IARJSET ISSN (O) 2393-8021, ISSN (P) 2394-1588

International Advanced Research Journal in Science, Engineering and Technology

Impact Factor 8.066 ⁒ Peer-reviewed / Refereed journal ⁒ Vol. 11, Issue 11, November 2024

DOI: 10.17148/IARJSET.2024.111109

Literature Review On Wind Turbines Braking Systems

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Abstract: This paper focuses on the importance of wind turbine braking systems and their role in controlling and stopping the rotor during maintenance, emergencies, and extreme weather conditions. It highlights the significance of safe and controlled shutdowns in preventing excessive wear and tear on turbine components, reducing the risk of catastrophic failures, and ensuring the safety of maintenance personnel. The paper will also discuss the main types of braking systems used in wind turbines; Aerodynamic, Electrical and Mechanical braking systems, comparing their advantages and limitations. By examining these systems, the paper aims to provide a comprehensive understanding of their functionality and assist in the selection, implementation, and maintenance of appropriate braking systems for efficient and safe wind turbine operation.

Keywords: Wind Turbine, Braking Systems, Turbine’s Rotor, Emergency Stop.

I. INTRODUCTION

Wind energy has emerged as a prominent renewable power source, offering sustainable and clean alternatives to conventional energy. Wind turbines harness the wind's kinetic energy to generate electricity. To ensure efficient and safe turbine operation, various systems are employed, including the critical braking system. Wind turbine braking systems are essential for controlling and stopping the rotor during maintenance, emergencies, and extreme weather. These systems enable safe and controlled shutdowns, reducing wear on turbine components, mitigating catastrophic failures, and ensuring personnel safety. The need for reliable wind turbine braking systems arises from several factors. During maintenance or repairs, a functioning braking system is necessary to halt the rotor and protect personnel. Uncontrolled rotor movement poses significant risks during tasks like blade inspections or equipment repairs. Additionally, wind turbines are exposed to extreme weather conditions, necessitating the ability to stop the rotor and minimize stress on the turbine structure and components. Uncontrolled rotor speeds in severe weather can lead to excessive vibrations, blade damage, and potential tower collapse, jeopardizing the entire turbine's integrity. Furthermore, wind turbines are integrated into electricity grids and require reliable braking systems to respond to grid disruptions or emergencies. A responsive braking system allows for swift turbine disconnection, ensuring grid stability and preventing damage to the turbine or electrical system.

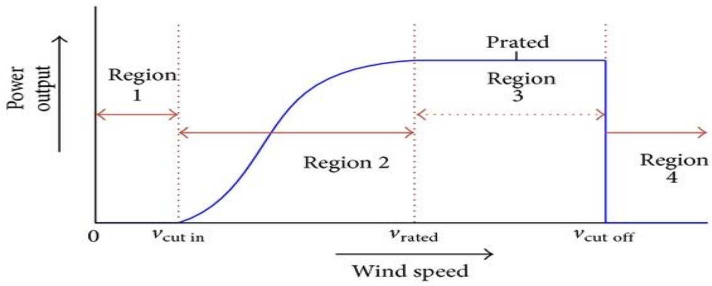

Figure 1 Wind Turbine Speed Curve

Failure of wind turbine braking systems can have severe consequences. Uncontrolled rotor speeds accelerate component wear, reducing their lifespan and requiring expensive repairs or replacements. Inadequate braking systems also compromise personnel safety, increasing the risk of accidents or injuries during maintenance activities. This paper aims to provide a detailed exploration of wind turbine braking systems, emphasizing their significance, discussing the main types of systems used, and providing insights into functionality and selection criteria. By understanding these systems,

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operators and designers can optimize turbine performance, enhance safety measures, and ensure reliable and sustainable wind energy generation.

II. LITERATURE REVIEW

Extensive research and development efforts have been dedicated to wind turbine braking systems in the field of renewable energy. These systems, including aerodynamic, electrical, and mechanical braking, are pivotal for ensuring the safe and efficient operation of wind turbines by effectively controlling rotor speed in various operational scenarios. The literature review on wind turbine braking systems highlights advancements in the design, performance, and reliability of these three main systems.

A. Aerodynamics Brakes

Aerodynamic braking is a method used to regulate the speed of wind turbines by manipulating the impact of the wind on the turbine blades. This technique involves controlling the interaction between the blades and the wind to effectively adjust the rotor speed. Various approaches and mechanisms are employed to regulate the wind's influence on the turbine blades, which will be thoroughly explained in the subsequent sections.

1- Passive Stall Regulated Wind Turbines:

Wind turbines with passive stall control rely on the airfoil design of the rotor blades to control the amount of energy extracted from the wind. Unlike other types of turbines, these turbines' blades are fixed to the hub and do not rotate about their longitudinal axis. Particularly at high wind speeds, the aerodynamic profile of the blades is meticulously designed to generate turbulence on the side of the blade that is not directly facing the wind. This induced turbulence initiates a stall phase, which counteracts the lifting force exerted on the rotor blades and prevents the rotor from spinning too quickly in high winds. The blade is twisted along its longitudinal axis to achieve a controlled and gradual stall process, allowing for a smoother transition rather than an abrupt stall occurrence at critical wind speeds (Choi et al., 2019).

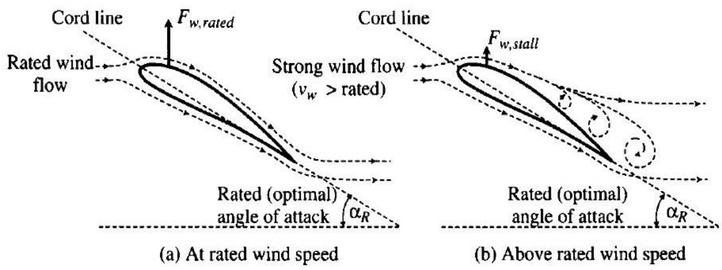

Figure 2 Airfoil of Wind Turbine

Passive stall-regulated wind turbines feature a simple and economical design. However, their control capabilities are limited because they rely solely on natural stall phenomena, rendering them incapable of adapting to torque fluctuations caused by unpredictability and instability in wind conditions (Apata & Oyedokun, 2020).

2- Pitch Regulated Wind Turbines:

The blades of a pitch-regulated wind turbine are able to rotate about their longitudinal axis. Utilising control systems, the power output of the turbine is continuously and repeatedly measured multiple times per second. On the basis of these measurements, the blades are adjusted either towards the wind at low wind speeds to maximise power production by increasing the angle of attack, or away from the wind at high wind speeds to maintain a safe power level by decreasing the angle of attack (Apata & Oyedokun, 2020). Nevertheless, pitch-regulated wind turbines have some disadvantages. Although they perform better than stall-regulated turbines at low wind speeds, they experience fluctuating torques and unsteady power output in high wind speeds and turbulent wind conditions, which can damage the generator.

3- Active Stall Regulated Wind Turbines:

Similar to pitch-regulated wind turbines, the rotor blades of active stall wind turbines can be rotated or pitched. In low-wind conditions, the blades are adjusted to maximise torque and power output. However, unlike pitch-regulated wind turbines, the blades are rotated to increase the angle of attack rather than decrease it at high wind speeds. Utilising the

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aerodynamics of the airfoil design, this intentional increase in angle of attack causes the turbine to enter a deeper stall phase (Thomas Ackermann, 2005).

4- Blade Tip Brakes:

In a tip brake mechanism, the rotation of the blade tip about its longitudinal axis is used to generate braking force. Initially, this rotation was accomplished automatically by a spring that counteracted the wind's force. When the wind exceeded a certain threshold, the blade tip would be pushed, causing it to rotate against the wind and initiate the braking process. The occurrence of turbine fluctuations was, however, a drawback of this design. As soon as the wind speed decreased and the turbine slowed down, the spring would return to its initial position, causing the turbine to once again overspeed. This cycle would continue until the wind velocity decreased. To address this issue, the design was modified to incorporate distinct trigger and reset values for the tip actuation, thereby preventing the fluctuations (Widseth et al., n.d.).

B. Electrical Brakes

Electrical braking in wind turbines involves applying electrical loads to the generator in order to generate a back torque that opposes the rotor torque. Wind turbines utilise a variety of standard electrical braking methods.

1- Electro-Dynamic Braking:

In small wind turbines, electrodynamic braking is frequently used to slow down or stop the rotor by creating a back torque on the generator through short-circuiting its stator windings. The strength of the back torque depends on the generator's speed and flux configuration. However, this method has some disadvantages. It is only suitable for small turbines and can generate excessive heat that may damage the generator coils. Additionally, transient electrical effects during short-circuiting can lead to component failures. Finally, the assumption that the back torque will consistently exceed the wind turbine's torque is not always true because the generator's torque has a single peak at short circuit, while the turbine's torque varies with wind speed, requiring different peak back torque values for optimal braking effectiveness each time. McMahan et al. (2015).

2- Electro-Magnetic Braking:

By connecting a capacitor between the stator terminals of the generator, electromagnetic braking is achieved. In this mode, a self-excited voltage is produced, causing a large current to flow through the stator and rotor of the generator. The induced current causes a back torque on the generator, which slows down the turbine's rotor. This induced current generates significant heat, which must be dissipated by external resistors (Rajambal et al., 2005) A disadvantage of electromagnetic braking systems is that they are frequently combined with mechanical brakes for mutual support. Mo et al. (2016) state that electromagnetic brakes can reduce the turbine's speed by up to 60 percent before a mechanical brake

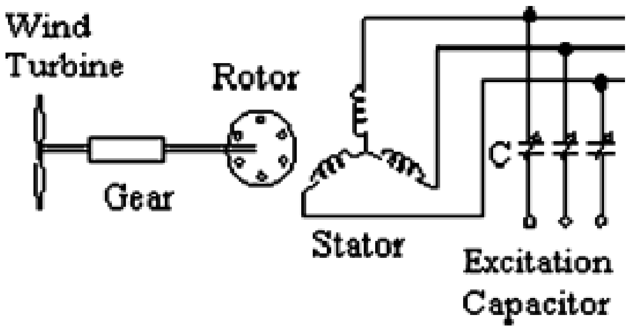

Figure 3 Electromagnetic brakes

is required to completely stop the turbine. Similar to electrodynamic braking, electromagnetic braking generates a significant amount of heat, which can lead to generator overheating and damage (Rajambal et al., 2005).

C. Mechanical Brakes

A wind turbine's mechanical brake relies on a friction force exerted on a disc located on either the low-speed or high-speed shaft of the rotor. The purpose of the mechanical brake is to bring the rotor to a full stop and allow the rotor to be locked during maintenance operations. Typically, the friction force is applied to a braking pad, which makes contact with

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the rotor's disc to generate the friction necessary for slowing or stopping the rotor. Various activation methods are utilised to bring the brake pad into contact with the disc.

1- Hydraulic & Pneumatic Brakes:

In a hydraulic braking system, the braking pad is activated by hydraulic oil supplied by a hydraulic pump. The hydraulic oil flows through hydraulic actuators, which then apply pressure to the attached braking pad. This hydraulic force generates substantial power that applies a strong force to the braking pad, causing friction between the pad and the rotor's disc. This friction generates a negative torque that opposes the wind turbine's torque. Similarly, in a pneumatic braking system, the concept is identical to that of a hydraulic system, but compressed air is used instead of hydraulic oil as the working fluid. The pneumatic braking system may include a spring for the return stroke, or it may function without a spring, with both strokes powered by compressed air. Both hydraulic and pneumatic braking systems apply braking force to the rotor of a wind turbine, allowing for control over its rotational speed and the ability to stop the turbine when necessary.

2- Magnetic Brakes:

Magnetically actuated pads are an alternate form of mechanical braking. This type of brake employs a coil that is energised by an electric current to cause the braking pad to move. When the coil is energised, a magnetic field is produced that attracts or repels the braking pad, causing it to move and apply the necessary braking force to the rotor's disc. The magnetic actuated brake provides effective braking capabilities for wind turbines via a novel method of achieving mechanical braking through the controlled interaction of magnetic forces.

D. Contactless Magnetic Brakes

Koswatta and colleagues (2020) introduced a new approach to braking for wind turbines that eliminates the drawbacks of traditional friction-based braking systems. According to Faraday's law, when a non-ferromagnetic material moves in a magnetic field, it generates eddy currents in the opposite direction of the field. Their design involves placing copper plates on the turbine's rotor, which rotate with the blades. The copper plates are the non-ferromagnetic material, and three magnets are positioned next to them. During braking, a servo motor rotates the magnets closer to the rotating plates,

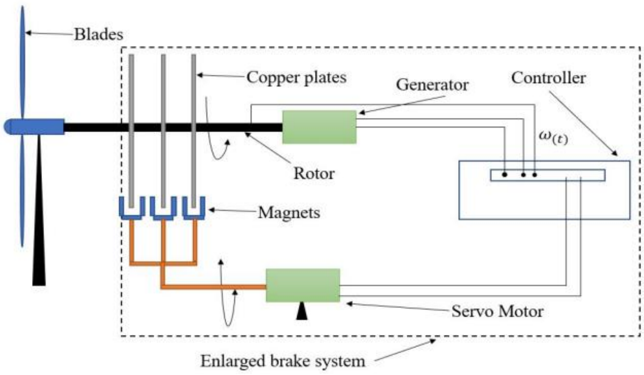

Figure 4 Magnetic Contactless brakes

inducing opposite-direction eddy currents in the copper plates. This generates a braking force that opposes the rotor's rotation. By using this innovative design, Koswatta et al. aimed to develop a braking system that avoids the limitations of friction-based brakes and provides an alternative method for effectively controlling wind turbine rotor speed.

III. DISCUSSION

Aerodynamics control is reliable for regulating power under normal wind conditions, but not for stopping turbines in emergency situations or when the wind is abnormal. Therefore, laws, standards, and manufacturers recommend that secondary braking systems be present in addition to aerodynamic control. Particularly Danish wind turbine manufacturers advocate for at least two braking mechanisms to guarantee turbine safety. The use of dual braking systems is mandated by Danish law and GL regulations, particularly for large wind turbines. The international standard IEC 61400-1 stipulates that a wind turbine must have at least one aerodynamic braking system that acts directly on the rotor. If this requirement is not met, the braking system must apply force to the rotor shaft or rotor itself.

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Electrical braking permits precise control of rotor speed, but generates excessive heat that can damage generator coils, electrical components, and electronic components of the turbine. In addition, if the turbine becomes disconnected from the grid by accident, the electric brakes may malfunction, causing the rotor to rotate at high speeds without any braking force.

Mechanical brakes provide precise rotor stoppage and superior control, but their reliance on friction presents challenges. The high temperatures generated during braking necessitate the use of specialised brake pads that can withstand temperatures of up to 700 degrees Celsius. Pad deterioration can result in non-uniform braking profiles and potential disc-to-pad slippage.

The proposed design employing magnetically actuated pads provides a frictionless and contactless braking mechanism. Due to its relatively low braking force, it can only be used on small wind turbines. In addition, it is only capable of capping the rotor speed at a certain limit by bringing the magnets close to the copper plates; it does not offer precise control over the rotor speed or complete turbine shutdown.

IV. CONCLUSION

In conclusion, wind turbine braking systems are crucial component of a wind turbine. Aerodynamics brakes showed an accurate control of wind turbine speeds, whether it is active or passive, or pitch regulated wind turbines or even blade tips. However, not to be reliable in emergency stops. Moreover, the electrical brakes where presented, including both types; electrodynamic and electromagnetic, both showed very accurate stoppage of wind turbines. However, the failures are repeatable as a result of the opposite torque exceeding the generators torque. Furthermore, mechanical brakes were presented, showing a high accuracy and fail-safe techniques, but on the other hand, consuming spare parts as a result of the huge amount of heat generated through friction stopping. Finally, a magnetic brakes were presented, which avoid contact braking mechanisms, however, it was restricted to small wind turbines due to the small braking power.

ACKNOWLEDGMENT

Thanks to the British university in Egypt’s library where all the research has been made through. Thanks to my colleagues who are well experienced to the extent to help me throughout my research.

REFERENCES

[1] Ali, A., Mohamed, A. T., & Rashed, A. (2021). Reliability analysis of wind turbine braking systems. *Renewable and Sustainable Energy*.

[2] Apata, O., & Oyedokun, D. T. O. (2020). An overview of control techniques for wind turbine systems. In *Scientific African* (Vol. 10). Elsevier B.V. https://doi.org/10.1016/j.sciaf.2020.e00566

[3] Choi, H. S., Yu, H., Lee, E. Y., Loza, B., Pacheco-Chérrez, J., Cárdenas, D., Minchala, L. I., & Probst, O. (2019). Comparative fatigue life assessment of wind turbine blades operating with different regulation schemes. *Applied Sciences (Switzerland)*, *9*(21). https://doi.org/10.3390/app9214632

[4] CSSC. (2023). *CSSC*.

[5] Energy, U. D. (2010). *History of Wind Energy*.

[6] Entezami, M., Hillmansen, S., Weston, P., & Papaelias, M. P. (2012). Fault detection and diagnosis within a wind turbine mechanical braking system using condition monitoring. *Renewable Energy*, *47*, 175–182. https://doi.org/10.1016/j.renene.2012.04.031

[7] Giebel, G., Pierik, J., & Sorensen, P. (2018). *Analysis of wind turbine accident data in Europe and the United States*.

[8] Global Wind Energy Council. (2023). *Global Wind Energy Council*.

[9] Koswatta, A., Alsharif, F., Shiroma, Y., Khosravy, M., Tamaki, S., & Tamura, J. (2020). Alternative braking method for small scaled-wind turbines connected DC green house with analogical experiment on blade destruction. *Advances in Science, Technology and Engineering Systems*, *5*(2), 500–511. https://doi.org/10.25046/aj050264

[10] Krenz, A. (2017). Control of Wind Turbines: Monitoring and Fault Diagnosis. *Springer*.

[11] Mcmahon, N. M., Burton, P. R., & Sharman, D. M. (2015). On Electrodynamic Braking for Small Wind Turbines. *Source: Wind Engineering*, *39*(5), 549–555. https://doi.org/10.2307/90007091

[12] Mo, Q., Wen, J., Liu, X., & Wang, J. (2016). *The Brake System and Method of the Small Vertical Axis Wind Turbine*.