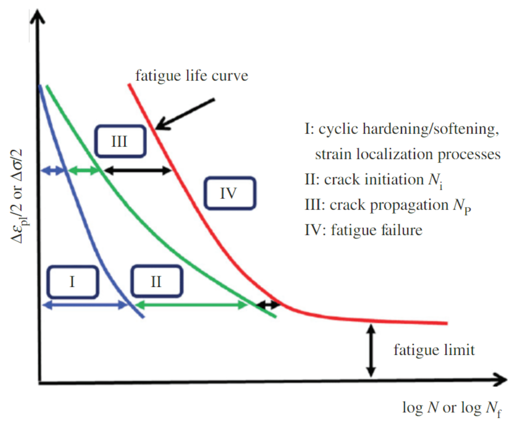

Figure 8. Fatigue failure stages [12].

6. PARAMETERS EFFECT ON FATIGUE

Fatigue life of an engineering structure is highly affected by different parameters that are related to the environmental conditions as well as its material properties. A tidal turbine blade is affected by a cyclic loading to be considered the main source of fatigue life. These cyclic loadings are not stable and fluctuate from a season to another over the year [13]. Different studies had been applied in order to outline the main parameters that influence the fatigue lifetime of a tidal turbine blade. A study is applied on a tidal turbine blade made of glass fibre reinforced polymer (GFRP) and carbon fibre reinforced polymer (CFRP) investigated that, increasing blade thickness is estimated result in a significant increase of the blade fatigue lifetime that assures achieving a higher mechanical performance. The study suggested optimizing the blade thickness in order not to increase its weight to such extent that results in reducing the turbine's efficiency as well as assuring the desired safety factor [14]. A mechanical design engineer should aware the vitality of mass reduction of a turbine blade. As increasing the mass of the blade would result in increasing friction between the moving parts as well as increasing inertia forces of the blade leading to increasing energy losses and decreasing the turbine efficiency. However, reducing the blade mass should not be achieved by reducing its safety. Consequently, the key factor of the blade performance and safety is related to the material of the blade. Different studies had been applied to investigate such an opportunity of enhancing the blade performance based on changing the material of the blade. Although metallic materials are assumed as being the most suitable type due to their high mechanical performance, they provide a low resistance against corrosion and erosion under seabed [15].

Blade design

The blade installed in such a tidal turbine is designed mainly to convert the tidal energy into mechanical power. To achieve the aforementioned criteria efficiently, several parameters should be optimized;

Profile

A blade profile should be designed to achieve the highest energy conversion efficiency. This requires designing complex profiles of the blade that making optimizing their mechanical performance extremely complex. The following figure 9 shows a schematic of a tidal turbine blade's profile and how hydrodynamic forces are applied on it. This complex profile of the blade increases the complexity of testing the performance of the blade as well as optimizing its safety factor [16].

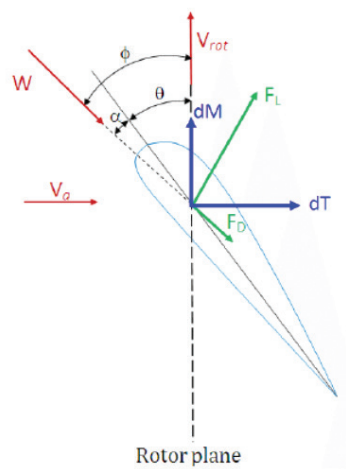

Figure 9. Hydrodynamic forces applied on the profile [16].

Thickness

The blade strength can be enhanced by increasing its thickness. In fact, this is not estimated as being an unlimited choice as increasing the blade thickness leads to a noticeable increase in its mass. The following figure 10 shows the internal construction of a blade. This design aims to reduce the blade mass in order to achieve an efficient performance [14].

Figure 10. Schematic representation of the internal construction of a tidal turbine blade [17].

Material

The material highly influences the performance of the blade as well as its resistance against fatigue, corrosion, mechanical failure and other fracture forms. The blade material should be selected to satisfy a group of duties and desirable properties while reduces others. The selected material should be characterized by high manufacturability, availability and mechanical properties and should not be characterized by high initial cost, high density and high toxicity [18].

Blades were conventionally manufactured from metallic materials. Unfortunately, these metallic materials provide a poor resistance against corrosion the results in reducing the expected lifetime of a tidal turbine. But developed modern materials and alloys allowed overcoming these challenges perfectly [19]. Aluminium alloys are estimated as being one of the highest performing materials. They have the ability of satisfying a very wide range of complex requirements efficiently, economically and with low toxic effect on the environment. These alloys are estimated to provide a high mechanical performance, high corrosion resistance and high fatigue resistance. Their performance can be enhanced by adding other materials such as Scandium. Different studies investigated that, adding Scandium with a predetermined weight concentration ratio resulted in a significant enhancement of the alloy mechanical performance. A study had been applied for different Scandium mixing ratios (0.2, 0.4 and 0.6 wt %) and obtained results showed that; increasing scandium mass concentration resulted in maximizing the mechanical properties and increasing its density as well. Hence, Scandium mass concentration should be optimized based on the required mechanical performance [20].

Scandium is investigated to result in enhancing the aluminium alloys' performance noticeably due to its unique mechanical properties. Adding Scandium to aluminium alloy is investigated to effect on the microstructure as well [21]. However, not only the alloy's contents can influence its performance. As there are such new techniques that can be used in enhancing the material performance as well such as the pulse magnetic field (PMF). Applying a pulsed magnetic field on different aluminium alloys had been studied by different researchers. A study had been applied on a eutectic (Al-12.4Si) Al-Si alloy after it is affected by a pulsed magnetic field. Obtained results showed a significant enhancement in the micro structure of the alloy leading to enhancing its mechanical properties [22]. Another study investigated the effect on pulsed magnetic field on A357 aluminium alloy and it investigated that, treating the A357 aluminium alloy using pulsed magnetic field resulted in refining its microstructure, increasing its mechanical strength and reducing micro cracks on its surfaces. The treated aluminium alloy had a significant enhancement on the material mechanical performance [23].

7. METHODOLOGY

The main goal of the presented study tend to estimate the fatigue life for a blade turbine made of scandium strengthened (0.4 % by weight) aluminium composite. The study will be applied for the same material when it is affected by different pulsed magnetic fields that vary respect to the supplied voltage. This is predicted to help in understanding the effect of the pulsed magnetic field on the blade fatigue life as well as optimizing it (understanding the best performing voltage). The following figure 11 illustrates a horizontal triple blade tidal turbine. A comprehensive technical illustration of the tidal turbine shown in table 1.

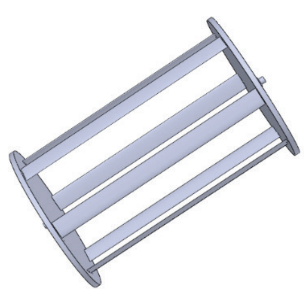

Figure 11. 3D prototype of the turbine under research.

Table 1. A detailed technical illustration of the turbine under research.

Parameter	Value	Units
Turbine Diameter	10000	mm
Hub Diameter	1788.46	mm
Blade Pitch	6	Deg
Distance From Centre of Turbine Blade to Centre of Stanchion	2500	mm
Stanchion Diameter	1500	mm
Fluid Domain (Box)		
Length	150000	mm
Width	50000	mm
Height	50000	mm
MRF Domain (Cylinder)		
Depth	4500	mm
Radius	6000	mm
TSR	3.61	
V	3.086	m/s
TurbRad	5	m
Omega	2.228092	rad/s

Generally, the project is divided into two main studies as firstly the S-N diagram of the studied materials had been investigated experimentally using fatigue test rig. And the other study tended to simulate fatigue mechanism experimentally after determining the applied thrust forces on the blades. Fatigue life of the studied material had been examined since samples of the researched material (0.4% weight scandium) aluminium composites in the presence of different pulsed magnetic fields (0, 100 and 180 voltages) had been examined experimentally. The geometry of the samples had been tested experimentally is represented in the following figure 12.

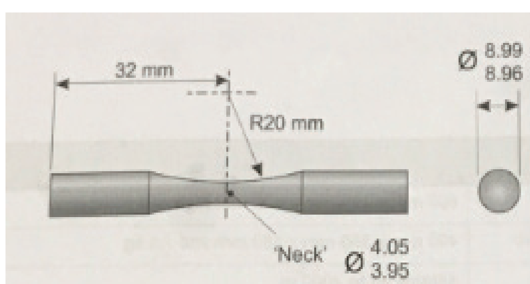

Figure 12. Geometry of the tested specimen.

The specimen had been represented in figure 12 is the standard of the machine represented in figure 13. Testing fatigue lifetime of a material depends on applying a cyclic loading on the material until fracture takes place after certain number of cycles. By repeating the aforementioned step for different cyclic loadings, fracture will take place for different number of cycles. Hence, S-N diagram can be plotted for each material.

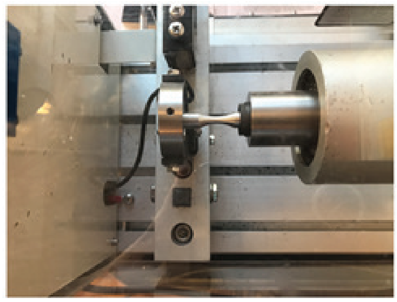

Figure 13. Fatigue life test machine.

Figure 14. Fracture forms of the examined specimens.

A curve of magnitude of fatigue stress against the number of cycles can be used in evaluating the shelf life of a material by using a rain-flow algorithm. Material fatigue is a scenario where structures fail when exposed to a cyclic stress, fatigue occurs even when the subjected stress span is far lower than the static firmness of the material. Fatigue is very important to be indicated to be able of predicting the tidal turbine lifetime. Fatigue stress can therefore be examined so as to estimate life span of a turbine. The research presumed that, the life cycle of the tidal turbine is dependent on the thrust loading resulted from tides. The main determinant that influences the working span of a turbine is the type of fabrication material used to manufacture the blades. Some of preferred materials that have shown excellent performances are steel and aluminium. However, mathematical equations used to evaluate cyclic loading are quite complex and may require partitioning the cyclic stresses into frequencies.

Practical fatigue analysis for a tidal turbine is quite an expensive process especially the heavy duty tidal blades. This is because it depends on impacts caused on the blade by several cyclic stresses for a fracture to happen, this ends up in causing unnecessary financial losses. Simulation and practical researches were done on different aspects to estimate the operational life of the turbine with reference to fatigue specifically. Since engaging two or more types of failure would cause an observable rise in the complex levels of the research. The life pattern in this research was clearly shown according to the thrust force that the tidal blades have been subjected for a specific period. MATLAB was used to offer the feed information that greatly relied on the measurements that had been taken earlier. It had been used in arranging the cyclic loadings applied on the turbine to simulate the fatigue mechanism mathematically.

To counter the effect of hydro-forces on the tidal turbine, sufficient information on the source of this forces is necessary. The endowed kinetic energy within the flowing fluid (sea water) is transformed to mechanical power by the turbine hydro-dynamic mechanism. Hydro-dynamic forces affect the two main forces involved i.e. the drag and the lift forces. It should be noted that the environmental conditions where the turbine blades are working keeps changing drastically. Therefore, the lift and drag forces change periodically, this related change in forces magnitude are shown in the two figures below. The sinusoidal features due to thrust loading is caused by the irrational nature of the tidal blades together with the level of turbulences from one period to another. The relationship between time and rotational angles is graphically shown below for a period of 27 seconds and a span of 3300 degrees. The figures generated here had been used in the rain-flow algorithm to be used in predicting fatigue life of the turbine mathematically.

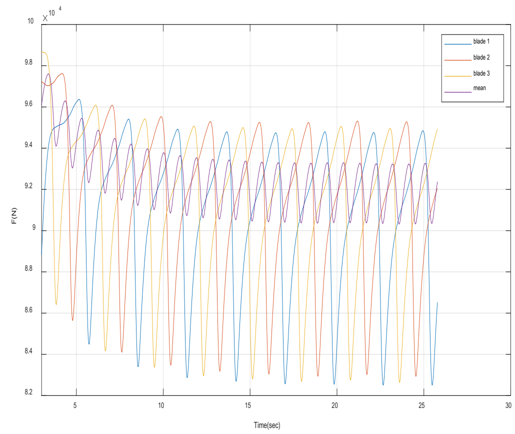

Figure 15. Oscillation of the thrust forces respect to time.

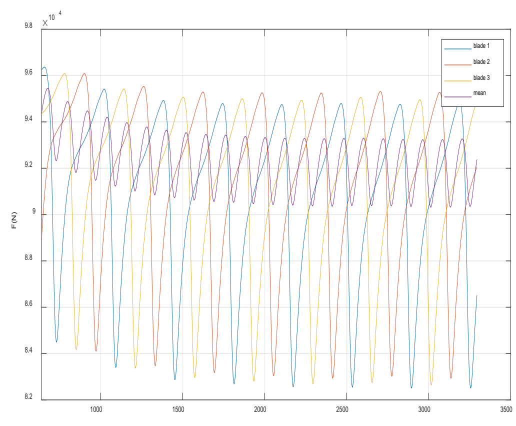

Figure 16. Oscillation of the thrust forces respect to rotating angles.

As soon as the mean thrust forces applied on the turbine had been calculated, Rainflow algorithm will be used in counting cycles. The data had been plotted in figures 15 and 16 will be added to the Matlab code. The average thrust load executed on each blade, rotational degrees, time span and mean load are presumed to be the most crucial information needed. Bringing in more figures that describe other parameters can make the study more difficult. As increasing number of parameters involved in the study would increase the simulation cost and time.

Evaluating the cyclic stress by the rain flow algorithm makes use of a lot of mathematical equations to quantify the cycles, this is achieved by disorienting then arranging the cycle peaks just as that for the rain droplets. The figure 17 below illustrates the process of cycle quantification using Rainflow algorithm command in the utilized program that has an effect in drafting the histogram. This ascertains that the counted cycles are only within the stress span.

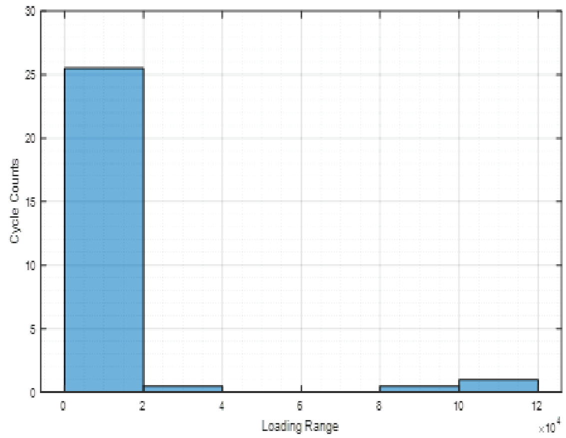

Figure 17. Mean thrust force frequencies using rainflow algorithm command in Matlab.

A mathematical equation on how to calculate damage equivalent load (D.E.L) is given below;

$$D.E.L = (\frac{\sum_i (l_i^m * n_i)}{t})^{m^{-1}}$$

Given that;

t = blade thickness in mm.

l_i= previous periodic occurrences.

m = negative inverse S-N curve gradient and it is estimated to differ from a material to another. Hence, m is estimated to have different values due to changing the pulsed magnetic field voltages.

m_i=number of cycles.

i = describes the no. of trials undertaken (here 20 trials were done).

The study will be applied on the same material but it will be affected by three different pulsed magnetic field. The value of m for one material varies from another since the S-N curve of the researched material is found by alternating the voltage of executed vibrated magnetic field flux. The table 2 below indicates the m values for aluminum composites for different pulsed magnetic fields voltages.

Table 2. m values for aluminum alloy for different PMF voltages.

PMF voltage	m value
0 V	7.18
100 V	6.99
180 V	6.79

A similar process had been followed to estimate the equivalent load depending on the damage equivalent load over the projected area of the blade. The area is assumed to be have a rectangular shape and the mathematical correlation is represented as follow;

$$\mathrm{S.E.L_i} = \frac{\mathrm{D.E.L}}{A}$$

The predicted operational life of the tidal blade can be estimated using the equation below;

$$\text{lifetim } e_i = \left(\frac{S.E.L_i}{S_f}\right)^{-m}$$

Where;

S_f=the fatigue stress (its value is determined experimentally).

After examining the PMF effect on the aluminum composite, the study will be repeated for different operating hours to predict the effect of the operation time on the fatigue lifetime of the turbine.

8. RESULTS ANALYSIS

The experimental study had been applied on the three specimens made of (Scandium 0.4% wt.) allowed plotting S-N diagrams for each sample. Fatigue strength at different fluctuating loadings had been considered in the study, which allows plotting the S-N curve for each specimen. It was observed that, increasing voltage of the pulsed magnetic field resulted in a noticeable decrease in m value. Hence, increasing voltage of the pulsed magnetic field used in treating the specimen resulted in increasing its fatigue strength.

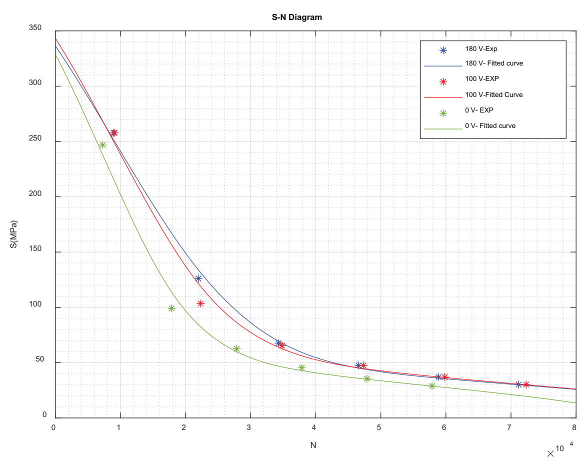

Figure 18. S-N curves for the three studied specimens.

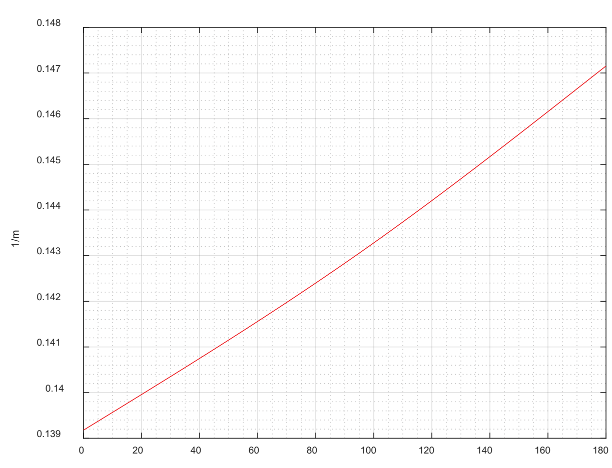

Figure 19. and PMF voltage relationship.

A linearly increasing behaviour of the m value is investigated to be attained when increasing the pulsed magnetic field voltage. Three different samples had been studied to investigate their fatigue life for different blade thicknesses, obtained results are represented as follow;

Without PMF

Referring to the first sample, obtained results allowed predicting that; increasing blade thickness increases the fatigue lifespan. However, any change in the blade thickness would result in increasing its mass. Therefore, reducing the performance of the entire turbine. Results represented graphically in figure 20 shows the relationship between the expected fatigue lifetime of the blades and their thicknesses. Optimizing the blade thickness based on the desired operating lifespan of the turbine is important to assure attaining a smooth and efficient operation.

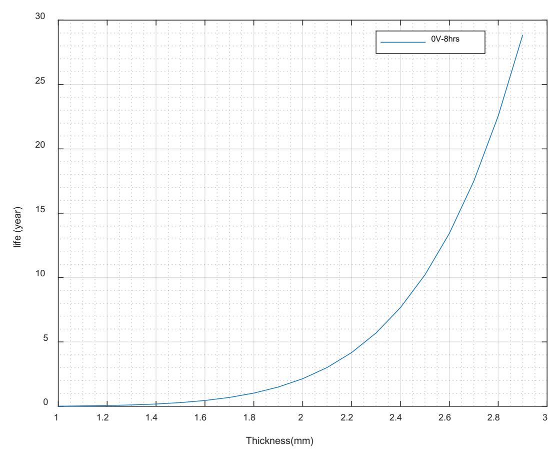

Figure 20. Relationship between the blade thicknesses and fatigue life without PMF.

Increasing operating hours of the turbine is not predicted to be efficient although the significant increase in the turbine's output. Three different periods had been simulated using the same scientific approach and results represented in the following figure. It is observed that, increasing the operating hours of the turbine results in increasing the cyclic loading leading to a dramatic reduction in the fatigue lifespan of the turbine for the same studied thicknesses.

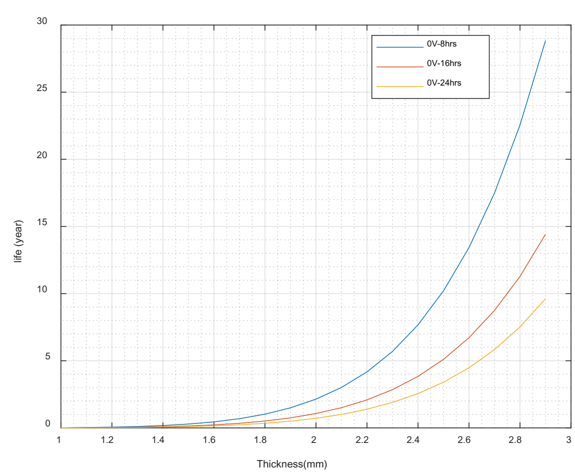

Figure 21. Relationship between the blade thicknesses and fatigue life for different operating hours without PMF.

With PMF (100 v)

Referring to the second sample, the same scientific approaches had been followed and obtained results showed that; increasing blade thickness increases the fatigue lifespan. In fact, it is highly predictable to witness an increase in the fatigue lifespan due to increasing the blade thickness. However, the rate of increase is predicted to be changed due to treating the material using pulsed magnetic field with a voltage of 100 v. Results represented in figure 21 shows the relationship between the expected fatigue lifetime of the blades and their thicknesses.

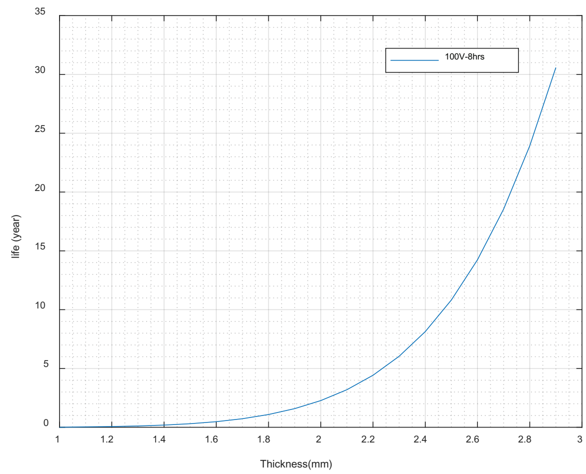

Figure 22. Relationship between the blade thicknesses and fatigue life with PMF (100 v).

Similarly, the operating hours of the turbine had been studied for the treated material. The same three different periods had been simulated using the same scientific approach and results represented in figure 22. It was observed that, increasing the operating hours of the turbine results in increasing the cyclic loading leading to a dramatic reduction in the fatigue lifespan of the turbine for the same studied thicknesses.

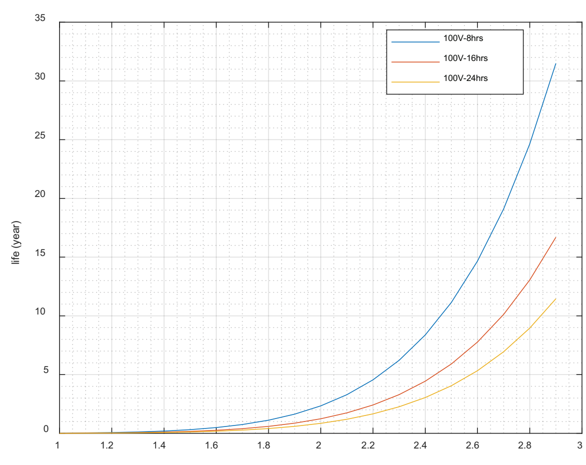

Figure 23. Relationship between the blade thicknesses and fatigue life for different operating hours with PMF (100 v).

With PMF (180 v)

The same scientific approach had been followed for the third studied specimen (treated with a pulsed magnetic field with a voltage of 180 v) had been applied. Obtained results represented in figure 24 showed an increase in the blade lifetime due to increasing the blade thickness. However, the rate of increase is predicted to be changed due to treating the material using pulsed magnetic field with a voltage of 180 v.

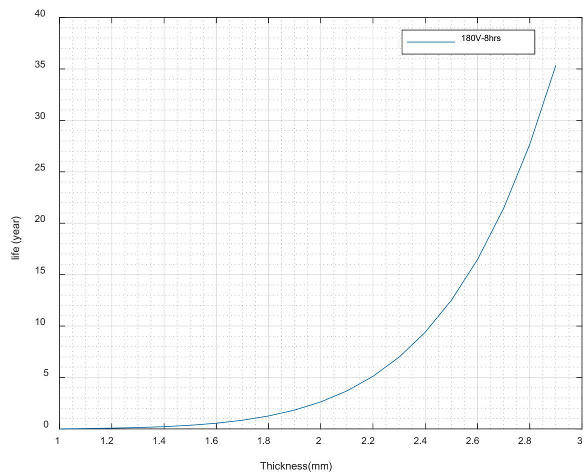

Figure 24. Relationship between the blade thicknesses and fatigue life with PMF (180 v).

The same three different periods had been simulated using the same scientific approach and results represented in figure 25. It was observed that, increasing the operating hours of the turbine results in increasing the cyclic loading leading to a dramatic reduction in the fatigue lifespan of the turbine for the same studied thicknesses. Comparing with other materials, it is clearly noted that, the fatigue lifespan increased at the same operating hours. In other words, increasing voltage of the pulsed magnetic field resulted in increasing the fatigue lifespan of the turbine for each studied operating hours (8, 16 and 24).

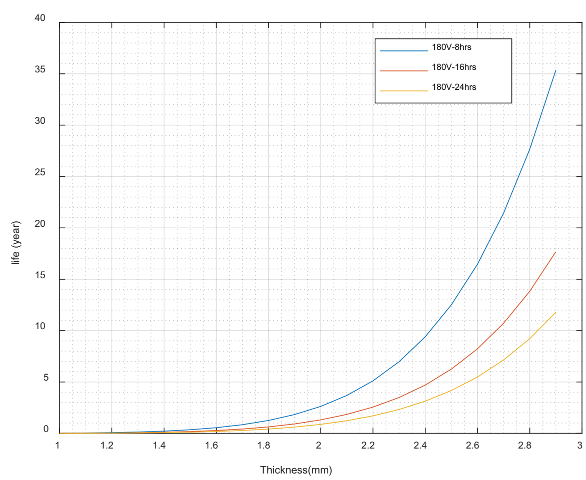

Figure 25. Relationship between the blade thicknesses and fatigue life for different operating hours with PMF (180 v).

9. DISCUSSIONS

Tidal turbines are such devices that mainly designed to convert the kinetic energy of a flowing fluid into electricity. This process requires understanding several parameters and identifying the main sources of fractures to avoid them for a purpose of assuring smooth and efficient operation. The material of the blade is the key factor that allows achieving the desired performance of a designed tidal turbine. Tidal turbines are expensive and assuring achieving a minimum lifespan is vital to avoid unnecessary economic losses. One of the most important mechanical failures should be studied is fatigue, which resulted from the cyclic loadings applied on the blades due to the turbulence intensity change respect to time.

Fatigue mechanism had been expressed mathematically, the main source of complexity is subjected to the huge amount of data of the thrust forces applied on the blades. Rainflow algorithm eased dealing with these amounts of data by rearranging them respect to their peaks. This helped noticeably in predicting the fatigue life of the blade made of scandium 0.4% wt. aluminium alloy.

The material performance can be enhanced if it is treated using pulsed magnetic field, which refines its microstructure resulting in enhancing its mechanical properties. This study predicted the fatigue lifespan of three identical turbines made of the same material but treated differently. The first sample is decided not to be treated while the second and third samples are decided to be treated for different voltages (100 and 180 v). Obtained results showed that, the treated material with a voltage of 180 v is predicted to provide the highest fatigue lifespan for the same operating and environmental conditions as well as the blade thickness. The three specimens had been compared graphically in figure 26.

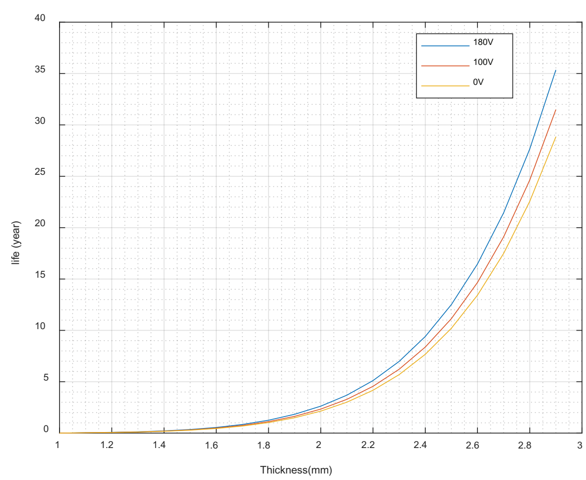

Figure 26. Comparison among the three studied specimens according to their fatigue life for different blade thicknesses.

The number of hours that a turbine designed to operate within is vital to be determined during the design stage. As the mathematical mechanism of fatigue, lifespan of the studied turbine showed a significant reduction in its life when increasing its operating hours for the same thickness. The operating hours of a tidal turbine should be optimized based on the environmental and operating conditions that the turbine is expected to serve in. This can be achieved through estimating the desired electrical output based on the electrical load required to be supplied.

The blade thickness should be optimized as well, as increasing the material would increases the blade mass. In fact, the aforementioned circumstance is not desired as increasing mass of the blade would increase the power losses during the energy conversion processes.

10. CONCLUSIONS

Designing a tidal turbine to operate efficiently and smoothly is not a simple process. Several parameters should be taken into account during designing it to be able of predicting its mechanical fracture and lifespan. This paper studied fatigue mechanism of a tidal turbine operates in tough operating and environmental conditions to be able of outlining the main parameters influence its performance and service lifespan. Fatigue lifetime of a turbine is affected by the blade thickness, the cyclic loadings resulted from the seasonal fluctuations of the thrust forces, operating hours, depth of the turbine, possibility of collision occurrence, corrosion resistance of the blade and the environmental conditions of the location. Among all these parameters, this study investigated the material treatment effect (using PMF) on a turbine fatigue lifetime for different blade thickness and for different operating hours.

Aiming to reduce the complexity of the study, cyclic thrust forces applied on each blade had been averaged and analysed using Rainflow algorithm. Three samples had been studied to investigate the pulsed magnetic field effect on the turbine performance and obtained results showed that, increasing pulsed magnetic field effect on the material (Scandium 0.4% wt. aluminium alloy) increased the fatigue lifetime of the turbine. Alternatively, increasing number of hours expected that the turbine will generate electricity is investigated to lead a massive reduction on the turbine lifespan. Therefore, both of the blade thickness as well as the operating hours of the turbine should optimized to assure smooth, efficient and safe operation of a designed tidal turbine.

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