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Experimental Analysis of a Vertical Wind Turbine using Plastic Blades

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ABSTRACT

It had presented for current investigation the powered performance of H vertical wind turbines for wind speed of (1, 2, 3, 4, 5, 6, 7, 8) m/s region in Al-Mussaib city-Iraq, located at 3205' North latitude and 4403' East longitude. The Experimental test rig includes H vertical wind turbine which configured and made-up in order to analyze the effect of different ambient and wind speed variable conditions on the powered performance of H typre vertical wind turbine which consists of blades which are made from plastics. The turbine blades are designed from plastic strips with a thickness of 3 mm, each part is along 50 cm in diameter, 16 cm in diameter, and the number of blades used in this experiment is six blades to form required turbine. The experiments were tested outdoor at Technical College in AL-Mussaib city-Babylon-Iraq for a period of March and April 2022. The results showed that the power output, with wind speed of minimum value 1 m/s generate 5 Watts, while with wind speed of maximum value 7 m/s generate 100 Watts. Also, the power output, with turbine rotational speed of minimum value 100 rpm generate 8 Watts, while with turbine rotational speed of maximum value 1000 rpm generate 120 Watts. Moreover, the power output, with turbine elevation of minimum value 7 m generate 100 Watts, while with turbine elevation of maximum value 21 m generate 250 Watts.

1. Introduction

Grasping the dynamics of liquids and gases, perceiving their behavior, and knowing how to enhance and improve them all require a grasp of the characteristics of fluids and heat transfer [1-7]. Also, Improvements in fluid characteristics and heat transfer brought about using nanotechnology have had a big impact on the fields of energy, medicine, agriculture, materials, industry, and many other applications [8-13]. Researchers, experts, and international and governmental organizations were also prompted to promote clean energy as an alternative energy, such as solar energy, wind energy, etc., in response to the pressure on the world to reduce carbon emissions in order to control the ozone hole and try to control those emissions in order to preserve human life. Numerous

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researchers have examined the aerodynamic properties of wings as well as the effects of nanofluids, wind turbines, and turbine blades in addition to renewable energy sources. The impact of the flow rates and speeding on the efficiency via a four blades tubular the water bulbs turbines exploitation simulation of numerical flow model, the consequence of blades spaces on the powered performance of a two-stages gravitation water swirl turbine, and the velocities patterns analysis of aggregate Savoniuses wind turbine arrays are all explored using different blade materials [14-25].

The human involvement for planetary warmth, imputable the employed and energies productions, is at the present time one of the almost important environmental problems [26, 27]. The production of greenhouses emissions, including CO2, NOx, and methane gases, has been linked to global warming. The use of conventional fuels for electric power generation is the main cause of human CO2 emissions [28, 29]. The use of fossil fuels to produce electricity can be decreased technically by using inexhaustible energy sources, one of the almost highly developed renewable energies reference in the world is winds energies, which has reached affordable costs per kWh produced by huge horizontal axis wind turbines (HAWTs), when compared to those in fossil fuel power plants. This is what will be addressed in our current research. 72% of the world's total wind power production is accounted for by China, the United States, Germany, Spain, and India [30]. Darrieus with Savonius were the two various kinds of wind turbines of vertical axis (VAWTs) [31]. VAWTs are appropriate for typical applications since they are compact, quiet, and simple to design, produce, and install. The rotor in Darrieus revolves about a mid-axis via the lift produced with the revolve around aero foils, whereas the rotor in Savonius rotated via the drag forces produced by the blades. According to Figure 1, at that point were three different types of Darrieus rotors: helix, D and H [32].

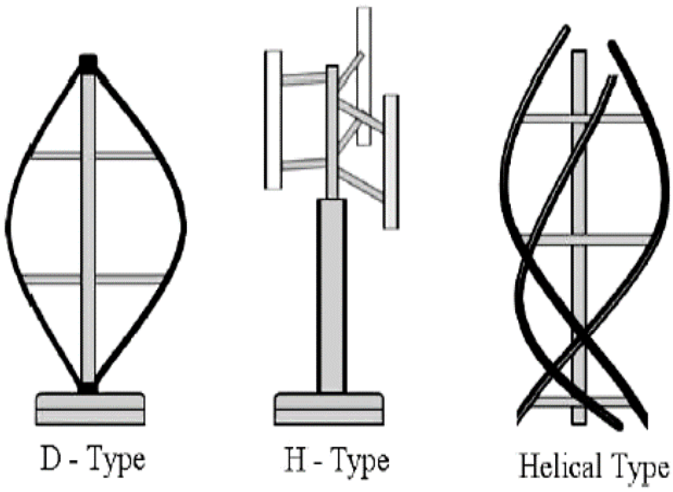

Fig. 1. Different types of Darrieus rotor VAWT [32]

The three major models used to calculate the relative velocities and the irrelevant forces components of the several blades at various places are models of momentum, models of vortex, and models of computational fluid dynamics (CFD), due to its superior aerodynamic performance over horizontally axis of rotation wind turbines in challenging wind environments, vertical axis wind turbines (VAWT) have gained popularity as study topics recently [33]. Through his investigation of wind-driven water pumpers, Kentfield [34], one of many academics who have studied this issue, concluded which the VAWT cannot self-start without outside aid. Ackermann and Söder [35] and Biadgo *et al.,* [36] used numerical and analytical methods to investigate the performance of the straight-type VAWT. The findings display that the VAWT employing the NACA0012 airfoil with a solidity of 0.15 would produce at low tip speed ratios negative torque, making it incapable of starting on its own.

The investigation conducted by Hill *et al.,* [37] on the self-started properties of an H-rotating mechanism Darrieus turbines in steadying wind circumstances used wind tunnels testing and numerical studies. It has been discovered that a turbine with a consistency of 0.34 can start by itself at a constant free stream velocity of 6 m/s. The unsteadiness aerodynamic, or flap wing mechanism, connected with the rotor is the primary cause of the turbine's capacity to start on its own, according to additional research by Worasinchai *et al.,* [38, 39]. However, in their analysis, the specifics of the flow field were not taken into account. Dominy *et al.,* [40] created a numerical simulation to study the self-started performance of a Darrieus turbine and identify the variables that control the turbine's capacity to start on its own. The findings showed that a two bladed device's ability to start depends on its initial starting orientation, whereas a softly loading three blades' rotors always have the capability to self-start under steadying wind circumstances.

El-Samanoudy *et al.,* [41] conducted a study concentrated on the effects of several VAWT design factors, such as the blades number, pitch angles, and type of airfoil. They discovered that the large indefinite quantity powered coefficients for the NACA 0021 airfoil is around 25% below a 10, degrees pitch angles. Castelli *et al.,* [42] analyzed the power performance of the three blades wind turbine (NACA 0021 type) used a CFD code to translate the fundamental BEM theory. In their comparison of three NACA airfoils (00125, 00157, and 0018) and a larger, thicker NACA 0023, Durrani *et al.,* [43] found that the NACA 0016 performs more consistently at different tip speeds ratios (TSRs) over the other two. Eleni *et al.,* [44] examined NACA 0012's behavior from various attack angles. They discovered that the k-performing is the high-grade strategy for solving problems that fits the experimental data. In order to increase the powered outputs of an H-rotor turbine, Mohamed [45] used the CFD method to examine both typical symmetrical and unsymmetrical airfoils.

Wind turbines' aerodynamic performance can be impacted by air turbulence, but vertical wind turbines are less likely to have this impact than horizontal wind turbines are. Additionally, vertical wind turbines have a lot of benefits, but there isn't much research on how to use them to generate electricity yet. This examination used two-dimensional numerical simulation to examine the impact of free-stream turbulent on the aerodynamics performances of vertical wind turbine of the Darrieus type. The powers (P) and turbines powered coefficients (Cp) can be used to track this performance. Simulations were run with modifications in wind speed (Uoo) and 5% turbulence intensity (Tu). It was the conventional k_SKE and k_ SST -SSTKW- turbulent model that was employed.

The two turbulence models' simulation results demonstrate the applicability of the power values (P) and coefficients (Cp) to the experimental findings. The simulation consequences errors for CP using the conventional k- turbulence models were 0.58%; for CP using the k- SST model, it was 0.15%; for P using the standard k- model, it was 0.6%; and for P using the k- SST model, it was 0.18% [46].

In comparisons for horizontally wind turbine, vertically axis wind turbine (VAWT) has several advantages, including a structure that is many balances, less noisy, easier to adapt to discipline design [47], compact in design, easy connected to gears or apparatus, easier to control the blades, and reduced level of weariness [48]. Vertical axis wind turbines may continue to be used because of these benefits. There hasn't been a lot of study done on power utilization in vertical wind turbines. The typical way for obtaining power curves is to calculate the output power by averaging the recorded power and wind speed [49], however this approach ignores the free-stream turbulence effect.

In research by Kooiman and Tullis [50], the energy production of vertical wind turbines was evaluated under the impact of air speed and variations in flow direction without regard to the intensity of free streams turbulency. The findings show that the turbine's output power varies with speed changes but not with direction changes. The output data for this study are separated into data groups, and the turbulence intensity and aerodynamic properties of each data group are identified. This method heavily depends on the sample size of the output data, so using various sample sizes may yield different results. According to the research conducted by Kooiman and Tullis [50], testing with turbulent flow control is required. The area of the vertical turbine blade in the turbulence-free streams has not received much serious examination. In this study, the effect of free-stream turbulence intensity on the performance of aerodynamic for vertical Darrieus wind turbines is investigated using two-dimensional numerical models. Numerous numerical analyses in numerous applications had been published on by references [50-52].

ANSYS fluent software is used to simulate the flow all over Darrieus kind straight-blades vertically axis wind turbines (VAWT) exploitation NACA 0022 blades profiles. The two-dimension, unstable simulation employs the SST k-turbulency modeles. A portion of the issue field, excluding the rotating blade, is modeled exploitation the sliding meshes proficiency with wind speed assumed to be 7 m/s. With carefully planned runs, the personal effects of the time steps, convergence tolerance, and boundary layer mesh parameters on the solution accuracy are examined. At various tip speed ratios, the powered performance of VAWTs with 3 and 2 blades—both of which are intended to have the same solidness ratio—is compared. Examining the contours of velocity and pressure allows one to examine the instantaneous flow patterns of unstable flow fields. Start-up performance, which was best-known to be crucial for Darrieus turbines, is carefully examined, and the contribution of the blade count to this problem is researched [53, 54].

A 3-blades turbine with 36% solidity had the high-grade self-started quality and efficiency among the all geometries, according to research by Sabaeifard *et al.,* [55] on the aerodynamics and performances of little scales Darrieus-type straight-blades VAWT. Using the NACA0012 profile, De Coste [56] created a model of the SB-VAWT and evaluated its performance. It was discovered that VAWT functions asymptomatic at particular TSR. When turned, it encounters a "dead band" of down or unsupportive torque where it is unable to start the turbine because of its low TSR. Therefore, it is seen as a major flaw in VAWT. In order to simulate different air flows and direction for a model of VAWT, Chopade and Malashe [57] assessed the efficacy of CFD. Various computational models that can numerically estimate the performance of a wind turbine can be used to reliably forecast the performance of a VAWT. This method has many advantages over traditional experimental methods. Using the commercialized computationally fluid dynamics program ANSYS Fluent, the powered performances of a vertical axis wind turbine (VAWT) blades for NACA0015 airfoil subdivision had been studied.

The algorithm used to solve the incompressible Navier-Stokes equations is the semifinal Implicit methods for pressures joined equations. For the turbulence flow simulations, the k-x shear stress conveyance turbulence models were chosen. The findings demonstrated that, mostly because of the structure of the vortices created at the star edges of the turbine's blades, the values of the thrust dropped with increasing amplitudes and detractive wavelengths [57]. The current study's objective is to determine the impact of various ambient and wind speed variable circumstances on the powered performance of a H vertical wind turbines in Al-Mussaib City, Iraq.

2. Methodology

One strategy to lessen our reliance on fossil fuels is to investigate renewable energy sources. Wind energies are the sole sources of renewable energy that will be discussed in this study. The project's main goal is to employ wind energy, a renewable resource that generates electricity that is both clean and safe. The experimental tests were carried out at the Technical College in Al-Mussaib City, Iraq, which is situated at 3205' North Latitude and 4403' East Longitude. This site was used to account for wind speeds and weather conditions. The wind speeds and ambient temperatures were measured daily using an application, and the results were collected every 15 minutes. The H vertical wind turbine is part of the experimental test rig, which was built in order to investigate the impact of various environmental and wind-speed variables on the powered performance of the H vertical wind turbine. During the months of March and April 2022, the outdoor experimental test rig depicted in Figure 2 was put to the test at the Technical College in AL-Mussaib City, Babylon, Iraq. The experimental tests rig consists of blades which are made of plastics which have specifications given in Table 1. The blades of turbine were designed from plastic strips with a thickness of 3 mm, each part is along 50 cm in diameter, 16 cm in diameter, and the number of blades used in this experiment is six blades to form required turbine. The turbine frame which manufactured from rectangular steel tubes. The constant Base frames have been built and developed to withstand harsh weather conditions. The revolving hollow steel shaft was connected to the vertically aligned blades. The wind's force caused the wind turbine blades to rotate, which in turn caused the neodymium magnet-based wind turbine and shaft assembly to rotate.

Fig. 2. Experimental test rig

2.1 Wind Speed Measurements

A Taiwan-made Lutran multipurpose anemometer instrument with an accuracy of (3%) was employed to measuring the wind speeds. According to Figure 3, the anemometer has a measurement range of (0.4-30 m/s) and a resolution of 0.1 m/s and figure 4, shows a tachometer device which is used for measuring the rotational speed.

Fig. 3. Anemometer device

Fig. 4. Tachometer device

Table 1
H vertical wind turbine specifications

Parameter	Value/type
Collector aperture area	2 m^2
Blade long	0.5 m
Blade diameter	160 mm
Steel tube length	21 m
Tube wall thickness	2 mm
Tube diameter	51. mm
Tracking model	Stationary

3. Results

The experimental results obtained from analyzing the effects of various ambient and wind speed variable conditions on the powered performance of H vertical wind turbine Figure 5, show the wind speed for selected clear days in February and March 2022.

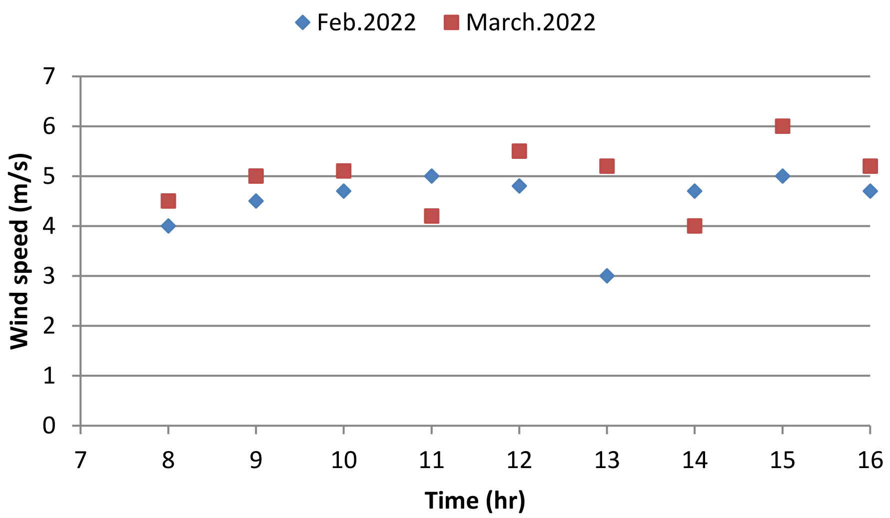

Fig. 5. Wind speed with hourly time

Operational issues like instability and insufficient wind speed had an impact on the performance of the vertical wind turbine. Also, to enhance the powered performance of the turbine, it is necessary to improve both torque and power coefficient, which were impacted by the direction of air flow. Future research must first concentrate on the effects of blade surface friction and dust contamination, which are frequent in arid environments. Additionally, friction in rotating components such as bearings, rods, generator shafts, and controller panel wires must be decreased for greater efficiency. Second, due to challenges with manufacturing, it was challenging to achieve the consistency of the arc angle in each blade as it related to the improvement of the geometrical side of the turbine. As the wind speed increases, this lack of homogeneity generates vibrating effects that degrade the vertical wind turbine's performance. The effects of wind speed to the power outputs produced are shown in Figure 6.

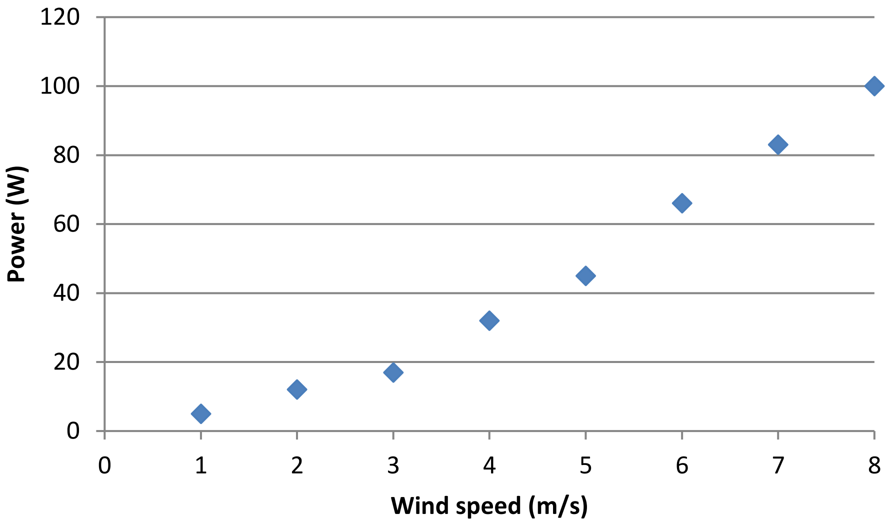

Fig. 6. Power with wind speed

Meanwhile, the power outputs produced by the effects of turbine rotational speed are shown in Figure 7. It could be found that the power outputs are increasing with increased of turbine rotational speed, and the maximum power output is 120 Watt occurred at turbine rotational speed of 1000 rpm, while the minimum power output is 8 watts at turbine rotation speed of 100 rpm. As the turbine rotation speed increased, more power was generated.

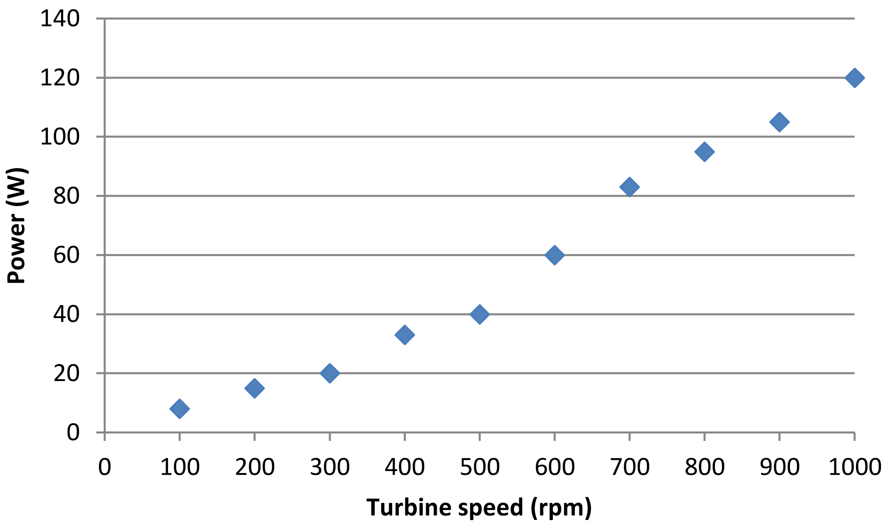

Fig. 7. Power with turbine rotational speed

The power outputs produced by the effect of turbine elevation is shown in the Figure 8. It can be found that the power output is increasing with increased of turbine elevation, and the maximum power outputs is 250 Watt occurred at turbine elevation of 21 m, while the minimum power outputs is 100 watts at turbine elevation of 7 m. As the turbine elevation increased, the more power was generated.

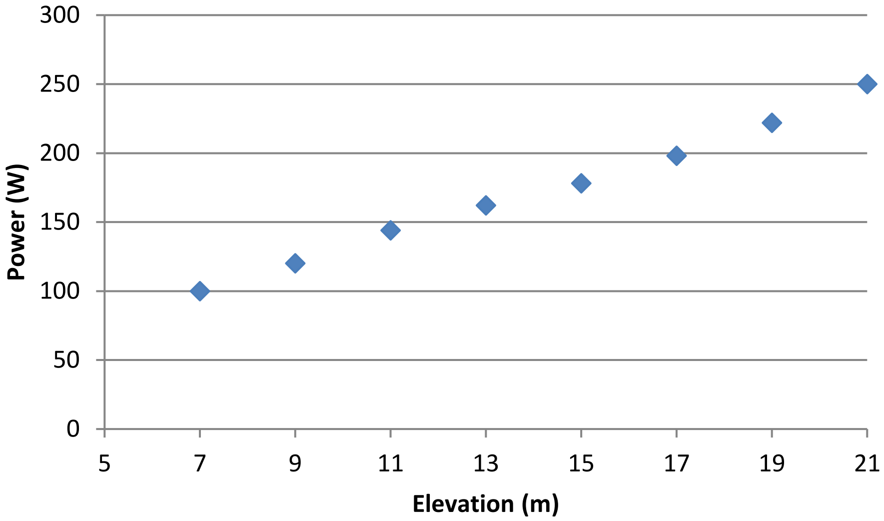

Fig. 8. Power with turbine elevation

4. Conclusion

It had presented in current study the performance of H vertical wind turbines for wind speed of (1, 2, 3, 4, 5, 6, 7, 8) m/s region in Al-Mussaib city-Iraq, located at 3205' North latitude and 4403' East longitude. The results showed that the power output, with wind speed of minimum value 1 m/s generate 5 Watts, while with wind speed of maximum value 7 m/s generate 100 Watts. Also, the power output, with turbine rotational speed of minimum value 100 rpm generate 8 Watts, while with turbine rotational speed of maximum value 1000 rpm generate 120 Watts. Moreover, the power output, with turbine elevation of minimum value 7 m generate 100 Watts, while with turbine elevation of maximum value 21 m generate 250 Watts.

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References

[1] Cai, Xiaowei, Chun Zhang, and Baoshou Wang. "Numerical Study on Fluid Dynamic Characteristics of a Cross-Flow Fan." *Journal of Marine Science and Engineering* 11, no. 4 (2023): 846. https://doi.org/10.3390/jmse11040846

[2] Abdullah, Mahir Faris, Humam Kareem, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, Wan Aizon, and W. Ghopa Ghopa. "Heat transfer and flow structure of multiple jet impingement mechanisms on a flat plate for turbulent flow." *International Journal of Mechanical & Mechatronics Engineering IJMMEIJENS* 19, no. 03 (2020).

[3] Jasim, Rasha Abdulrazzak, Wajdi Qasim Hussen, Mahir Faris Abdullah, and Rozli Zulkifli. "Numerical Simulation of Characterization of Hydraulic Jump Over an Obstacle in an Open Channel Flow." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 106, no. 1 (2023): 1-15. https://doi.org/10.37934/arfmts.106.1.115

[4] Abdullah, Mahir Faris, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, and Wan Aizon W. Ghopa. "Studying of convective heat transfer over an aluminum flat plate based on twin jets impingement mechanism for different Reynolds number." *Int. J. Mech. Mechatron. Eng* 17, no. 6 (2017): 16.

[5] Harun, Zambri, Suang N, J. M. Faizal W. Mahmood, Mahir Faris Abdullah, and Eslam Reda Lotfy. "Computational fluid dynamics simulation on the heat sink performance of a graphics processing unit thermal management." *Jurnal Kejuruteraan* 31, no. 1 (2019): 139-147. https://doi.org/10.17576/jkukm-2019-31(1)-17

[6] Abdullah, Mahir Faris, Humam Kareem Jalghaf, and Rozli Zulkifli. "A Critical Review of Multiple Impingement Jet Mechanisms for Flow Characteristics and Heat Transfer Augmentation." *Vehicle and Automotive Engineering* (2022): 374-393. https://doi.org/10.1007/978-3-031-15211-5_32

[7] Abdullah, Mahir Faris, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, Wan Aizon W. Ghopa, and Ashraf Amer Abbas. "Experimental investigation on comparison of local nusselt number using twin jet impingement mechanism." *Int. J. Mech. Mechatron. Eng. IJMME-IJENS* 17 (2017): 60-75.

[8] Jalghaf, Humam Kareem, Ali Habeeb Askar, and Mahir Faris Abdullah. "Improvement of heat transfer by nanofluid and magnetic field at constant heat flux on tube." *Int. J. Mech. Mechatron. Eng* 20 (2020): 110-120.

[9] Faris Abdullah, Mahir, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, Wan Aizon Wan Ghopa, Asmaa Soheil Najm, and Noor Humam Sulaiman. "Impact of the TiO2 nanosolution concentration on heat transfer enhancement of the twin impingement jet of a heated aluminum plate." *Micromachines* 10, no. 3 (2019): 176. https://doi.org/10.3390/mi10030176

[10] Raj, CP Christin, SA Ananthapuri Surendran, B. Amjathkhan, J. Antony Baksi Metilda, S. Eben Devaraj, and Elango Aristotle. "Nano fluids for improving efficiency in wind turbine cooling system." Advanced materials research 984 (2014): 784-791. https://doi.org/10.4028/www.scientific.net/AMR.984-985.784

[11] Faris Abdullah, Mahir, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, Wan Aizon Wan Ghopa, Asmaa Soheil Najm, and Noor Humam Sulaiman. "Impact of the TiO2 nanosolution concentration on heat transfer enhancement of the twin impingement jet of a heated aluminum plate." *Micromachines* 10, no. 3 (2019): 176. https://doi.org/10.3390/en14030595

[12] Balla, Hyder H., Shahrir Abdullah, Rozli Zulkifli, Wan Mohd Faizal, and Kamaruzaman Sopian. "Effect of oxides nanoparticle materials on the pressure loss and heat transfer of nanofluids in circular pipes." *Journal of Applied Sciences(Faisalabad)* 12, no. 13 (2012): 1396-1401. https://doi.org/10.3923/jas.2012.1396.1401

[13] Abdullah, Mahir Faris, Rozli Zulkifli, Zambri Harun, Shahrir Abdullah, and W. A. Wan Ghopa. "Discussion paper: Effect of the Nanosolution Concentration on a Heated Surface of the Heat Transfer Enhancement using Twin Impingement Jet Mechanism." *Int. J. Eng. Technol* 7 (2020): 6200-6206.

[14] Islam, Md Saifi Bin, Muhammad Faiz Ahmed, and Abdullah Al Saad. "Numerical Investigation on the Aerodynamic Characteristics of a Wing for Various Flow and Geometrical Parameters." *Malaysian Journal on Composites Science and Manufacturing* 12, no. 1 (2023): 13-30. https://doi.org/10.37934/mjcsm.12.1.1330

[15] Ilham, Zul. "Multi-criteria decision analysis for evaluation of potential renewable energy resources in Malaysia." *Progress in Energy and Environment* 21 (2022): 8-18. https://doi.org/10.37934/progee.21.1.818

[16] Shameli, Kamyar, Siti Rahmah Aid, Nur Farhana Arissa Jonny, and Yutaka Asako. "Green Synthesis of Gold Nanoparticles Based on Plant Extract for Nanofluid-based Hybrid Photovoltaic System Application." *Journal of Research in Nanoscience and Nanotechnology* 4, no. 1 (2021): 19-34. https://doi.org/10.37934/jrnn.4.1.1934

[17] Bajuri, Muhammad Nur Arham, Djamal Hissein Didane, Mahamat Issa Boukhari, and Bukhari Manshoor. "Computational fluid dynamics (CFD) analysis of different sizes of savonius rotor wind turbine." *Journal of Advanced Research in Applied Mechanics* 94, no. 1 (2022): 7-12. https://doi.org/10.37934/aram.94.1.712

[18] Shafie, Sharidan, Rahimah Mahat, and Fatihhi Januddi. "Numerical Solutions of Mixed Convection Flow Past a Horizontal Circular Cylinder with Viscous Dissipation in Viscoelastic Nanofluid." *Journal of Advanced Research in Micro and Nano Engineering* 1, no. 1 (2020): 24-37.

[19] Mazlan, Mohamad Zahid, Fazila Mohd Zawawi, Teeab Tahzib, Kamarulafizam Ismail, and Syahrullail Samion. "Performance analysis of highway wind turbine enhanced with wind guide vanes using the Taguchi method." *CFD Letters* 13, no. 3 (2021): 25-42. https://doi.org/10.37934/cfdl.13.3.2542

[20] Abdurrahman, Ridwan, and Lely Deswita. "Experimental Study on the Effects of Turbine Blades Types on the Performance of Centrifugal Pump as Pico-Hydropower Generation." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 106, no. 1 (2023): 158-164. https://doi.org/10.37934/arfmts.106.1.158164

[21] Alhassan, Yusuf, Bashir Isyaku Kunya, and Nor Azwadi Che Sidik. "Numerical Analysis of Wind Turbine Performance Using Different Blade Materials under Wind Load Deflection." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 103, no. 2 (2023): 1-11. https://doi.org/10.37934/arfmts.103.2.111

[22] Hashim, Wan Alif Mustaqim Wan, Nurul Farhanah Azman, Mohamad Nor Musa, Syahrullail Samion, Nor Azwadi Che Sidik, and Yutaka Asako. "Air flow analysis and effect of angle on rotation vane blade through 90-degree by computational fluid dynamic." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 95, no. 2 (2022): 84-98. https://doi.org/10.37934/arfmts.95.2.8498

[23] Darsono, Febri Budi, Rahmad Doni Widodo, and Akhmad Nurdin. "Analysis Of the Effect of Flow Rate and Speed on Four Blade Tubular Water Bulb-Turbine Efficiency Using Numerical Flow Simulation." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 90, no. 2 (2021): 1-8. https://doi.org/10.37934/arfmts.90.2.18

[24] Sinaga, Danieal Aderson, Muhamad Dwi Septiyanto, Zainal Arifin, Gunawan Rusdiyanto, Singgih Dwi Prasetyo, and Syamsul Hadi. "The Effect of Blade Distances on the Performance of Double-Stage Gravitational Water Vortex Turbine." *Journal of Advanced Research in Fluid Mechanics and Thermal Sciences* 109, no. 1 (2023): 196-209. https://doi.org/10.37934/arfmts.109.1.196209

[25] Zakaria, Ahmad, and Mohd Shahrul Nizam Ibrahim. "Velocity Pattern Analysis of Multiple Savonius Wind Turbines Arrays." (2021). https://doi.org/10.37934/cfdl.12.3.3138
[26] Reneses, Javier, and Efraim Centeno. "Impact of the Kyoto Protocol on the Iberian Electricity Market: A scenario analysis." *Energy Policy* 36, no. 7 (2008): 2376-2384. https://doi.org/10.1016/j.enpol.2008.01.036
[27] Yoro, Kelvin O., and Michael O. Daramola. "CO2 emission sources, greenhouse gases, and the global warming effect." In *Advances in carbon capture*, pp. 3-28. Woodhead Publishing, 2020. https://doi.org/10.1016/B978-0-12-819657-1.00001-3
[28] Chandramowli, Shankar N., and Frank A. Felder. "Impact of climate change on electricity systems and markets–A review of models and forecasts." *Sustainable Energy Technologies and Assessments* 5 (2014): 62-74. https://doi.org/10.1016/j.seta.2013.11.003
[29] Kaygusuz, Kamil. "Energy and environmental issues relating to greenhouse gas emissions for sustainable development in Turkey." *Renewable and Sustainable Energy Reviews* 13, no. 1 (2009): 253-270. https://doi.org/10.1016/j.rser.2007.07.009
[30] World Wind Energy Association. "The world wind energy association: 2014 half-year report [R/OL]." (2012): 12-15.
[31] Islam, Mazharul, David S-K. Ting, and Amir Fartaj. "Aerodynamic models for Darrieus-type straight-bladed vertical axis wind turbines." *Renewable and sustainable energy reviews* 12, no. 4 (2008): 1087-1109. https://doi.org/10.1016/j.rser.2006.10.023
[32] Das, Amlan, and Pradip Kumar Talapatra. "Modelling and analysis of a mini vertical axis wind turbine." *International Journal of Emerging Technology and Advanced Engineering* 6, no. 6 (2016): 184-194.
[33] Carrigan, Travis J., Brian H. Dennis, Zhen X. Han, and Bo P. Wang. "Aerodynamic shape optimization of a vertical-axis wind turbine using differential evolution." *International Scholarly Research Notices* 2012 (2012). https://doi.org/10.5402/2012/528418
[34] Kentfield, John AC. Fundamentals/wind-driven water. CRC Press, 1996.
[35] Ackermann, Thomas, and Lennart Söder. "Wind energy technology and current status: a review." *Renewable and sustainable energy reviews* 4, no. 4 (2000): 315-374. https://doi.org/10.1016/S1364-0321(00)00004-6
[36] Biadgo, Mulugeta Asress, Aleksandar Simonović, Dragan Komarov, and Slobodan Stupar. "Numerical and analytical investigation of vertical axis wind turbine." *FME transactions* 41, no. 1 (2013): 49-58.
[37] Hill, N., Robert Dominy, Grant Ingram, and J. Dominy. "Darrieus turbines: the physics of self-starting." *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* 223, no. 1 (2009): 21-29. https://doi.org/10.1243/09576509JPE615
[38] Worasinchai, Supakit, Grant L. Ingram, and Robert G. Dominy. "The physics of H-darrieus turbines self-starting capability: flapping-wing perspective." In *Turbo Expo: Power for Land, Sea, and Air*, vol. 44724, pp. 869-878. American Society of Mechanical Engineers, 2012. https://doi.org/10.1115/GT2012-69075
[39] Worasinchai, Supakit, Grant L. Ingram, and Robert G. Dominy. "The physics of H-Darrieus turbine starting behavior." *Journal of Engineering for Gas Turbines and Power* 138, no. 6 (2016): 062605. https://doi.org/10.1115/1.4031870
[40] Dominy, Robert, P. Lunt, A. Bickerdyke, and J. Dominy. "Self-starting capability of a Darrieus turbine." *Proceedings of the Institution of Mechanical Engineers, Part A: Journal of Power and Energy* 221, no. 1 (2007): 111-120. https://doi.org/10.1243/09576509JPE340
[41] El-Samanoudy, M., A. A. E. Ghorab, and Sh Z. Youssef. "Effect of some design parameters on the performance of a Giromill vertical axis wind turbine." *Ain Shams Engineering Journal* 1, no. 1 (2010): 85-95. https://doi.org/10.1016/j.asej.2010.09.012
[42] Castelli, Marco Raciti, Alessandro Englaro, and Ernesto Benini. "The Darrieus wind turbine: Proposal for a new performance prediction model based on CFD." *Energy* 36, no. 8 (2011): 4919-4934. https://doi.org/10.1016/j.energy.2011.05.036
[43] Durrani, Naveed, Haris Hameed, Hammad Rahman, and Sajid Chaudhry. "A detailed aerodynamic design and analysis of a 2-D vertical axis wind turbine using sliding mesh in CFD." In *49th AIAA aerospace sciences meeting including the new horizons forum and aerospace exposition*, p. 541. 2011. https://doi.org/10.2514/6.2011-541
[44] Eleni, Douvi C., Tsavalos I. Athanasios, and Margaris P. Dionissios. "Evaluation of the turbulence models for the simulation of the flow over a National Advisory Committee for Aeronautics (NACA) 0012 airfoil." *Journal of Mechanical Engineering Research* 4, no. 3 (2012): 100-111. https://doi.org/10.5897/JMER11.074
[45] Mohamed, M. H. "Performance investigation of H-rotor Darrieus turbine with new airfoil shapes." *Energy* 47, no. 1 (2012): 522-530. https://doi.org/10.1016/j.energy.2012.08.044
[46] Syaiful, Ilham Maulana, and Nazaruddin Sinaga. "Numerical Analysis of Flow Field in Vertical Wind Turbine at Free-Stream Turbulence Region." *International Journal of Emerging Trends in Engineering Research* 8, no. 6 (2020). https://doi.org/10.30534/ijeter/2020/58862020

[47] Bhutta, Muhammad Mahmood Aslam, Nasir Hayat, Ahmed Uzair Farooq, Zain Ali, Sh Rehan Jamil, and Zahid Hussain. "Vertical axis wind turbine–A review of various configurations and design techniques." *Renewable and Sustainable Energy Reviews* 16, no. 4 (2012): 1926-1939. https://doi.org/10.1016/j.rser.2011.12.004
[48] Abu-El-Yazied, Taher G., Hossam N. Doghiem, Ahmed M. Ali, and Islam M. Hassan. "Investigation of the aerodynamic performance of Darrieus vertical axis wind turbine." *IOSR journal of engineering* 4, no. 5 (2014): 18-29. https://doi.org/10.9790/3021-04571829
[49] Gottschall, Julia, and Joachim Peinke. "Stochastic modelling of a wind turbine's power output with special respect to turbulent dynamics." *In Journal of Physics: Conference Series*, vol. 75, no. 1, p. 012045. IOP Publishing, 2007. https://doi.org/10.1088/1742-6596/75/1/012045
[50] Kooiman, S. J., and S. W. Tullis. "Response of a vertical axis wind turbine to time varying wind conditions found within the urban environment." *Wind Engineering* 34, no. 4 (2010): 389-401. https://doi.org/10.1260/0309-524X.34.4.389
[51] Suresh, Badugu, K Nikhel Sathvik, Syed Imran, O V Gopi Reddy, V Gopi Tilak, A Vijayalakshmi, and V S Ghali. "Diagnosing Osteoporosis through Numerical Simulation of Bone Sample by Non-Stationary Thermal Wave Imaging." *International Journal of Emerging Trends in Engineering Research* 8, no. 3 (2020): 776–79. https://doi.org/10.30534/ijeter/2020/27832020
[52] Julianto, Eko, Waluyo Adi Siswanto, and Marwan Effendy. "Characteristics of temperature changes and stress of float glass under heat radiation." *International Journal of Emerging Trends in Engineering Research* 7, no. 9 (2019): 228-233.https://doi.org/10.30534/ijeter/2019/03792019
[53] Trubilin, Evgeniy Ivanovich, Svetlana Ivanovna Borisova, Vladimir Ivanovich Konovalov, Mikhail Ivanovich Chebotarev, and Anatoliy Dmitrievich Gumbarov. "Experimental studies of parameters of pneumatic slot sprayer." *International journal of emerging trends in engineering research* 8, no. 1 (2020): 170-176. https://doi.org/10.30534/ijeter/2020/23812020
[54] Gömeç, Fazıl Selçuk. "Performance prediction of darrieus type vertical axis wind turbines using numerical simulations." Master's thesis, Middle East Technical University, 2014.
[55] Sabaeifard, Payam, Haniyeh Razzaghi, and Ayat Forouzandeh. "Determination of vertical axis wind turbines optimal configuration through CFD simulations." In *International Conference on Future Environment and Energy*, vol. 28, pp. 109-113. 2012.
[56] De Coste, Jon, Denise McKay, Brian Robinson, Shaun Whitehead, and Stephen Wright. "Design Project Vertical Axis Wind Turbine." PhD diss., Thesis, Dalhousie University, 2005.
[57] Chopade, M. R., and A. Malashe. "Vertical axis wind turbines (VAWT) and computational fluid dynamics (CFD): A Review." *vol* 1: 45-49.