Proceedings of the 10th World Congress on Mechanical, Chemical, and Material Engineering (MCM'24)
Barcelona, Spain –August 22-24, 2024
Paper No. HTFF 174
DOI: 10.11159/htff24.174

Maximizing The Aerodynamic Performance Of Wind And Water Turbines By Utilizing Advanced Flow Control Techniques

Edwin Javier Cortes[1,2,3], Dr. Surupa Shaw[1,2,3]
[1]Department of Multidisciplinary Engineering
TAMU Higher Education Center at McAllen[2] | Texas A&M University[3]
edwin.cortes@tamu.edu; surupashaw@tamu.edu

Abstract **-** In recent years, there has been a growing emphasis on enhancing the efficiency and performance of wind and water turbines to meet the increasing demand for sustainable energy sources. One promising approach is the utilization of advanced flow control techniques to optimize aerodynamic performance. This paper explores the application of advanced flow control techniques in both wind and water turbines, aiming to maximize their efficiency and output. By manipulating the flow of air or water around the turbine blades, these techniques offer the potential to improve energy capture, reduce drag, and minimize turbulence-induced losses. The paper will review various flow control strategies, including passive and active techniques such as vortex generators, boundary layer suction, and plasma actuators. It will examine their effectiveness in optimizing turbine performance under different operating conditions and environmental factors. Furthermore, the paper will discuss the challenges and opportunities associated with implementing these techniques in practical turbine designs. It will consider factors such as cost-effectiveness, reliability, and scalability, as well as the potential impact on overall turbine efficiency and lifecycle. Through a comprehensive analysis of existing research and case studies, this paper aims to provide insights into the potential benefits and limitations of advanced flow control techniques for wind and water turbines. It will also highlight areas for future research and development, with the ultimate goal of advancing the state-of-the-art in turbine technology and accelerating the transition towards a more sustainable energy future.
Keywords**:** Flow Control, aerodynamics, Wind Turbine, Water Turbine, Efficiency, Passive Control, Active Control

1. Introduction

The significant technological advancements of the 21st century have spurred a shift away from fossil-fuel energy sources towards eco-friendly renewables, driven by energy and environmental concerns. This transition aims not only to mitigate environmental damage but also to establish sustainable energy sources capable of maximizing their potential. The development of energy sources such as hydro, solar, wind, and bioenergy has been key to achieving sustainable power production. These methods offer cleaner alternatives to traditional energy sources and hold the promise of inexhaustible and locally available power. According to the Global Wind Energy Council (GWEC), there has been a 10% increase in Global Wind Energy (GWE) capacity, with an expected growth rate of 9.2% over the next five years. The demand for clean and renewable energy sources has led to significant advancements in the design and implementation of wind and water turbines for power generation. However, despite their widespread use, these turbines often face challenges in maximizing their aerodynamic performance, which directly impacts their efficiency and energy output. In response to this challenge, researchers and engineers have turned to advanced flow control techniques to optimize the aerodynamic performance of wind and water turbines. Xu et. al [1] integrated plasma flow control technology at three locations on the Savonius VAWT blade to stabilize flow separation, mitigate flight disturbances, and optimize boundary layer dynamics, improving performance by altering pressure distribution. Akhter et. al. [2] introduced a control mechanism utilizing active and passive flow systems. Active control involves blade sensors for local condition analysis, while passive mechanisms stabilize pressure gradients through geometric shaping. Likewise, Acarer, S. [3] focused on enhancing the peak lift-to-drag ratio of the DU12W262 airfoil through passive flow control, offering benefits such as an allowance to the suction side, trailing edge slots and an increase of 3.2% of power coefficient to wind turbines with both horizontal (three-bladed propelled turbines), and vertical axes (Alternative crosswind-axis turbines, which capture wind in almost any direction). Additional approaches involve optimizing cycloidal water turbines, displaying how strategies for individual blade control can enhance performance by maximizing rotor power to decrease tip speed ratio. Decreasing the pitch and increasing the phase angles will also contrast the Tip speed ratio. Hwang, I.S., [4], amplify power generation by 4.2% in annual energy production (AEP) in horizontal axis wind turbines Cooney, J.A. [5].

Each implementation may have different advantages once placed on the turbines, and it is important to consider which system leads to the greatest efficiency depending on the area and the technology. In their 2019 study, Bay et al. [6] demonstrated a significant increase in total efficiency, of 10-15%, by implementing downwind rotors to enhance wind power plant performance. Other systems included non-traditional control systems for wind turbine blade design, Wiratama, I.K., [7] and modulated circulation, which mimics the fluid motion as a kinematic-control method by setting the velocity and pitch to control the blades of specifically vertical axis hydrokinetic turbines which improved their efficiency as the free-stream velocity increments, Gorle, J.M.R., [8]. On the other hand, the use of split blade passive flow management, Moshfeghi et al. [9] examined the aerodynamic performance of horizontal axis wind turbines and noticed that separation on the blades is a common phenomenon which he experimented on 2-D simulations and that effects of these separations which can be fixed with passive flow control devices, such as vortex generators. For the problem of mitigation and lifespan-extending options, Van Dam et al. [10] investigated wind turbine active load control methods such as shape change airfoil, and Active Flexible Wall to increase turbine life and counter the loading from turbulent winds. Now, for passive flow control, the blade design also increases aerodynamic efficiency if uses adequate flow control technologies which are directly linked to power production and load reduction. Passive control methods are cheaper and easier to implement while active methods are more effective, they require more studies and 2-D and 3-D simulations, González-Salcedo [11]. For water turbines, there are fewer studies compared to wind turbines, but to optimize wave power harvesting, Lekube et al. [12] demonstrated a great energy conversion efficiency by proposing a control scheme of Oscillating Water Column (OWC) chamber sensors, flow controller and pressure sensors to maximize the power by 9.8% in good turbines, which increases almost 1kW in a 5 min period.

A very interesting and relevant method used was made by Shourangiz-Haghighi et al. [13] who provided an overview of state-of-the-art methods using computational fluid dynamics (CFD) to optimize the shape of an airfoil with optimization algorithms, testing different materials and shapes of airfoils for wind turbine performance, since it can visualize flow fields as well as testing new designs.

The objective of this paper is to explore the potential of advanced flow control techniques in maximizing the aerodynamic performance of wind and water turbines. By leveraging principles from fluid dynamics, researchers have developed innovative strategies to manipulate the flow of air and water around turbine blades, thereby improving their efficiency and energy capture capabilities. In this paper, we will delve into the underlying principles of flow control and examine how they can be applied to enhance the performance of wind and water turbines. We will explore various flow control techniques, including active flow control methods such as vortex generators, plasma actuators, and synthetic jets, as well as passive techniques such as aerodynamic shaping and surface coatings.

2. BASIC STRUCTURE OF WIND TURBINE & WATER TURBINE

Key elements in the process of obtaining renewable energy from natural resources are wind turbines and water turbines. The distinct structures of each type of turbine are designed to best capture the kinetic energy of flowing water and wind, respectively.

A wind turbine's design usually consists of a few key parts. The turbine's core component is the rotor, which is made up of many blades fastened to a central hub. The aerodynamic design of these blades allows them to effectively harvest wind energy. The wind rotates the rotor because of its force. A generator located inside the nacelle receives rotational energy from the rotor through a shaft. The gearbox, engine, and control systems are all centered in the nacelle, a box structure placed above the turbine tower. The generator transforms the mechanical energy from the spinning shaft into electrical energy, which is then distributed throughout the grid by way of wires that travel down the tower, as shown in Figure 1.

According to Hansen [14,15] and van der Tempel and Molenaar [16], the fundamental construction of a wind turbine is intended to effectively capture wind energy's kinetic energy and transform it into electrical power. The rotor consists of several blades fixed to a central hub, which is the control system of a wind turbine. These blades have aerodynamic profiles that are tuned to increase lift and minimize drag, and they are carefully engineered to successfully harness wind energy. The wind propels the rotor's spin, which converts kinetic energy into rotational motion. The rotor assembly is situated situated inside the nacelle, a housing structure that houses vital parts like the gearbox, generator, and control systems, and is and is mounted atop a tall tower. To enable the best possible energy conversion and wind capture, the nacelle is positioned positioned strategically. As the generator transforms mechanical energy into electrical power, the gearbox raises the rotor rotor shaft's rotating speed to a level appropriate for power generation. To maximize energy capture and guarantee safe operation, control devices within the nacelle monitor wind conditions and modify the rotor blade orientation.

Water turbines are made to capture the kinetic energy of water moving through rivers, streams, or ocean currents. A water turbine's fundamental construction consists of a wind turbine-like rotor with blades that are adapted for underwater use. Depending on the operating principle, there are several types of water turbines, such as impulse turbines and reaction turbines. While reaction turbines also use the water's pressure energy, impulse turbines use the kinetic energy of the flowing water to power their turbine blades, as depicted in Figure 2. Like wind turbines, a water turbine's rotor is attached to a shaft that sends rotational energy to a generator. Water turbines can be built directly in flowing water bodies or inside specifically designed dams and hydroelectric power establishments, depending on their size and intended use.

As described by Van der Tempel and Molenaar [16], a rotor assembly with blades, similar to a wind turbine but designed for use in water settings, is the fundamental component of a water turbine. Water turbines come in a variety of designs, from low river turbines to massive offshore structures, depending on the need and environment. Like in wind turbines, the rotor assembly is attached to a shaft that transmits the rotational energy to a generator. However, certain designs and materials are needed for the building of water turbines due to the dynamics of water flow and the need for structure for underwater operation. To maximize energy conversion, Zanette et al. [17] address a design methodology for crossflow water turbines that emphasizes elements such as blades, form, and pitch. Sick et al. [18] also examine the dynamic analysis of water turbines, emphasizing the significance of stability and structural integrity under different flow conditions.

The uniform appearance will assist the reader in reading the paper of the proceedings. It is therefore suggested that authors use the example of this file to construct their papers. This particular example uses an American letter format with 25 mm margins left, right, top, and bottom.

All text paragraphs should be single-spaced, with the first line intended by 7 mm. Double spacing should NOT be used anywhere in the manuscript. The position and style of headings and subheadings should follow this example. One empty line (11 pt) should be left between every two consecutive sections. Two empty lines should be left before and after the abstract.

All headings and subheadings should be in bold and Arial font. Major headings must be 12 pt and subheadings should be 11 pt. No empty lines are required between the heading/subheading and the text.

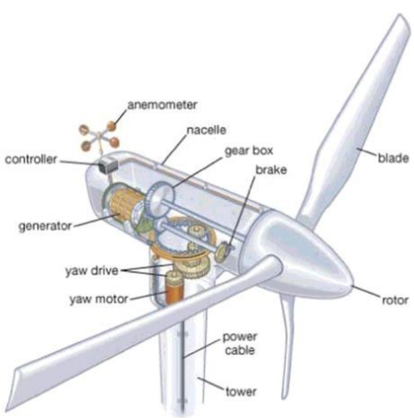

Figure 1 Description of diagram of a wind turbine [30].

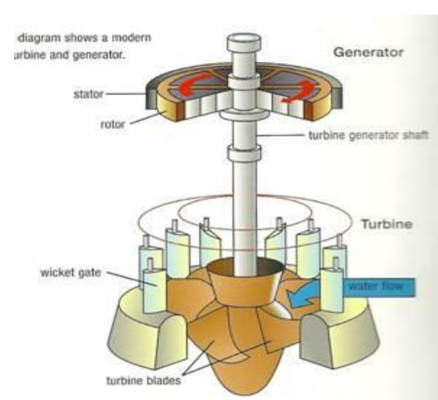

Figure 2 Schematic diagram of a hydroelectric turbine [31]

2.1 CHALLENGES – TABLE: COMPARISON OF WIND V/S WATER TURBINE

It is important to analyze the systems involving the functionality of the wind and the water turbines. In Table 1 we can refer to these similarities and differences and how their functions address the specific environment.

Table 1 comparison of wind v/s water turbine

Current challenges	Wind turbine	Water turbine
Environmental impact	• Local fauna may be impacted by wind plants, due to the large blades. [19] Saidur, R., • Visual impedance due to large components.	• Installation-related regulations involve conformity to environmental impact. [20] McKenna, R.
Resource	• Remote areas tend to be home to ideal wind settings. • Highly dependent on locations and wind patterns [21] Tasneem, Z. • Large amount of material to set up and transport.	• Requires consistent water flow and certain velocity. [22] Nielsen, F.G
Availability	• Initial investment will be high. • Low win speeds decrease energy production. [23] Guerra, O.J.	• Turbine efficiency and availability of water. • vulnerability to floods or droughts which influence the availability of water and the performance of turbines. [24] Konstantinidis, E.I.
Efficiency	• Production of energy decreases at low wind speeds: Reduced effectiveness when there is little wind. • Fatigue Loads affect control. [25] McKenna, R • Low wind creates low efficiency.	• Concerns of structural stability in dynamic water currents due to unstable waters. • Turbulence around the blades of turbines and the velocity of water flow affect efficiency. [26] Liu, X.,
Maintenance	• Components at optimal performance and lifetime require regular maintenance. [27] Tchakoua, P. • Deterioration of moving parts as a result of continuous use and weather exposure • Risk of strikes by lightning on towering wind turbines	• There is a chance of fouling and corrosion in submerged situations. • Obtaining and maintaining submerged turbine parts presents difficulties. [28] Yang, W.

3. ADVANCED FLOW CONTROL TECHNIQUES TO COMBAT THE CHALLENGES

3.1 Wind turbines:

- **Plasma flow control**

Innovative flow control techniques have been developed by researchers and engineers as a response to issues that wind wind and water turbines encounter while trying to maximize their energy created and efficiency. For example, Guoqiang, L L [29]. used plasma flow control technology to optimize boundary layer dynamics, reduce flight disturbances, and stabilize stabilize flow separation in Savonius VAWT blades.

- **Blade sensors.**

Similarly, blade sensors are used in active control to analyze local conditions, while geometric shaping is used in passive mechanisms to stabilize pressure gradients. This changed the pressure distribution and enhanced performance. The problem of materials and blades changing form and appearance was addressed by this modification and requires less maintenance since the system slows down the degeneration of the blades, and it also increases their life.

- **Yaw system regulation**

The dynamic and turbulent nature of wind flows is one of the obstacles in operating wind turbines, as it can result in mechanical stress and poor performance. Turbines can optimize energy capture and reduce aerodynamic loads by adjusting yaw systems to regulate the power by 40% of fatigue and reducing extreme load by up to 19% in extreme wind conditions, as explored by Kim [32].

- **Lidar technology, sonic sensor, Blade pitch angles**

Blade pitch angles in real-time through the use of advanced control algorithms such as cross-axis wind turbines and magnetic-based turbines, as demonstrated by Roga et al. [33]. Furthermore, as Shourangiz-Haghighi et al. [34] and Adekanbi [35] note, the combination of sensor technologies such as Lidar technology, sonic sensor, predictive control systems, collective pitch control, grid integration control, incorporate a tracker that can operate in normal and abnormal conditions, allows turbines to quickly adjust to changing wind conditions, optimizing power output while reducing structural wear and tear. By extending the operational lifespan of wind turbines and increasing their efficiency and dependability, these methods improve the overall affordability of wind power generation.

- **voltage support and frequency adjustment.**

Grid integration and stability, which are related to the instability of wind power supply, provide additional challenges. By comparing wind and wave energy models described by Ringwood [36], wind turbines as well as water turbines can provide the grid with ancillary services like voltage support and frequency adjustment.

- **Internal Model Control (IMC) and ultrasonic testing**

Control solutions like integrated high/low-level controllers and Internal Model Control (IMC) promote grid endurance against disturbances by adjusting turbine capacity in reaction to grid frequency variations. Concluding that the power coefficient can be maximized if, rotor velocity and blade pitch are set based on the incident wind flow velocity. This lowers the possibility of grid instability and improves overall system reliability. Furthermore, as demonstrated by Márquez, F.P.G [37], the optimization of wind turbine operation through ultrasonic testing, acoustic emission, and strain measurements allows integrated monitoring of several turbines and their blade maintenance to correctly detect any faults and reduce wake effects, increasing the effectiveness and financial viability of wind energy generation.

3.2 Water turbines:

- **Speed regulations, electronic load Controller ELC, and flow control machines.**

The variable nature of water flow is one of the main challenges that water turbines face, as it can greatly affect their effectiveness and performance. According to Parish [38], incorporating speed regulations, flow control machines to meet power demands, and decreasing electrical power input by adding an electronic load Controller ELC enables turbines to respond dynamically to changes in water flow, maximizing energy extraction under a range of operating conditions.

- **Blade pitch angle adjustment**

Turbines with advanced control algorithms can make real-time adjustments to guide vane locations or blade pitch angles to ensure maximal energy capture and minimize performance losses caused by undesirable operating conditions. Because of their increased adaptability, water turbine systems are more resilient and can continue to function well even when flow rates fluctuate.

- **PID controls and MSC control loops**

Moreover, Sahraei et al. [39] demonstrate improved grid stability and integration, especially in micro-hydro power plants. Sami et al. [40] provide control strategies like PID controls and MSC control loops that allow micro-hydro systems to actively support grid stability, much like synchronous generators do. Similarly, it allows the speed or torque to be either released or absorbed depending on the power imbalance. These methods include synthetic inertia frequency support. These control solutions among fast frequency reserves enhance grid resilience against disturbances by modifying turbine output in response to grid frequency variations. This lowers the risk of grid instability and improves overall system durability.

- **Axial flow water turbines, inclined axis, and rigid mooring**

Plant optimization and grid interaction are addressed in the optimization of water turbine systems, which goes beyond the optimization of individual units. Within a hydroelectric structure, advanced flow control systems allow for the simultaneous operation of many turbines, optimizing overall energy capture and reducing negative effects like cavitation or structural wear. Research findings from studies like Khan et al. [41]. show how axial flow water turbines, inclined axes, and rigid mooring can change the performance of the system.

- **Blade pitch angles, shaft inclinations, or guide vane placements in real-time**

Blade pitch angles, shaft inclinations, or guide vane placements in real-time allow for the optimization of energy capture of about 30% in mechanical control under a range of flow situations. This flexibility ensures water turbines' consistent functioning even in the presence of variable water flow rates, while also increasing their efficiency. Other designs also allow for better performances such as the Darrieus turbine which in comparison to the Savonious performs 55% better with a 5kVA turbine, Kiho S [42].

4. COMPARATIVE ANALYSIS OF FLOW CONTROL METHODS

Optimizing energy capture and general productivity of wind and water turbines is based on their aerodynamic performance. Several flow control methods have been presented and analyzed in Table 2 to present the benefits and impacts of these methods implemented in turbines to maximize their overall aerodynamic performance.

Table 2 Comparative analysis of flow control methods

Flow Control Methods	Wind Turbines	Water Turbines
Plasma flow & passive control techniques	- Optimized boundary layer dynamics - Decreased flow disturbances in VAWT blades - Stabilizing flow separation - Active control systems with blade sensors	- Flow control mechanisms - Speed regulations - Electronic load controllers (ELCs) - Micro-hydro systems
Yaw systems control	- Refining energy capture - Lowering aerodynamic loads - Real-time blade pitch angle change	- Multi-Step Control (MSC) loops - Proportional-Integral-Derivative (PID) controllers
Sensors & program controls	- Sonic and Lidar sensors combined with predictive control - Grid integration control - Collective pitch control	- Real-time adjustments to guide vane locations or blade pitch angles - Varying turbine's rotational speed
Monitoring techniques	- Acoustic emission measurements - Ultrasonic testing - Minimize wake effects - Early problem diagnosis	- Optimization of individual units and plants - Real-time modifications to shaft inclinations or guide vane placements - Modern turbine designs like Darrieus turbine - Individual blade control - Direct power control

5. CONCLUSION: FUTURE DIRECTIONS AND POTENTIAL INNOVATIONS

Even though improved flow control systems in wind and water turbines have advanced significantly, there are still various opportunities for further study and development. First, additional optimization and improvement of current flow control techniques are required to improve their efficiency and dependability in a variety of operating environments and environmental circumstances. Additionally, to further enhance turbine performance and longevity, future research should concentrate on fusing cutting-edge flow management methods with cutting-edge technologies including artificial intelligence, machine learning, and sophisticated materials. These technologies could be used to create autonomous turbine control systems that can optimize and adapt in real time.

Furthermore, extensive field testing and validation of sophisticated flow control methods in actual turbine installations are required to evaluate their long-term reliability and performance. To accelerate the transition towards a more sustainable energy future and enable the wider deployment of these technologies, collaboration among researchers, industry players, and policymakers will be essential. the key to realizing the full potential of wind and water turbines as dependable, effective, and ecologically sources of renewable energy lies in ongoing innovation and research in cutting-edge flow control systems.

In summary, the implementation of sophisticated flow control methodologies presents considerable potential for enhancing the efficiency of wind and water turbines, consequently aiding in the shift towards sustainable energy sources. The challenges faced by wind and water turbines, such as aerodynamic limitations, structural stresses, and grid integration issues, have been successfully addressed by researchers and engineers through creative approaches like plasma flow control, passive geometric shaping, active blade sensors, and real-time control algorithms.

For wind turbines, cutting down on turbulence-induced losses, improving energy capture efficiency, and maintaining flow separation are all made possible by implementing different controls such as passive, which directly affects the material of the turbine, or active control which is more expensive but more efficient. Wind turbines can now quickly react to changing wind conditions thanks to techniques like sensor-based predictive control systems, real-time blade pitch control, and yaw system modifications. This has increased overall efficiency. Similar to this, water turbines have benefited from advanced flow control devices, such as flow control machines, speed limits, and creative turbine designs. Through modern control algorithms and multi-turbine operation strategies, these innovations have made it possible for water turbines to maximize energy extraction, respond dynamically to varying flow rates, and support grid stability.

References

[1] Xu, W., Li, C.C., Huang, S.X. and Wang, Y., 2022. Aerodynamic performance improvement analysis of Savonius vertical axis wind turbine utilizing plasma excitation flow control. Energy, 239, p.122133.

[2] Akhter, M.Z. and Omar, F.K., 2021. Review of flow-control devices for wind-turbine performance enhancement. Energies, 14(5), p.1268.

[3] Acarer, S., 2020. Peak lift-to-drag ratio enhancement of the DU12W262 airfoil by passive flow control and its impact on horizontal and vertical axis wind turbines. Energy, 201, p.117659.

[4] Hwang, I.S., Lee, Y.H. and Kim, S.J., 2009. Optimization of cycloidal water turbine and the performance improvement by individual blade control. Applied Energy, 86(9), pp.1532-1540.

[5] Cooney, J.A., 2014. Increasing power generation in horizontal axis wind turbines using optimized flow control (Doctoral dissertation, University of Notre Dame).

[6] Bay, C.J., Annoni, J., Martínez-Tossas, L.A., Pao, L.Y. and Johnson, K.E., 2019, July. Flow control leveraging downwind rotors for improved wind power plant operation. In 2019 American Control Conference (ACC) (pp. 2843-2848). IEEE.

[7] Wiratama, I.K., 2012. Aerodynamic design of wind turbine blades utilizing nonconventional control systems (Doctoral dissertation, Northumbria University).

[8] Gorle, J.M.R., Chatellier, L., Pons, F. and Ba, M., 2019. Modulated circulation control around the blades of a vertical axis hydrokinetic turbine for flow control and improved performance. Renewable and Sustainable Energy Reviews, 105, pp.363-377.

[9] Moshfeghi, M., Shams, S., & Hur, N. (2017, May 2). Aerodynamic performance enhancement analysis of horizontal axis wind turbines using a passive flow control method via split blade. Journal of Wind Engineering and Industrial Aerodynamics, 167, pp.148-152.

[10] Van Dam, C.P., Berg, D.E. and Johnson, S.J., 2008. Active load control techniques for wind turbines (No. SAND2008-4809). Sandia National Laboratories (SNL), Albuquerque, NM, and Livermore, CA (United States).

[11] González-Salcedo, Á., Croce, A., Arce León, C., Nayeri, C.N., Baldacchino, D., Vimalakanthan, K. and Barlas, T., 2020. Blade design with passive flow control technologies. Handbook of Wind Energy Aerodynamics, pp.1-57.

[12] Lekube, J., Garrido, A.J., Garrido, I., Otaola, E. and Maseda, J., 2018. Flow control in wells turbines for harnessing maximum wave power. Sensors, 18(2), p.535.

[13] Shourangiz-Haghighi, A., Haghnegahdar, M.A., Wang, L., Mussetta, M., Kolios, A. and Lander, M., 2020. State-of-the-art in the optimization of wind turbine performance using CFD. Archives of Computational Methods in Engineering, 27, pp.413-431.

[14] Hansen, M.O., 2000. Aerodynamics of wind turbines: rotors, loads and structure (Vol. 17). Earthscan.

[15] Hansen, M., 2015. Aerodynamics of wind turbines. Routledge.

[16] van der Tempel, J. and Molenaar, D.P., 2002. Wind turbine structural dynamics–a review of the principles for modern power generation, onshore and offshore. Wind engineering, 26(4), pp.211-222.

[17] Zanette, J., Imbault, D. and Tourabi, A., 2010. A design methodology for cross-flow water turbines. Renewable Energy, 35(5), pp.997-1009.

[18] Sick, M., Michler, W., Weiss, T. and Keck, H., 2009. Recent developments in the dynamic analysis of water turbines.
[19] Saidur, R., Rahim, N.A., Islam, M.R. and Solangi, K.H., 2011. Environmental impact of wind energy. Renewable and sustainable energy reviews, 15(5), pp.2423-2430.
[20] McKenna, R., vd Leye, P.O. and Fichtner, W., 2016. Key challenges and prospects for large wind turbines. Renewable and Sustainable Energy Reviews, 53, pp.1212-1221.
[21] Tasneem, Z., Al Noman, A., Das, S.K., Saha, D.K., Islam, M.R., Ali, M.F., Badal, M.F.R., Ahamed, M.H., Moyeen, S.I. and Alam, F., 2020. An analytical review on the evaluation of wind resource and wind turbine for urban application: Prospect and challenges. Developments in the Built Environment, 4, p.100033.
[22] Nielsen, F.G., 2022. Perspectives and challenges related to offshore wind turbines in deep water. Energies, 15(8), p.2844.
[23] Guerra, O.J. and Reklaitis, G.V., 2018. Advances and challenges in water management within energy systems. Renewable and Sustainable Energy Reviews, 82, pp.4009-4019
[24] Konstantinidis, E.I. and Botsaris, P.N., 2016, November. Wind turbines: current status, obstacles, trends, and technologies. In IOP conference series: materials science and engineering (Vol. 161, No. 1, p. 012079). IOP Publishing.
[25] McKenna, R., vd Leye, P.O. and Fichtner, W., 2016. Key challenges and prospects for large wind turbines. Renewable and Sustainable Energy Reviews, 53, pp.1212-1221.
[26] Liu, X., Luo, Y., Karney, B.W. and Wang, W., 2015. A selected literature review of efficiency improvements in hydraulic turbines. Renewable and Sustainable Energy Reviews, 51, pp.18-28.
[27] Tchakoua, P., Wamkeue, R., Ouhrouche, M., Slaoui-Hasnaoui, F., Tameghe, T.A. and Ekemb, G., 2014. Wind turbine condition monitoring: State-of-the-art review, new trends, and future challenges. Energies, 7(4), pp.2595-2630.
[28] Yang, W., Tavner, P.J., Crabtree, C.J., Feng, Y. and Qiu, Y., 2014. Wind turbine condition monitoring: technical and commercial challenges. Wind energy, 17(5), pp.673-693.
[29] Guoqiang, L., Weiguo, Z., Yubiao, J. and Pengyu, Y., 2019. Experimental investigation of dynamic stall flow control for wind turbine airfoils using a plasma actuator. Energy, 185, pp.90-101.
[30] Bianchi, F.D., De Battista, H. and Mantz, R.J., 2007. Wind turbine control systems: principles, modeling and gain scheduling design (Vol. 19). London: Springer.
[31] Spilsbury and Spilsbury (2008). Diagram of the hydroelectric turbine.
[32] Kim, M.G. and Dalhoff, P.H., 2014, June. Yaw Systems for wind turbines–Overview of concepts, current challenges, and design methods. In Journal of Physics: Conference Series (Vol. 524, No. 1, p. 012086). IOP Publishing.
[33] Roga, S., Bardhan, S., Kumar, Y. and Dubey, S.K., 2022. Recent technology and challenges of wind energy generation: A review. Sustainable Energy Technologies and Assessments, 52, p.102239.
[34] Shourangiz-Haghighi, A., Diazd, M., Zhang, Y., Li, J., Yuan, Y., Faraji, R., Ding, L. and Guerrero, J.M., 2020. Developing more efficient wind turbines: A survey of control challenges and opportunities. IEEE Industrial Electronics Magazine, 14(4), pp.53-64.
[35] Adekanbi, M.L., 2021. Optimization and digitization of wind farms using internet of things: A review. International Journal of Energy Research, 45(11), pp.15832-15838.
[36] Ringwood, J.V. and Simani, S., 2015. Overview of modeling and control strategies for wind turbines and wave energy devices: Comparisons and contrasts. Annual Reviews in Control, 40, pp.27-49.
[37] Márquez, F.P.G., Tobias, A.M., Pérez, J.M.P. and Papaelias, M., 2012. Condition monitoring of wind turbines: Techniques and methods. Renewable energy, 46, pp.169-178.
[38] Paish, O., 2002. Small hydro power: technology and current status. Renewable and sustainable energy reviews, 6(6), pp.537-556.
[39] Sahraei, M.H., McCalden, D., Hughes, R. and Ricardez-Sandoval, L.A., 2014. A survey on current advanced IGCC power plant technologies, sensors, and control systems. Fuel, 137, pp.245-259.
[40] Sami, I., Ullah, N., Muyeen, S.M., Techato, K., Chowdhury, M.S. and Ro, J.S., 2020. Control methods for standalone and grid-connected micro-hydro power plants with synthetic inertia frequency support: A comprehensive review. IEEE Access, 8, pp.176313-176329.

[41] Khan, M.J., Iqbal, M.T. and Quaicoe, J.E., 2008. River current energy conversion systems: Progress, prospects, and challenges. Renewable and sustainable energy reviews, 12(8), pp.2177-2193.
[42] Kiho S, Shiono M, Suzuki K. The power generation from tidal currents by Darrieus turbines. In: Proceedings of the World Renewable Energy Congress, vol. 2. Denver, Colorado, USA; 1996. p. 1242–5.
[43] Greenblatt, D., Schulman, M. and Ben-Harav, A., 2012. Vertical axis wind turbine performance enhancement using plasma actuators. Renewable Energy, 37(1), pp.345-354.
[44] Bossanyi E, Delouvri T, and Lindahl S 2013 Long-term simulations for optimizing yaw control and start-stop strategies. EWEA Annual Event 2013
[45] Chong, W.T., Wong, K.H., Wang, C.T., Gwani, M., Chu, Y.J., Chia, W.C. and Poh, S.C., 2017. Cross-axis wind turbine: a complementary design to push the limit of wind turbine technology. Energy Procedia, 105, pp.973-979.
[46] Yuan, Y. and Tang, J., 2017. Adaptive pitch control of wind turbine for load mitigation under structural uncertainties. Renewable Energy, 105, pp.483-494.
[47] Walford, C.A., 2006. Wind turbine reliability: understanding and minimizing wind turbine operation and maintenance costs (No. SAND2006-1100). Sandia National Laboratories (SNL), Albuquerque, NM, and Livermore, CA (United States).
[48] Su, J., Dehghanian, P., Nazemi, M. and Wang, B., 2019, October. Distributed wind power resources for enhanced power grid resilience. In 2019 North American Power Symposium (NAPS) (pp. 1-6). IEEE.
[49] Emadifar, R., Tohidi, D. and Eldoromi, M., 2016. Controlling Variable Speed Wind Turbines Which Have Doubly Fed Induction Generator by Using of Internal Model Control Method. International Journal of Advanced Research in Electrical, Electronics and Instrumentation Engineering, (5), pp.3464-3471.
[50] Alberizzi, J.C., Renzi, M., Righetti, M., Pisaturo, G.R. and Rossi, M., 2019. Speed and pressure controls of pumps-as-turbines installed in a branch of a water-distribution network subjected to highly variable flow rates. Energies, 12(24), p.4738.
[51] Perng, J.W., Kuo, Y.C. and Lu, K.C., 2020. Design of the PID controller for hydro-turbines based on optimization algorithms. International Journal of Control, Automation and Systems, 18, pp.1758-1770.
[52] Tian, Y., Hu, A. and Zheng, Q., 2020. The effect of guide vane type on the performance of multistage energy recovery hydraulic turbine (MERHT). Open Physics, 18(1), pp.352-364.
[53] Kirke, B. and Lazauskas, L., 2008. Variable pitch Darrieus water turbines. Journal of Fluid Science and Technology, 3(3), pp.430-438.
[54] Hwang, I.S., Lee, Y.H. and Kim, S.J., 2009. Optimization of cycloidal water turbine and the performance improvement by individual blade control. Applied Energy, 86(9), pp.1532-1540.
[55] Hauck, M., Munteanu, I., Bratcu, A.I., Bacha, S. and Roye, D., 2010. Operation of grid-connected cross-flow water turbines in the stall region by direct power control. IEEE Transactions on Industrial Electronics, 58(4), pp.1132-1140.