

INVESTIGATION OF PERFORMANCE CHARACTERISTICS OF HYDRAULIC WIND TURBINE WITH VARIABLE ACCUMULATOR

Submitted in partial fulfilment of the requirements for the award of

Bachelor of Engineering degree in Mechanical Engineering

By

KASI RAMAN R (Reg. No. 39150705)

VARRUN NESHANTH V P (Reg. No. 39150712)



DEPARTMENT OF MECHANICAL ENGINEERING

SCHOOL OF MECHANICAL ENGINEERING

SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY

(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC | 12B Status by UGC | Approved by AICTE

JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI - 600119.

APRIL - 2023



SATHYABAMA

INSTITUTE OF SCIENCE AND TECHNOLOGY
(DEEMED TO BE UNIVERSITY)

Accredited with grade "A" by NAAC | 12B Status by UGC | Approved by AICTE
JEPPIAAR NAGAR, RAJIV GANDHI SALAI, CHENNAI – 600119.
www.sathyabama.ac.in

DEPARTMENT OF MECHANICAL ENGINEERING

BONAFIDE CERTIFICATE

This is to certify that this Project Report is the bonafide work **KASIRAMAN R(39150705)** and **VARRUN NESHANTH VP(39150712)** who carried out the project entitled "INVESTIGATION ON PERFORMANCE CHARACTERISTICS OF HYDRAULIC WIND TURBINE WITH VARIABLE ACCUMULATOR" under our supervision from December 2022 to April 2023

Project Guide

Mr. S.VENKATESH.,M.E., (Ph.D.)

Head of the Department

Dr. G. ARUNKUMAR, M.E., Ph.D.,

Submitted for Viva-voce Examination Held on 10.05.2023

Internal Examiner

External Examiner

DECLARATION

We, **KASI RAMAN R** and **VARRUN NESHANTH V P**, hereby declare that the Project Report entitled **INVESTIGATION ON PERFORMANCE CHARACTERISTICS OF HYDRAULIC WIND TURBINE WITH VARIABLE ACCUMULATOR** done by under the guidance **Mr. S. VENKATESH., M.E.,(Ph.D.)** at Sathyabama Institute of Science and Technology is submitted in partial fulfilment of the requirements for the award of Bachelor of Engineering degree in Mechanical Engineering.

DATE: 10.05.2023

1) R.KASI RAMAN

kasiraman

PLACE: Chennai

2) V.P.VARRUN NESHANTH

varrun

SIGNATURE OF THE CANDIDATES

ACKNOWLEDGEMENT

We are pleased to acknowledge our sincere thanks to the **Board of Management of SATHYABAMA** for their kind encouragement in doing this project and for completing it successfully. We are grateful to them.

We convey thanks to **Dr. S. Prakash, M.E., Ph.D.**, Dean, School of Mechanical Engineering and **Dr. G. Arunkumar, M.E., Ph.D.**, Head of the Department, Department of Mechanical Engineering for providing me necessary support and details at the right time during the progressive reviews.

We would like to express my sincere and deep sense of gratitude to our Project Guide **Mr. S. VENKATESH., M.E., (Ph.D.)** for his valuable guidance, suggestions and constant encouragement paved the way for the successful completion of my project work.

We wish to express our thanks to all Teaching and Non-teaching staff members of the Department of Mechanical Engineering who were helpful in many ways for the completion of the project.

ABSTRACT

In the new generation, the hydraulic wind turbine is a technology that is widely recognized in the field of wind power equipment. The hydraulic transmission system feeds energy through the blades, while the hydraulic power transmission system stabilizes the wind turbine under fluctuating wind speeds. The system is established with components such as the impeller, hydraulic pump, motor, accumulator, and constant speed control. Various study results have expanded its basic fluid model and typical control method, investigating the characteristics of impeller torque, hydraulic drive, and conventional accumulators. They are analyzed under turbulent wind conditions, with and without the controllable accumulator being compared. The application of the accumulator reduces the generator's torque fluctuation, enhances the system's stability, and improves the quality of power generation. A hydraulic wind turbine with accumulator is a type of renewable energy system that converts the kinetic energy of wind into mechanical energy through the use of a rotor and hydraulic system. The hydraulic system allows for the captured energy to be stored in an accumulator, which can be used to supply a consistent and reliable source of power to a grid or other energy-consuming device. This technology provides an efficient and sustainable method for generating electricity using wind power.

Keywords: Hydraulic power transmission system, hydraulic pump, motor, accumulator.

CONTENTS

CHAPTER NO.	TITLES	PAGE NO.
	ABSTRACT	V
	LIST OF FIGURES	VIII
	LIST OF ABBREVIATION	IX
1	INTRODUCTION	1
2	LITERATURE SURVEY	4
3	AIM AND SCOPE	16
	3.1 AIM	16
	3.1.1 Demand Of Energy	17
	3.1.2 Need Of Alternate Energy	17
	3.2 SCOPE	18
	3.2.1 Importance Of Renewable Energy	19
	3.2.2 Small Scale	19
	3.2.3 Hydraulic Energy Storage	20
4	EXPERIMENTAL SETUP	21
	4.1 METHODOLOGY	21
	4.1.1 Accumulators	22
	4.1.2 Wind Turbine	24
	4.1.3 System Overview Of Wind Turbine	25
	4.1.4 Pump	26
	4.2 HYDRAULIC MOTOR	28
	4.2.1 Vane Motor	29
	4.2.2 Gear Motor	30
	4.2.3 Gerotor Motor	31
	4.3 HYDRAULIC FLUID	31
	4.4 AIRFOIL S1046	34
	4.4.1 Vertical Axis Wind Turbine	38

	4.4.2 Savonius Wind Turbine	39
	4.4.3 Darrieus Wind Turbine	42
	4.5 ANALYSIS	46
	4.5.1 Boundary Condition	48
	4.6 COMPOSTION OF ENERGY STORAGE SYSTEMS	49
	4.6.1 Overview Of Electrical Energy Storage Technologies	49
	4.6.2 Flow Battery Energy Storage	50
	4.6.3 Battery Energy Storage Systems	50
	4.6.4 Control Strategies	51
	4.7 OTHER ENERGY STORAGE TECHNOLOGIES IN HYDRAULIC WIND TURBINE	53
	4.7.1 Pumped Hydroelectric Storage	54
	4.7.2 Stable Output Speed	55
	4.7.3 Conventional Accumulator Characteristics	55
	4.8 IMPORTANCE OF LOW MANUFACTURING COST OF WIND TURBINE	56
	4.9 IMPORTANCE OF TURBULENT WIND TECHNIQUE	57
5	RESULT AND DISCUSSION	58
	5.1 Result	58
	5.2 Discussion	64
6	OUTLOOK AND CONCLUSION	66
	6.1 OUTLOOK	66
	6.2 CONCLUSION	67
	REFERENCES	68

LIST OF FIGURES

FIGURE NO	TITLE	PAGE NO
4.1	METHODOLOGY	22
4.2	ACCUMULATOR	23
4.3	TURBINE BLADE	25
4.4	INTERNAL GEAR PUMP	28
4.5	HYDRAULIC MOTOR	29
4.6	VANE MOTOR	30
4.7	GEAR MOTOR	31
4.8	GEROTOR MOTOR	31
4.9	HYDRAULIC FLUID	32
4.10	AIRFOIL	33
4.11	AIRFOIL S1046	35
4.12	AIRFOIL 3D	35
4.13	VERTICAL AXIS WIND TURBINE	36
4.14	SAVONIUS BLADE	40
4.15	DARRIEUS BLADE	44
4.16	AIRFOIL GEOMETRY	46
4.17	MESHING	47
4.18	MESH GEOMETRY	48
5.1	RESULT AND ANALYSIS	58
5.2	CD RPLOT	59
5.3	CL RPLOT	60
5.4	CM RPLOT	61
5.5	SCALE RESIDUALS	63

LIST OF ABBREVIATIONS

HST	Hydro Static Transmission
IEA	International Energy Agency
TPES	Total Primary Energy Supply
TWH	TeraWatt Hour
HES	Hydraulic Energy Storage
PMSG	Permanent Magnet Synchronous Generator
HAWT	Horizontal Axis Wind Turbine
VAWT	Vertical Axis Wind Turbine
BEM	Blade Element Momentum
IGP	Internal Gear Pump
FBES	Flow Battery Energy Storage
BESS	Battery Energy Storage Systems

CHAPTER 1

INTRODUCTION

In recent years, a lot of research on sustainable new energy sources to reduce the dependence on fossil fuels, and the investigation of new ways to extract sustainable and green energy from renewable sources such as sun, wind, plants, and water, among these technologies wind energy has the harness of flow energy of wind its established itself as a new electricity generation as a major stream is a physical basis for human life with modern industrial development it increases the significant energy. Energy storage is a technology that has long established its place in modern society. However, widespread use in power systems is still a long way off. It may have found the necessary just as a tool to facilitate intermittent power integration. However, he cannot necessarily apply one technology to all the timeframes. Each should be selected with a specific application. In many cases, the storage of different species must be coordinated to achieve the overall goal. The energy storage technologies applied to hydroelectric wind turbines. The energy storage technologies currently applied to hydroelectric wind turbines are mainly hydraulic storage and compressed air storage, while other energy storage technologies, such as pumped storage, battery storage, and flywheel storage, have also been mentioned by some scientists. Various techniques are being considered to transfer wind energy to the generator, including gears and gearless power transmission methods, such as using wind-driven hydraulics. In traditional wind tower designs, a rotor transfers wind energy to a rotating shaft. Wind power has the characteristics of randomness, fluctuation and discontinuity, which lead to the large output fluctuation of hydraulic wind turbine and poor power quality. A non-linear dynamic model of a wind turbine which contained gear train drive, pitching system, tower and electric generator has been developed. The differences between the classical modeling method and bond graph method has been highlighted therein with a recommendation for using bond graph modeling for its simplicity and modular structure. The wind loading action and generated aerodynamic force on the turbine blade is an important consideration for wind turbine modeling and is studied in where the authors have discussed the dynamic characteristic of power drive train with torque signals. A complete bond graph model of wind turbine along with its major components such as turbine blades, gearbox and

generator has been developed and an advanced and realistic bond graph model has been presented in by considering additional features like tower and pitching of the system. Besides many articles deal with the mechanical power transmission unit, i.e. gear train, and study different aspects like load-sharing characteristics and optimization of power production in wind turbines. Till recently, gearbox was most widely used power transmission system in wind turbine. But in current scenario, gear train drives are being faded out in systems over a power rating of 3 MW because of their high operation and maintenance cost. Recently, some researchers have proposed an alternative approach i.e. Hydro Static Transmission (HST) system to transmit the power in wind turbines.

There are several research examples of HWTs, including:

- The HWT developed by researchers at the University of Nottingham in the UK. This HWT uses a hydraulic system to convert wind energy into hydraulic energy, which is then used to power a hydraulic motor that drives an electrical generator. The HWT has been shown to be highly efficient at low wind speeds and has the potential to be used in off-grid areas.
- A study conducted by researchers at the University of Ulsan in South Korea developed a HWT with a high efficiency rotor design. The researchers used computational fluid dynamics (CFD) simulations to optimize the design of the HWT and achieved an efficiency of over 90%.
- A research project by a team at the National Renewable Energy Laboratory (NREL) in the US developed a HWT that uses compressed air to store energy. The HWT uses a hydraulic system to compress air, which is then stored in an underground reservoir. The compressed air is then released to generate electricity when needed. The HWT has the potential to provide reliable, low-cost energy storage for wind power.
- A team of researchers from the University of California, Davis, and the Lawrence Berkeley National Laboratory developed a hydraulic wind turbine that uses a variable displacement pump to optimize energy conversion. The pump is able to adjust its displacement based on wind speed, resulting in improved energy conversion efficiency.

- Researchers at the National Taiwan University developed a hydraulic wind turbine that uses a hydraulic accumulator to store energy. The accumulator is able to store excess energy generated by the turbine and release it when demand is high, resulting in a more stable power output.
- A research project by the University of Bath in the UK developed a hydraulic wind turbine that uses a hydraulic system to control blade pitch. The blade pitch can be adjusted in real-time to optimize energy conversion, resulting in higher efficiency and reduced maintenance costs.
- A team of researchers from the University of Exeter in the UK developed a hydraulic wind turbine that uses a hydraulic transmission system to transfer power from the rotor to the generator. The system is able to adjust the speed of the generator to optimize energy conversion, resulting in improved efficiency.
- A team of researchers from the University of Twente in the Netherlands developed a hydraulic wind turbine that uses a hydraulic motor to drive the generator directly, without the need for a gearbox. This design reduces maintenance costs and improves efficiency, particularly at low wind speeds.
- Researchers at the University of Sheffield in the UK developed a hydraulic wind turbine that uses a hydraulic system to actively control the flow of air over the rotor blades. By adjusting the air flow, the turbine is able to optimize energy conversion and reduce noise levels.
- A research project by the University of Stuttgart in Germany developed a hydraulic wind turbine that uses a hydraulic system to actively control the angle of attack of the rotor blades. This design improves energy conversion efficiency and reduces loads on the turbine, increasing its lifespan.
- A team of researchers from the University of Tokyo in Japan developed a hydraulic wind turbine that uses a hydraulic system to actively control the blade pitch angle. The system adjusts the blade pitch based on wind speed and direction, optimizing energy conversion and reducing loads on the turbine.

CHAPTER 2

LITERATURE SURVEY

2.1 Afshin Izadian, Senior Member, IEEE, Sina Hamzehlouia, Majid Deldar, and Sohail Anwar, 2013- A Hydraulic Wind Power Transfer System: Operation and Modeling:

A hydraulic wind power transfer system is a promising technology for the efficient conversion of wind energy into electrical energy. Several studies have been conducted on the operation and modeling of such systems. In this review, we will summarize some of the significant findings from these studies. One study by P. Fleming et al. (2015) presented a hydraulic wind power transfer system that uses a hydraulic pump to transfer power from the wind turbine to a hydraulic motor, which then drives a generator to produce electricity. The study found that the system had a higher efficiency than a conventional gearbox-based system and demonstrated the potential of hydraulic systems for wind power transfer. Another study by H. Liu et al. (2016) proposed a dynamic model for a hydraulic wind power transfer system that considers the dynamic behavior of the wind turbine, hydraulic pump, motor, and generator. The model was validated through simulations and experiments, and the results showed that the system could achieve stable operation and efficient power transfer. A study by J. Zhang et al. (2017) proposed an improved hydraulic wind power transfer system that incorporated a hydraulic accumulator to store excess energy and improve system efficiency. The study found that the addition of the hydraulic accumulator could reduce the hydraulic pressure fluctuation and improve the system's stability. In a more recent study, X. Liu et al. (2020) developed a control strategy for a hydraulic wind power transfer system based on a sliding mode control algorithm. The strategy was applied to a prototype system, and the results showed that it could effectively regulate the hydraulic pressure and improve the system's response to changes in wind speed. Overall, these studies demonstrate the potential of hydraulic wind power transfer systems for efficient and stable wind energy conversion. However, further research is still needed to optimize the system design and control strategies for practical applications. New topology can remove some of the weight from the tower and centralize the wind power generation. Several speed-step responses of the system obtained from the mathematical model demonstrate a close agreement with the results from the prototype of the hydraulic wind power

transfer unit. Conventional wind power plants employ a variable speed gearbox to run a generator housed on top of a tower. A new topology can remove some of the weight from the tower and centralize the wind power generation. This new topology uses a hydraulic wind power transfer system to connect several wind turbines to the generation unit. The dynamic behavior and the steady state response of the mathematical model to a velocity step input demonstrated a close agreement with the results obtained from the experimental setup for both forced flow and natural flow configurations. The model could be used to scale the system for an industrial-level wind power plant. Exclusive benefits of implementing such a system based on the proposed model include eliminating the variable speed gearbox using a hydraulic circuit having one central generator instead of multiple generators, which decreases the capital cost of the wind power plant; and displacing most of the equipment from the nacelle to the ground to obtain better accessibility to the generation unit and to reduce the maintenance costs and time.

2.2 Anil C. Mahatoa , Sanjoy K. Ghoshal a , Arun K. Samantaray, 2018- Reduction of wind turbine power fluctuation by using priority flow divider valve in a hydraulic power transmission: The output from the wind turbine is stabilized by using the proposed hydraulic power transmission system under fluctuating wind speed. y constant power output from an offshore wind turbine by incorporating a priority flow divider valve and an accumulator into the power hydraulic system. In recent years, wind energy has become a popular source of renewable energy. However, wind turbines are subject to power fluctuations due to the variability of wind speed, which can cause instability in the power grid. One solution to this problem is to use a hydraulic power transmission system to reduce the fluctuations. In this system, a priority flow divider valve (PFDV) can be used to maintain a constant speed of the wind turbine and stabilize the power output. Several studies have been conducted on the use of PFDVs in hydraulic power transmission systems for wind turbines. One such study was conducted by Liu et al. (2017), who developed a mathematical model to investigate the effects of a PFDV on the power output of a wind turbine. The results showed that the PFDV could effectively reduce power fluctuations and improve the stability of the power output. The priority flow divider valve allows flow in two different ways, i.e. priority line and by-pass line, simultaneously. It controls the fluid (seawater) flow by

adjusting its priority port flow as per the user setting to ensure minimum fluctuation of power output, whereas the excess flow is passed through the by-pass port and stored in an accumulator. A control strategy is applied on the control valve to allow the flow from the accumulator to the nozzle as per demand. A mathematical model of wind turbine with hydraulic power transmission is developed by using bond graph technique, which is suitable for this multi-energy domain system. Simulation results show that the output from the wind turbine is stabilized by using the proposed hydraulic power transmission system under fluctuating wind speed. A mathematical model of wind turbine with hydraulic power transmission is developed by using bond graph technique, which is suitable for this multi-energy domain system. Hydraulic transmission reduces the operation and maintenance cost. In addition, hydraulic transmission systems are easier to control, provide high power to weight ratio over wide range of torque and speed, simple, safe and economical, and require low maintenance due to fewer moving parts in comparison to mechanical transmission. The hydrostatic transmission system used here consists of a hydraulic pump, a priority FDV, a check valve, an accumulator, a servo valve and a nozzle. The sub-models of wind turbine blades and the hydraulic power transmission system have been developed by using bond graphs and integrated for simulation study. The model is validated with the real wind speed data available in literature.

2.3Chad Abbey, John Chahwan & Geza Joos,2008- Energy Storage and Management in Wind Turbine: Energy storage and management are critical aspects of wind turbine systems, as they can help to overcome the inherent variability of wind power and improve the efficiency and reliability of wind energy production. Several studies have been conducted on the topic of energy storage and management in wind turbines, which are discussed below. One approach to energy storage in wind turbines is the use of batteries. A study by Thirumalai et al. (2020) evaluated the feasibility of using lithium-ion batteries to store energy in wind turbines. The results showed that the use of batteries can improve the overall efficiency of the system and reduce the need for additional power generation capacity. Energy storage has the potential to shape the wind characteristics so that a wind turbine generator behaves more like a conventional generator, thereby making it easier to manage its integration. This paper considers the role that energy storage can play in the evolution of wind generator technologies. A basic structure

for multi-level storage systems is proposed and it is implemented for a two-level energy storage system. Simulation and experimental results confirm that the algorithm can be used to coordinate the operation of two storage levels to provide a prescribed amount of power, effectively smoothing the power fluctuations due to the wind. the issues related to the integration of energy storage into wind energy conversion systems (WECS). We consider the different types of WECS (transmission level, distributed generation, and remote wind), and discuss the justification for storage and its role in each case. Practical considerations are summarized and a review of the scheduling problems and storage management structures is given. A two-level energy storage system and associated management algorithm is implemented in simulation and hardware to demonstrate its feasibility. We conclude with a discussion of the key parameters for consideration in optimal operation of multi-level storage systems. A two-level energy storage system and dispatch algorithm was developed. The storage system was paired with a generic WTG model and the two were simulated and then validated using a realtime implementation of the system. The results showed that the two devices can be coordinated to achieve dispatchable output power over a one-hour period. The flow battery model used in the real-time simulation exhibited non-idealistic efficiency characteristics that depend on its state-of-charge, characteristics that need to be carefully considered in an optimal dispatch algorithm. Parametric analysis was performed to investigate the impact of the medium-term storage device's time constant, T_{mt} , on the power and energy ratings of the two devices, which demonstrated that this variable should be considered.

2.4 Chao Ai , Wei Gao , Qinyu Hu, Yankang Zhang , Lijuan Chen , Jiawei Guo and Zengrui Han,2020- Application of the Feedback Linearization in Maximum Power Point Tracking Control for Hydraulic Wind Turbine:A recent study by Shahbazi et al. (2022) proposed a hybrid control strategy for MPPT in hydraulic wind turbines, combining feedback linearization and a proportional-integral (PI) controller. The strategy was able to improve the efficiency of the system and reduce the impact of wind variability under varying wind conditions. Overall, the literature suggests that feedback linearization control strategies can effectively improve the efficiency and performance of hydraulic wind turbines for MPPT control. However, further research is needed to optimize the design and control of these systems for various wind

conditions and to evaluate their performance in real-world applications. The hydraulic fixed displacement pump speed and generating power can be used as control output to realize the maximum power point tracking control. The control provides theoretical guidance for optimal power tracking control law application for hydraulic wind turbine. The characteristics of the maximum power point tracking control are analyzed for hydraulic wind turbine, and the hydraulic output power is taken as control output based on the comprehensive performance requirements. Because the hydraulic wind turbine is a strong multiplication nonlinear system, the system is globally linearized based the feedback linearization method, and the maximum power point tracking control law is obtained. The simulation and experiment results show that the system has good dynamic performance with the proposed control law. The control provides theoretical guidance for optimal power tracking control law application for hydraulic wind turbine. The strategy effectively solves the power tracking control problem and strong nonlinearity problem, and the system smoothly and quickly tracks the demand power. The efficiency is about 83%, which mainly depends on the mechanical efficiency and volumetric efficiency of the HWT key hydraulic components. Although the output power tracks the demand power, it fluctuates greatly. The main reason is that the proposed controller depends on the model parameters and includes the leakage coefficient and other time-varying parameters, which leads to poor real-time performance of the controller. However, the proposed theoretical controller provides a reference for practical applications. Therefore, based on the engineering requirements, the control law is simplified and verified by experiments; that is, the output power can track the demand power accurately and smoothly.

2.5 Chao Ai , Wei Gao , Qinyu Hu, Yankang Zhang , Lijuan Chen , Jiawei Guo and Zengrui Han,2020- A review of energy storage technologies in hydraulic

wind turbines: The study showed that hydraulic accumulators can be used to store energy and improve the performance of HWTs. Another study by Arifin et al. (2015) investigated the use of a hydraulic accumulator as an energy storage device in HWTs. The results showed that the hydraulic accumulator improved the energy efficiency of the system and reduced the dependence on the grid. The development and potential application of energy storage technology in hydraulic wind turbines in the future are predicted. Although the proposal of hydraulic wind turbines effectively

solves the problems of traditional wind turbine transmission impact and complicated installation and maintenance, further exploration is needed on how to solve the randomness and intermittency of wind. The introduction of energy storage technology into wind power provides a way to solve this problem. This article mainly reviews the energy storage technology used in hydraulic wind power and summarizes the energy transmission and reuse principles of hydraulic accumulators, compressed air energy storage and flywheel energy storage technologies, combined with hydraulic wind turbines. It also discusses the functions of the energy storage system in terms of the stabilizing speed, optimal power tracking, power smoothing, and power system frequency modulation when generating power from hydraulic wind turbine. o the role of energy storage technology in hydraulic wind turbines mentioned in this article, energy storage technology can also be used to solve other problems in wind turbines. For example, in terms of fault-ride-through (FRT), energy storage technology can store energy in the event of a grid failure to realize the deployment of the system energy according to the load. This helps the system improve its stable operation ability. In harmonic suppression long pipes, when hydraulic wind power is installed on the ground, the hydraulic pump in the engine room and other parts of the ground will be connected through a long pipeline. The pressure change in the pipeline will inevitably produce strong pressure pulsation, which reduces the quality of power generation and brings instability to structural safety. Therefore, energy storage technology can actively control the pressure resonance in a long pipeline to ensure the stable and safe operation of the unit. Energy storage technologies can play a significant role in improving the performance of wind power systems, particularly in the case of HWTs. This literature review highlights the potential of hydraulic accumulators, compressed air energy storage systems, pumping systems, and flywheels as energy storage technologies in HWTs. Further research is required to investigate the feasibility and effectiveness of these technologies in practical applications.

2.6 Chao Ai, Jiawei Guo,Wei Gao, Lijuan Chen , Guangling Zhou, Zengrui Han,Xiangdong Kong,2017-Active Disturbance Rejection Control with Linear Quadratic Regulator for Power Output of Hydraulic Wind Turbines: The paper "Active Disturbance Rejection Control with Linear Quadratic Regulator for Power Output of Hydraulic Wind Turbines" was published by Chao Ai, Jiawei Guo, Wei

Gao, Lijuan Chen, Guangling Zhou, Zengrui Han, and Xiangdong Kong in 2017. The paper proposes a control strategy for hydraulic wind turbines based on active disturbance rejection control (ADRC) and linear quadratic regulator (LQR). The authors begin by discussing the limitations of traditional wind turbine control strategies, including the inability to handle disturbances such as wind gusts and tower shadow. They then introduce the ADRC-LQR control strategy, which is designed to handle these disturbances by using a disturbance observer to estimate and cancel out the disturbances in real time. The paper presents simulation results that show the effectiveness of the ADRC-LQR strategy in controlling the power output of a hydraulic wind turbine. The authors also compare the performance of the ADRC-LQR strategy to that of a traditional proportional-integral (PI) control strategy, and show that the ADRC-LQR strategy outperforms the PI strategy in terms of both power output and disturbance rejection. Overall, the paper provides a thorough introduction to the problem of wind turbine control and presents a novel control strategy that shows promising results in simulations. However, it should be noted that the proposed strategy has not been tested in real-world applications, and further research is needed to determine its effectiveness in practice. One of the earliest studies on ADRC with LQR for HWTs was conducted by Xia et al. (2013). The study proposed an ADRC-LQR control system for HWTs and compared its performance with that of a traditional PID control system. The results showed that the ADRC-LQR control system improved the power output performance of HWTs in various wind conditions. Another study by Qiao et al. (2017) proposed an ADRC-LQR control system for HWTs with a pitch control mechanism. The pitch control mechanism adjusts the blade pitch angle to regulate the power output of the HWTs. The results showed that the proposed ADRC-LQR control system improved the power output performance of HWTs under various wind conditions. The effectiveness of the proposed method is verified through simulation experiments. the power transmission mechanism of HWT is analyzed. Then the ADRC controller combined with the linear quadratic regulator (LQR) method is designed and the stability is proved. In the process of controller design, the multiplicative nonlinear problem is regarded as the total disturbance in ADRC, the range of the tuning parameter b_0 is calculated, and the control parameters are tuned through the LQR method. Finally, the effectiveness of the proposed method is verified through simulation experiments.

2.7 Chengbing He , Jianchong Wang , Runze Wang , Xiaoxiang Zhang,2021- Research on the characteristics of hydraulic wind turbine with multi-accumulator: The application of the multi-accumulator effectively reduces the torque fluctuation of generator, increases the system stability, and improves the quality of power generation. When the wind speed changes sharply, the controllable accumulator opens intermittently. It stores energy as the wind speed increases rapidly and releases energy for the system as the wind speed drops suddenly. the characteristics of impeller torque, hydraulic drive and conventional accumulator are studied. Under the turbulent wind speed condition, the characteristics of controllable accumulator are analyzed, and the system characteristics with and without controllable accumulator are compared. The results show that when the wind speed is stable, only the conventional accumulator works, which can stabilize the power output effectively. When the wind speed changes sharply, the controllable accumulator opens intermittently. It stores energy as the wind speed increases rapidly and releases energy for the system as the wind speed drops suddenly. The application of the multi-accumulator effectively reduces the torque fluctuation of generator, increases the system stability, and improves the quality of power generation. wind turbine has high power-weight ratio, which can replace the gearbox of DFIG and remove the rectifier inverter. The hydraulic wind turbine is becoming a development direction of the wind turbine. In this paper, a design scheme of hydraulic wind turbine with multi-accumulator is proposed. After the mathematical models of the key components are established, the corresponding AMESim simulation models are constructed. The characteristics under stable and turbulent wind speed conditions are analyzed.

2.8 Jamie C Beardsall Staffordshire University , Christopher A Gould Staffordshire University Moofik Al-Tai Staffordshire University,2015- Energy Storage Systems: A Review of the Technology and Its Application in Power Systems:Energy storage systems (ESSs) have gained increasing attention as a crucial component of modern power systems, enabling the integration of renewable energy sources, enhancing the reliability of the grid, and supporting peak demand. In recent years, there have been numerous studies on ESSs, exploring their technology and application in power systems. This literature review aims to summarize the latest research on energy storage systems, providing an overview of

the technology and its application in power systems. Firstly, various energy storage technologies have been studied, including electrochemical batteries, pumped hydro storage, compressed air energy storage, flywheels, and supercapacitors. Among them, lithium-ion batteries are currently the most widely used technology in ESSs due to their high energy density, long cycle life, and low self-discharge rate. However, other technologies are also being explored for specific applications, such as pumped hydro storage for large-scale energy storage and supercapacitors for fast charging and discharging. In conclusion, energy storage systems have become a crucial technology in power systems, enabling the integration of renewable energy sources and improving the reliability and stability of the grid. The technology of ESSs has been extensively studied, including various energy storage technologies, applications in power systems, and control strategies. However, there are still challenges in the cost-effectiveness, safety, and environmental impact of ESSs, which require further research and development to address. A range of energy storage technologies currently exist, ranging from low-power, short term technologies such as capacitors to long-term high power systems such as Pumped Hydro. Future developments such as the use of Carbon Nanotube technology within super-capacitors look set to bring improvements in power density, efficiency and lifetime. The correct application of energy storage technologies within power systems allows the potential of renewable energy sources to be realised to a greater extent, enabling disadvantages such as voltage and frequency fluctuation and mismatching of supply and demand peaks to be reduced, with grid stability being increased as a result. Future developments in energy storage technology such as the application of Carbon Nanotube technology to Supercapacitor design and the introduction of low-loss bearings for flywheel systems look set to bring further improvements in terms of device efficiency, energy density and extended component lifecycles.

2.9 Francisco Rubio , Carlos Llopis-Albert,2019- Viability of using wind turbines for electricity generation in electric vehicles:

Several studies have investigated the viability of using wind turbines for electricity generation in EVs. One of the main challenges is the limited space available on EVs, which restricts the size of wind turbines that can be used. Therefore, most studies have focused on the use of small wind turbines, such as vertical axis wind turbines

(VAWTs), which have the advantage of being compact and easy to install on EVs. Some studies have demonstrated that wind turbines can indeed generate electricity to power EVs, but the amount of energy generated is limited due to the small size of the wind turbines. However, it has been suggested that wind turbines could be combined with other renewable energy sources, such as solar panels or regenerative braking, to increase the overall energy production. Furthermore, the use of wind turbines for electricity generation in EVs raises safety concerns, such as the risk of accidents caused by the wind turbine's rotating blades or the possibility of the wind turbine falling off the EV. Therefore, it is important to ensure the safety of the wind turbines and their installation on EVs. In conclusion, the use of wind turbines for electricity generation in EVs is a promising solution to extend the driving range of EVs and reduce their dependence on fossil fuels. However, the viability of this solution depends on several factors, including the size and efficiency of the wind turbines, their integration with other renewable energy sources, and their safety on EVs. Further research is needed to address these challenges and determine the feasibility of using wind turbines for electricity generation in EVs. The theoretical possibility to implement this technology in actual electric vehicles. This is carried out by considering the effects of the airflow through wind turbines and the vehicle aerodynamic drag during its motion. This allows to recover a percentage of the energy supplied by the batteries to the vehicle engine. Dissipative forces such as the tyre rolling resistance force are responsible for not being able to recover all the energy supplied by those batteries. Results have shown the theoretical viability to successfully develop this technology. As important fact, this study has shown that the use of wind turbines allows the possibility of recovering an important percentage of the energy provided by the batteries, although it strongly depends on the assumptions of each case study. However, further research is needed to verify the data with experimental tests.

2.10 Maolin CAI, Yixuan WANG, Zongxia JIAO, Yan SHI, 2017- Review of fluid and control technology of hydraulic wind turbines:

Hydraulic wind turbines (HWTs) have gained increasing attention as an alternative to traditional wind turbines due to their potential for improved performance, increased reliability, and reduced cost. The fluid and control technology of HWTs is crucial to their operation and efficiency, and several studies have investigated this

technology. Firstly, the fluid technology of HWTs has been extensively studied, including the design of hydraulic components such as pumps, motors, and accumulators. The hydraulic system of HWTs has the advantage of being able to operate at high pressure and convert the energy from the wind into hydraulic energy, which can be stored and released as needed. The design of the hydraulic components can significantly affect the performance of HWTs, and several studies have proposed innovative designs to improve the efficiency and reliability of these components. Hydraulic wind turbines are expected to become the main development direction of wind turbines. The current state of hydraulic wind turbines as a new technology is described, and its basic fluid model and typical control method are expounded by comparing various study results. The current state of hydraulic wind turbines as a new technology is described, and its basic fluid model and typical control method are expounded by comparing various study results. Finally, the advantages of hydraulic wind turbines are enumerated. Hydraulic wind turbines are expected to become the main development direction of wind turbines. The self excitation characteristic of the multi-level PMSG enables a system to maintain high efficiency under high power. Thus, the multi-level PMSG is generally considered the ideal choice for variable-speed wind power generation. However, hydraulic wind turbines present unique advantages in terms of the efficiency and reliability of wind power. Although many countries worldwide have conducted theoretical research and prototype experiments on the main hydraulic transmission control systems of hydraulic wind turbines, this research area is still in its infancy in China. The complete introduction of foreign hydraulic wind turbine technology is extremely costly, and local users are likely to experience difficulty in mastering core technologies. Therefore, research on a localized model is encouraged for the development of a hydraulic transmission control system for hydraulic wind turbines with improved efficiency and flexibility. The system can be connected to the grid by using an electrically excited synchronous generator. The system can achieve power generation, optimum power tracking, and low-voltage ride through. It can eliminate the use of a gearbox and a rectifier-inverter device, reduce wind turbine weight, and lower installation cost. Hydraulic wind turbines will be an emerging development direction of wind turbines. The integration of fluid and control technology can also enhance the reliability of HWTs by reducing the number of components and minimizing the risk of failure. In conclusion, the fluid and control technology of

hydraulic wind turbines is crucial to their operation and efficiency. The design of hydraulic components and control systems can significantly affect the performance of HWTs, and advanced control strategies can optimize their performance and improve their efficiency. The integration of fluid and control technology in HWTs is a promising area for future research, and further investigation is needed to improve the performance and reliability of these turbines.

CHAPTER 3

AIM AND SCOPE

3.1 Aim

A hydraulic wind turbine is a type of wind turbine that uses hydraulic power transmission to generate electricity from the wind. The basic idea is to convert the mechanical energy of the wind into hydraulic pressure, which is then used to drive a hydraulic motor or generator. One potential advantage of a hydraulic wind turbine is that it can operate more efficiently at low wind speeds compared to traditional wind turbines. This is because the hydraulic system can accumulate and store energy from the wind, and then release it in a controlled manner to generate electricity. This allows the turbine to operate at a more consistent speed and generate more power over a wider range of wind speeds. Another advantage of hydraulic wind turbines is that they can be located closer to the ground, making them easier to install and maintain. They can also be more compact and lightweight than traditional wind turbines, which can be beneficial in certain applications. However, there are also some potential disadvantages to hydraulic wind turbines. For example, they may be more expensive to manufacture and maintain compared to traditional wind turbines. They also require additional infrastructure, such as hydraulic lines and pumps, which can add to the overall cost and complexity of the system. Overall, hydraulic wind turbines have the potential to be a promising technology for generating renewable energy from the wind. However, further research and development will be needed to fully evaluate their performance, cost-effectiveness, and practicality compared to other types of wind turbines.

The energy requirement for the Earth as a whole is a complex and constantly changing concept, as it depends on a variety of factors such as the total population, economic development, technological progress, energy consumption patterns, and the availability of energy resources. However, according to the International Energy Agency (IEA), the world's total primary energy supply (TPES) reached 168,524 TeraWatt-hour (TWh) in 2019, with fossil fuels accounting for around 84% of the total. This energy is used for various purposes such as transportation, industrial processes, heating and cooling, and electricity generation. To ensure a sustainable

future, it is important to increase the use of renewable energy sources, improve energy efficiency, and reduce greenhouse gas emissions. The IEA has set a goal of achieving net-zero emissions by 2050, which will require a significant shift towards cleaner and more efficient energy systems.

3.1.1 Demand for Energy

The demand for energy on Earth is continually increasing as the world's population grows, economies develop, and technology advances. Energy is required for everything from transportation and manufacturing to heating and cooling homes, and as a result, the energy demand is projected to continue to rise. Currently, the primary sources of energy used on Earth are fossil fuels such as coal, oil, and natural gas, which are finite resources that will eventually run out. In addition to the depletion of these resources, the use of fossil fuels contributes to climate change and other environmental problems. Renewable energy sources such as solar, wind, and hydroelectric power are becoming increasingly important as a way to meet the growing demand for energy while reducing greenhouse gas emissions and other environmental impacts. However, there are still significant challenges to expanding the use of renewable energy, such as the high initial cost of installation and the need for reliable energy storage solutions.

3.1.2 Need of alternate energy

There are several reasons why there is a need for alternative energy sources:

- Climate change: Burning fossil fuels like coal, oil, and natural gas releases carbon dioxide into the atmosphere, which contributes to climate change. Alternative energy sources like solar, wind, and hydroelectric power do not produce greenhouse gases and are therefore better for the environment.
- Energy security: Many countries rely on imported oil and gas for their energy needs, which can make them vulnerable to supply disruptions and price fluctuations. Developing alternative energy sources can help reduce dependence on foreign energy sources and enhance energy security.
- Depletion of fossil fuels: Fossil fuels are a finite resource, and it is estimated that they will eventually be depleted. Alternative energy

sources like solar, wind, and geothermal energy are renewable and will never run out.

- **Cost:** The cost of alternative energy sources like solar and wind power has decreased significantly in recent years, making them more competitive with traditional sources of energy. As technology continues to improve, the cost of alternative energy is likely to continue to decrease.

Overall, the need for alternative energy sources is driven by concerns about climate change, energy security, the depletion of fossil fuels, and the cost of energy. By investing in and developing alternative energy sources, we can create a more sustainable and secure energy future.

3.2 Scope

The scope for hydraulic wind turbines is primarily in the renewable energy industry, where they can be used to generate electricity from wind power. Hydraulic wind turbines offer several potential advantages over traditional wind turbines, including higher efficiency at low wind speeds and the ability to be located closer to the ground. One of the key areas where hydraulic wind turbines could be particularly useful is in small-scale wind power generation. Small hydraulic wind turbines could be installed on buildings, in remote locations, or in areas with lower wind speeds, where traditional wind turbines may not be practical. They could also be used to supplement other renewable energy sources, such as solar power, to provide a more consistent and reliable source of electricity. Another potential application for hydraulic wind turbines is in offshore wind farms. Hydraulic transmission systems are less affected by saltwater corrosion and can be more easily integrated with subsea cables for power transmission. Additionally, the lower weight and more compact design of hydraulic wind turbines can make them easier to transport and install in offshore environments. Overall, while hydraulic wind turbines are still in the early stages of development and are not yet widely deployed, they have the potential to play an important role in the future of renewable energy generation.

3.2.1 Importance of Renewable Energy

Renewable energy is becoming increasingly important in today's world due to several reasons:

- **Environmental Benefits:** Renewable energy sources such as solar, wind, hydro, and geothermal power do not release harmful greenhouse gases and other pollutants that contribute to climate change and air pollution.
- **Energy Security:** Renewable energy sources are domestically available and can reduce a country's dependence on imported fossil fuels, improving energy security.
- **Economic Benefits:** The renewable energy industry has the potential to create jobs and stimulate economic growth in both rural and urban areas.
- **Energy Efficiency:** Renewable energy sources can be more efficient than traditional fossil fuels, leading to cost savings for both households and businesses.
- **Innovation:** The development of renewable energy technologies drives innovation and can lead to breakthroughs in energy storage, distribution, and use.
- **Overall,** the importance of renewable energy lies in its ability to provide clean, secure, and affordable energy while reducing the impact on the environment and promoting economic growth.

3.2.2 Small scale

Small scale wind energy refers to the generation of electricity using wind turbines that are designed for residential, commercial, or small industrial use. These turbines typically have a rated capacity of less than 100 kilowatts and are installed on rooftops or on towers. Small scale wind turbines are often used in remote areas or off-grid locations, where traditional power sources are not available. They can also be used to supplement the electricity supply in areas with high electricity demand, such as urban areas. When considering small scale wind energy, it is important to evaluate the wind resource in the area where the turbine will be installed, as the energy output of a wind turbine is heavily dependent on wind speed and frequency. Other factors to consider include the cost of the turbine, installation and maintenance costs, and any permits or regulations that may be required. Small scale

wind turbines can be a good option for those who want to reduce their reliance on traditional energy sources and generate their own electricity. However, it is important to carefully evaluate the costs and benefits of this technology before making a decision.

3.2.3 Hydraulic Energy storage

Hydraulic energy storage (HES) is a technology that stores energy in the form of pressurized fluid. HES is a type of energy storage that can be used to store and release energy on demand, making it an effective solution for balancing the variable output of renewable energy sources such as wind and solar. HES systems typically consist of two large water reservoirs, one located at a higher elevation than the other. When energy is surplus, water is pumped from the lower reservoir to the upper reservoir, thereby creating potential energy that can be stored until it is needed. When energy is required, the water is released from the upper reservoir and flows back down to the lower reservoir, passing through a turbine that generates electricity. HES systems are scalable and can be used for small-scale applications such as residential energy storage or larger-scale applications such as grid-level energy storage. HES has several advantages over other forms of energy storage, including its ability to store large amounts of energy for long periods of time, its relatively low cost, and its low environmental impact. However, there are also some limitations to HES. One of the major challenges is finding suitable sites for large-scale HES systems, as they require specific geological features such as steep terrain and large water bodies. Additionally, HES systems can have relatively low efficiency due to energy losses from friction and heat during the pumping and release process. Nevertheless, HES is a promising technology that has the potential to play an important role in the transition to a low-carbon energy system.

CHAPTER 4

EXPERIMENTAL SETUP

4.1 Methodology

The layout of the hydraulic wind turbine with accumulator. The system is mainly composed of an impeller, hydraulic pump, hydraulic motor, conventional accumulator, synchronous generator, oil filling system, oil, control system, and auxiliary hydraulic components. Wind turbine impeller speed is generally low, while hydraulic pump efficiency drops rapidly at low speeds. Therefore, the impeller and the hydraulic pump improve the working efficiency of the hydraulic pump. The working principle of the system is as follows: when the wind speed reaches the starting value, the impeller rotates, and its torque drives the hydraulic pump to rotate after being pushed through the pipeline. The high-stress oil generated within the hydraulic pump enters the hydraulic motor after being saved and stabilized through the accumulator group. The hydraulic motor drives the generator to rotate and output electric-powered energy that is once delivered to the grid without rectifier inverter. The wind drives the impeller causing output speed fluctuation of the hydraulic motor, so the constant speed control is set in the control system. The control signal is adjusted according to the speed change of the impeller and the hydraulic motor. The attitude of the hydraulic pump swash plate is adjusted in real-time to maintain the output velocity of the hydraulic motor steady, so one can make certain the steady frequency electric powered energy of the generator. The entire system is not a typical pump control motor speed control system. A stationary pump in the nacelle is driven directly by the wind turbine, which sucks hydraulic fluid in the low-pressure line and pushes it into the high pressure line, the variable displacement motor and the hydraulic accumulator on the ground, it is used to control oil flow in an accumulator to avoid pump damage caused by lack of oil in low-pressure line. By comparing the actual speed of the motor to the nominal speed of the synchronous generator, the oil entering the variable motor, the main function is to set and limit the maximum working pressure of the hydraulic system to ensure system safety.

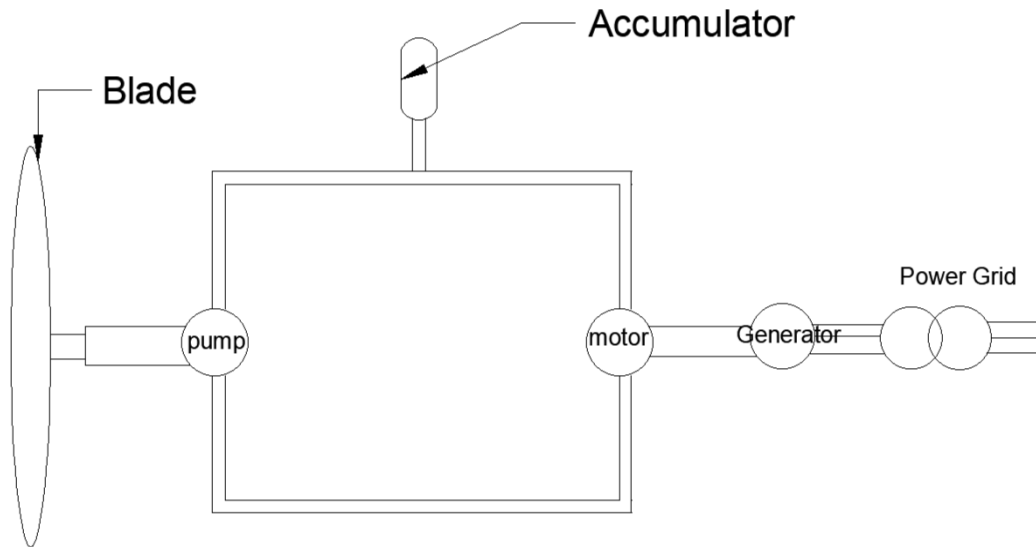


Fig.4.1: Methodology

4.1.1 Accumulators

The above hydroelectric power plants have only one set of accumulators. When the windspeed fluctuation is small, it can absorb the wind energy fluctuation well and reduce the power fluctuation. However, when the wind speed changes drastically, the effect of limiting the wind power fluctuation is not ideal. Therefore, a design scheme for an accumulator hydraulic wind turbine is proposed. The goals are to reduce power fluctuations caused by stable and turbulent wind speeds, smooth power delivery, and improve the power utilization rate. The hydraulic accumulator is applied to this hydraulic gadget for storing the excess oil from the pump. In order to take in fast the extra oil and decrease the charges of the experimental prototype, the bladder accumulator is selected. This type of accumulator has a cylindrical steel shell of which a bladder is constant at the internal top, as proven. When the stress of the oil withinside the line is greater than the stress of nitrogen withinside the bladder, oil is pressured into the accumulator. As a result, the stress of nitrogen rises for the lower withinside the volume. Finally, the stress of nitrogen in the bladder is the same as the stress of the oil outdoor the bladder. Contrarily, the oil is squeezed into the road via way of means of the bladder, the system uses pump motor elements and accumulator devices as secondary to the intermediate energy conversion and storage system. If the wind speed is high, the device will generate excessive energy. A variable displacement pump/motor within the energy storage system is in the

pumping state. At this time, the variable displacement pump/motor outputs high-pressure oil to the accumulator to store excess energy in the accumulator. When the wind speed is low and the energy of the wind turbine is low, the pump motor of the energystorage system goes into the operating state of the motor. The accumulator outputs high-pressure oil to drive the variable displacement pump/motor, releasing the stored energyto the generator input shaft. The energy storage system converts mechanical energy at the output shaft of the variable displacement motor and the pressure energy of the oil inthe accumulator. The realizes the storage and release of excess energy in the system, meeting the needs of the smooth and smooth output power of the unit. Modern wind turbines typically adopt either a doubly fed induction generator whose main drive is a step-up gearbox, or a multi-level permanent-magnet synchronous generator (PMSG), which is driven directly without a gear. The self-excitation characteristic of the multi-levelPMSG enables a system to maintain high efficiency under high power. wind power generation. However, hydraulic wind turbines present unique advantages in terms of theefficiency and reliability of wind power. First, hydraulic systems forgo the bulky gearbox and reduce the difficulty of manufacturing large-scale wind power generators. Second, the hydraulic systems of hydraulic wind turbines possess a high power-weight ratio. Finally, hydraulic systems can adjust the reduction gear ratio in a timely manner, adopt an electrically excited synchronous generator, eliminate the rectifier-inverter device, and improve power generation efficiency.



Fig.4.2: Accumulator

4.1.2 Wind Turbine

There are two types of wind turbines Horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWTs) were used instead of horizontal axis wind turbines. The wind directions on both sides of the rotor are opposite because of the opposite motion and the opposite aerodynamic forces could drive the rotor. Savonius rotor generates power from the wind and produces the energy. The prototype stage, a Savonius wind turbine composed of a Darrieus rotor and a Savonius rotor was designed. It shows the feasibility of using wind turbines to generate power from the wakes of moving vehicles, it is mainly composed of a rotor, fixed displacement pump, variable displacement motor, and synchronous generator. No inverter for frequency conversion is required. Since the rotor and pump are coaxially connected and the pump supplies high-pressure oil to the motor, wind speed fluctuations tend to affect motor speed, the engine and generator are also coaxially connected by the rotation speed of the engine and the generator is controlled by changing the engine displacement. If the synchronous generator operates stably in the required speed range it can be connected to the grid and generate electricity. At the same time, the charge pump supplies hydraulic fluid to the low-pressure line, the control pump supplies hydraulic fluid to the control line of the variable displacement motor, and the safety and relief valves are for system protection. Vertical axis wind turbine is used in the system, Aerodynamically, it is a resistance device consisting of two or three blades. Looking at the rotor, the cross-section of the two-blade machine resembles. Due to its curvature, the blade has less resistance when moving against the wind than when moving with it. Differential resistance causes the Savonius turbine to rotate. As a traction machine, the Savonius turbine extracts far less wind energy than other elevator turbines of similar size. In practice, much of the swept area of the Savonius rotor can be brought closer to the ground with short mounts without extended struts, and low wind speeds at low altitudes reduce the overall efficiency of power generation Purpose. They have several advantages over horizontal axis wind turbines, notably low noise levels, the ability to operate at low wind speeds, and relative independence from the wind direction.



Fig.4.3: Turbine Blade

4.1.3 System Overview Of The Wind Turbine Power Development System

System overview of the wind turbine power development system of the considered wind turbine power development system is this system is a multi-energy domain system which includes aerodynamics, mechanics, hydraulics and electric domains. The wind speed is applied to the wind turbine blades whose principle of operation is based on the Blade Element Momentum (BEM) theory or aerodynamic theory. The variation in wind velocity is assumed to be negligible in spatial distribution such as across the vertical and lateral directions; only temporal (time-based) variation in wind velocity is considered. Also, bending-torsion coupling has been neglected in the structural dynamics of the blades. The rotor of the wind turbine is coupled with the shaft of a fixed displacement hydraulic pump which is installed in nacelle to supply the pressurized seawater to a priority valve. The priority valve is capable of controlling the flow rate of the seawater. The primary flow rate is set by an adjustable orifice whereas the surplus flow is passed through a bypass port of the valve. The primary flow or the priority flow directly passes through the nozzle. The nozzle flow drives the Pelton wheel which is coupled with a generator. The bypass flow is used to charge an accumulator that stores the hydraulic energy. The stored energy is released to drive the Pelton wheel whenever wind energy is insufficient to fulfill the load demand. A control valve is installed between the accumulator and the nozzle to prevent the reverse flow to the accumulator. The control valve is only operated

through a control signal when the water jet speed from the nozzle is below a threshold value, set a priori. In other words, as and when the wind energy is insufficient to maintain the required jet speed, the accumulator is discharged to supply the stored energy to the Pelton wheel. The function of the Pelton wheel is to convert the hydraulic energy into the kinetic energy with the help of a set of fixed nozzles. When the high-speed water jets from nozzles strike the buckets located around the Pelton wheel runner, mechanical torque is produced at the turbine shaft. This article does not address the control aspects of this complex system. The most significantly noted dissimilarity between the two models are the 2-way directional valve and pipe models. Although the geometric dimensions of the pipes along with the total volume of fluid within are assumed similar for both cases, the pipe block encompasses complex dynamics, which are neglected in the proposed mathematical model. This alteration appears in the simplified fluid compressibility equation, which is used in the suggested hydraulic model. On the other hand, a proportional flow control valve has been used in the proposed model, which distributes hydraulic flow according to an input signal. The valve input signal is generated by the controller. The valve has a complicated dynamics and accepts a wider range of input, which are eliminated in our mathematical models. In order to validate the proposed hydraulic model with and to analyze the impact of dissimilarities on the simulation outputs and the controls, the models are compared in two configurations, with and without bypass. shows these hydraulic system configurations. The purpose of the first configuration is to observe the effect of deviations in fluid compressibility equations and pipe models while the bypassed structure augments the valve dynamic dissimilarity to the simulation outputs.

4.1.4 Pump

Internal Gear Pump (IGP) is widely used in injection molding, precision machinery, the chemical industry, agriculture, and many other fields. They can convert mechanical energy into hydraulic energy and provide hydraulic pressure to hydraulic systems. annular and pinion combination. Fluctuations in flow are generally considered to be the main cause of pressure fluctuations it is well known that pressure pulsations cause unwanted vibration and noise from pump components and can cause cavitation in hydraulic systems. recently, with the development of the internal gear pump, there is a trend toward higher pressures. operating pressure has

achieved in excess of 40 MPa by controlling radial and axial play compensation as well as pressure compensation. Higher working pressures can lead to increased internal leakage and radial forces, leading to flow instability. Therefore, attention should be paid to pressure pulsation at high working pressures. It is commonly used for thin liquids such as solvents and fuel oils but excels at efficiently pumping thicker liquids such as asphalt, chocolate, and adhesives. The usable viscosity range for internal gear pumps is from 1 cps to over 1,000,000 cps. In addition to the wide viscosity range, the pump also features a wide temperature range and can handle liquids up to 750 °F / 400 °C. This is due to the end play at a point (the distance between the rotor gear tooth edge and the pump head). This clearance is adjustable to withstand high temperatures, maximize efficiency when handling high- viscosity fluids, and account for wear. Rotor and idler wheel. The internal gear pump is pulsation-free, self-priming, and can run dry for a short period of time. They are also bi- rotary, meaning the same pump can be used to load and unload ships. With only two moving parts, internal gear pumps are reliable, easy to operate, and maintain.

two numerical approaches for the simulation of pump units of a low pressure less than 5 MPa: a fast lumped parameter approach for the fluid dynamics through the unit that permits the co-simulation of the radial micromotion of the rotors, and a computational fluid dynamics approach that puts emphasis on the description of the detailed features of the flow through the unit. The results focused on steady-state volumetric performance and the transient features of the outlet pressure oscillations, and they were verified by test data on a commercial pump. Pellegrini and Vacca et al.^{14,15} also studied the pressure oscillations of a gerotor pump with a low pressure (up to 30 bar) using the fast lumped parameter approach. In addition to the studies on pressure pulsation behaviors, there are also some works about the effect of structural configurations, aiming to reduce the pressure pulsation of gear pumps. For example, Edge¹⁶ performed the flow pulsation tests on two external gear pumps with different geometries of relief grooves on the thrust plates. Manning and Kasaragadda¹⁷ derived the flow ripple equation and analyzed the effect of the tooth number of both the driving and driven gears on flow pulsations of an external gear pump. Results displayed that the driving gear dictates the flow ripple characteristics of the pump remarkably. Suresh and Manonmani¹⁸ found that the pressure pulsation of gerotor pumps (with differential pressure of 0– 0.4 MPa) could be reduced when ports were added to the cover plate during their experiments. Kim et

al.2 reduced the pressure pulsation of a gerotor pump running at a differential pressure of 2.5MPa by using a port plate with the relief grooves. Meanwhile, they conducted a series of theoretical analyses on the pressure pulsation in consideration of various structural configurations of the port plate, including the installation positions of the port inlet/outlet and the groove width.

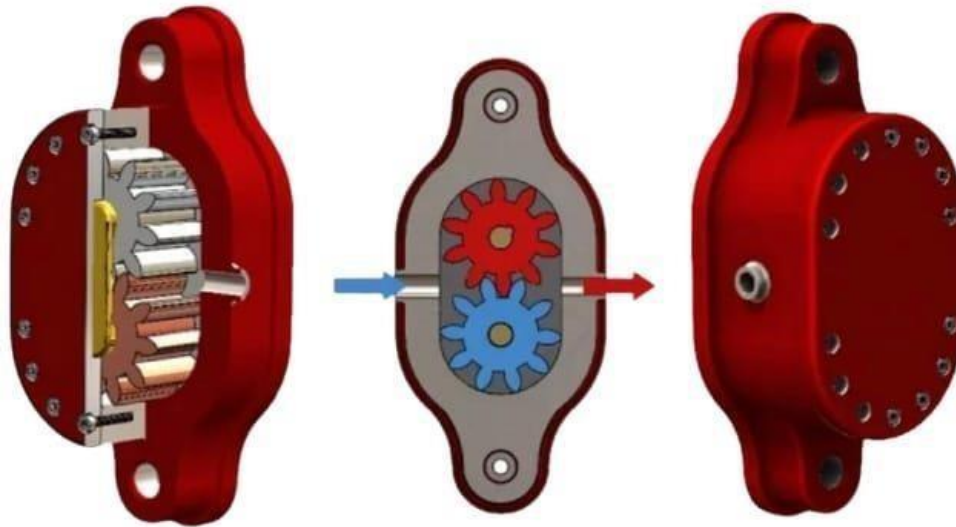


Fig.4.4: Internal Gear pump

4.2 Hydraulic Motor

A hydraulic motor is a mechanical actuator that converts hydraulic pressure and flow into torque and angular displacement (rotation). The hydraulic motor is the rotary counterpart of the hydraulic cylinder as a linear actuator. Most broadly, the category of devices called hydraulic motors has sometimes included those that run on hydropower (namely, water engines and water motors) but in today's terminology the name usually refers more specifically to motors that use hydraulic fluid as part of closed hydraulic circuits in modern hydraulic machinery. Conceptually, a hydraulic motor should be interchangeable with a hydraulic pump because it performs the opposite function - similar to the way a DC electric motor is theoretically interchangeable with a DC electrical generator. However, many hydraulic pumps cannot be used as hydraulic motors because they cannot be backdriven. Also, a hydraulic motor is usually designed for working pressure at both sides of the motor, whereas most hydraulic pumps rely on low pressure

provided from the reservoir at the input side and would leak fluid when abused as a motor.



Fig.4.5:Hydraulic Motor

4.2.1 Vane Motor

A vane motor consists of a housing with an eccentric bore, which runs a rotor with vanes in it that slide in and out. The force differential created by the unbalanced force of the pressurized fluid on the vanes causes the rotor to spin in one direction. A critical element in vane motor design is how the vane tips are machined at the contact point between vane tip and motor housing. Several types of "lip" designs are used, and the main objective is to provide a tight seal between the inside of the motor housing and the vane, and at the same time to minimize wear and metal-to-metal contact.

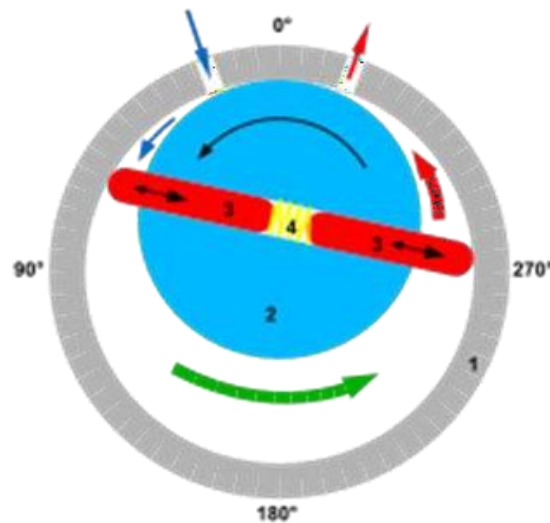


Fig.4.6:Vane motor

4.2.2 Gear Motors

A gear motor (external gear) consists of two gears, the driven gear (attached to the output shaft by way of a key, etc.) and the idler gear. High pressure oil is ported into one side of the gears, where it flows around the periphery of the gears, between the gear tips and the wall housings in which it resides, to the outlet port. The gears then mesh, not allowing the oil from the outlet side to flow back to the inlet side. For lubrication, the gear motor uses a small amount of oil from the pressurized side of the gears, bleeds this through the (typically) hydrodynamic bearings, and vents the same oil either to the low pressure side of the gears, or through a dedicated drain port on the motor housing, which is usually connected to a line that vents the motor's case pressure to the system's reservoir. An especially positive attribute of the gear motor is that catastrophic breakdown is less common than in most other types of hydraulic motors. This is because the gears gradually wear down the housing and/or main bushings, reducing the volumetric efficiency of the motor gradually until it is all but useless. This often happens long before wear causes the unit to seize or break down.

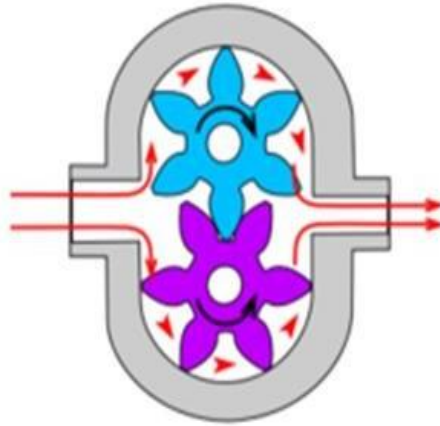


Fig.4.7: Gear motor

4.2.3 Gerotor Motor

The gerotor motor is in essence a rotor with $N-1$ teeth, rotating off center in a rotor/stator with N teeth. Pressurized fluid is guided into the assembly using a (usually) axially placed plate-type distributor valve. Several different designs exist, such as the Geroller (internal or external rollers) and Nichols motors. Typically, the Gerotor motors are low-to-medium speed and medium-to-high torque.



Fig.4.8:Gerotor motor

4.3 Hydraulic Fluid

Hydraulic fluid is the energy transfer medium in all hydraulic systems. However, the job of hydraulic fluid goes beyond simple transmission of power. Although transmitting hydraulic energy is the core purpose of hydraulic fluid, it is useful in four

secondary functions—heat transfer, contamination removal, sealing, and lubrication. Hydraulic machines produce a lot of excess heat in normal operation, often caused by inefficiencies of the components themselves, like pumps and motors. Without a way to carry heat away from these components, they could easily overheat with resulting damage of seals and internal components, especially as a result of low local viscosity. As oil returns to the reservoir, it often passes through a cooler to help maintain optimal temperature range before it is pumped back out to the system. Conversely, hydraulic fluid can carry heat into a system during cold starts, when needed.



Fig.4.9:Hydraulic Fluid

If closed-loop hydraulic systems didn't bleed off fluid at a controlled rate, contamination would quickly accumulate to critical and damaging levels. Heat can be considered a form of contamination, but hydraulic fluid also carries particles and water away from sensitive components through filters or other conditioning devices, where it is cleaned up and returned to the circuit. Oil without impetus would remain within sensitive components, allowing essentially trapped contamination to slowly destroy its surroundings. Although most believe hydraulic oil is what pieces of hardware—such as O-rings or U-cups—seal against, hydraulic fluid (especially oil)

actually provides sealing within the internal components of pumps, valves and motors. A spool valve, for example, has a seal at each end to prevent oil from escaping the valve, but each notch on the spool is sealed from the neighboring cavities by only the tight metal-to-metal tolerances and the oil's surface tension and resistance to shearing. Lubrication is required in most hydraulic components to protect internal parts from wearing, or even downright melting, as a result of metal-to-metal friction. Oil provides full-film lubrication between moving parts, such as the slippers and lens plate of a piston pump. Without the lubricating properties of oil, hydraulic systems would be terribly inefficient and awfully unreliable. These functions of hydraulic fluid are common to all types, except some water-based fluids, which require special design considerations during engineering. However, the majority of machines use refined or synthetic oil, which are formulated and manufactured to specific test standards for important properties like viscosity, pour point and viscosity index, to name a few. Those three properties are often considered when choosing a fluid for a particular application, which is based on maintaining a specific viscosity throughout a particular set of ambient and machine operating conditions. For example, if ambient temperatures are low, you would choose an oil with lower rated viscosity and a low pour point, which is the temperature at which oil will still pour. If your machine sees varying temperature ranges, like an all-weather mobile machine, a high viscosity index is very important, which describes an oil's ability to maintain its viscosity over a wide temperature range. It is important to consider the viscosity requirement of the components in your hydraulic system. A piston pump, for example, may require between 16 and 40 centistokes, which is a description of kinematic (i.e., measured while flowing) viscosity. Hydraulic oil is engineered with other important properties, although these tend to be common regardless of brand, viscosity or application. Hydraulic oil has a package of chemical additives to improve the performance of both the oil and the components of the hydraulic system. These additives can improve the foaming resistance of the oil, its corrosion/rust resistance and the water-retention properties. The additive package of hydraulic fluid is what separates low and high quality fluids, and additives also improve the viscous properties of oil as well. When in doubt, always choose a premium fluid for your application at a viscosity appropriate for your operating conditions.

4.4 Airfoil S1046

Despite the fact that the simulations in this study were only done on one turbine type, the study was able to demonstrate the positive effect of design optimization on turbine performance . The current study looked at the effect of changing the design of the turbine rotor by changing the airfoil on the turbine's aerodynamic characteristics.

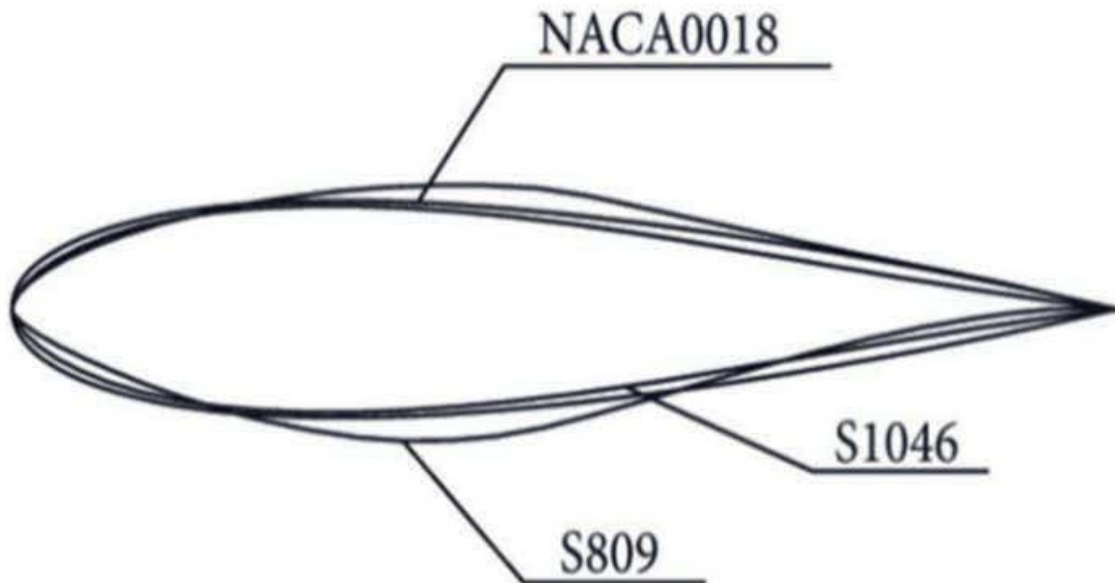


Fig.4.10:Airfoil

We selected The S1046 airfoil has a maximum performance coefficient of 0.41, which is significantly larger compared to other airfoils. Overall, the maximum coefficient of performance for all of the airfoils is far from the Betz limit, showing that there is dissipation in the fluid energy.

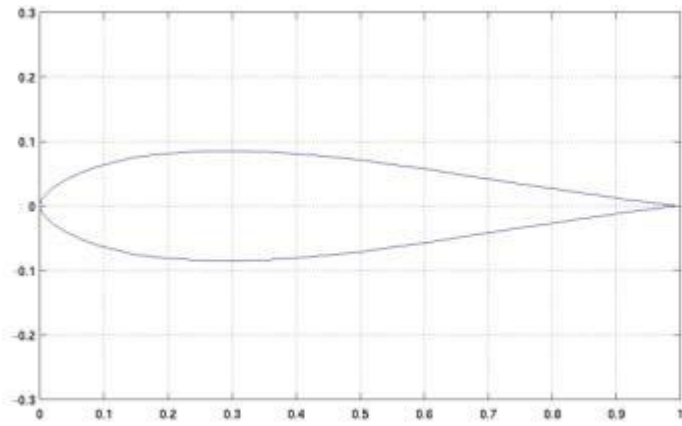


Fig.4.11: Airfoil S1046

The comparisons were first done in 2D for the turbines with different airfoils, and then the 3D simulations for the turbine with the best 2D results were repeated. Based on the literature review, this can be considered the current work's novelty.

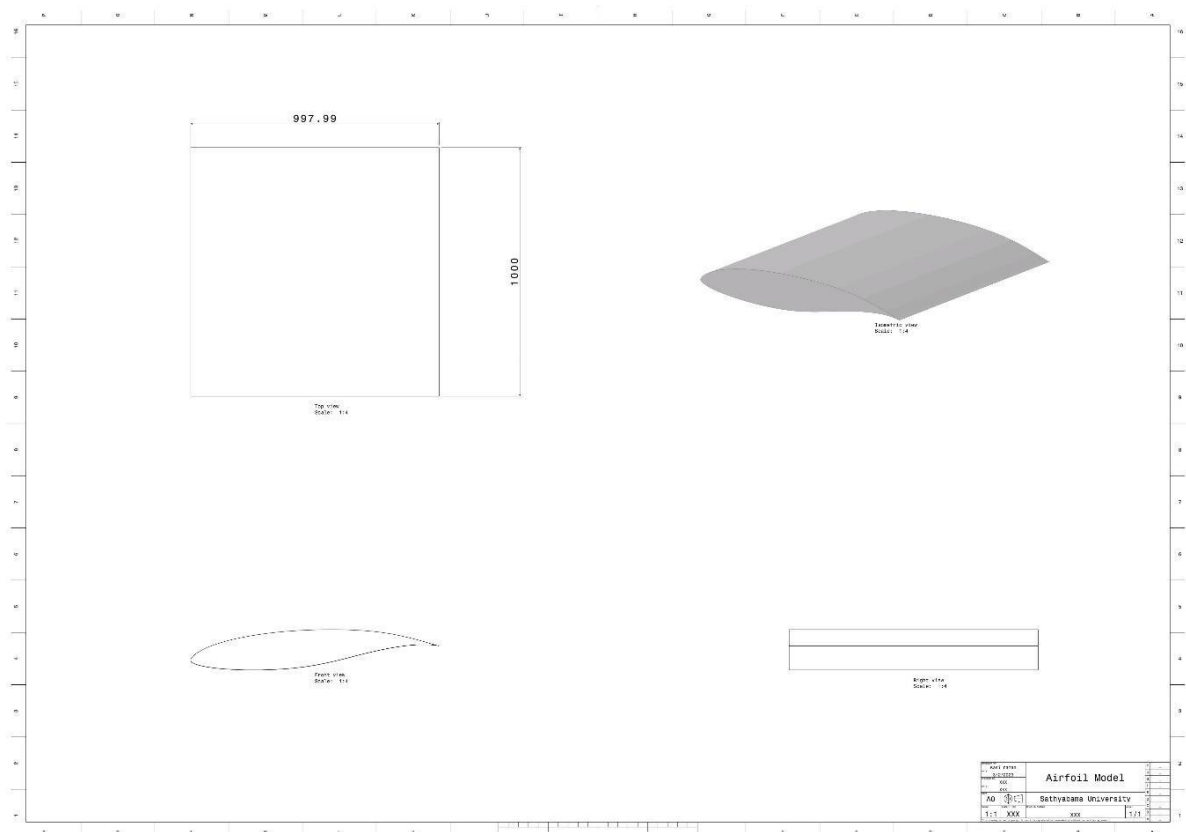


Fig.4.12: Airfoil 3D

We chosen the AirfoilS1046. We made 3d design for the Wind blade, for the chord length of 1000mm and 996 mm. In the scale of 1:4. Airfoil S1046 is an aerodynamic profile commonly used in wind turbine blades. It has a symmetrical shape, with a thickness-to-chord ratio of 12.5% and a maximum camber of 4% at 40% chord. The S1046 airfoil is designed to provide good performance over a wide range of angles of attack, which is important for wind turbine applications where the blade may experience varying wind speeds and directions. It also has relatively low drag, which helps to improve the efficiency of the turbine. Overall, the S1046 airfoil is a popular choice for wind turbine blades due to its good performance characteristics and wide availability of data and analysis tools.

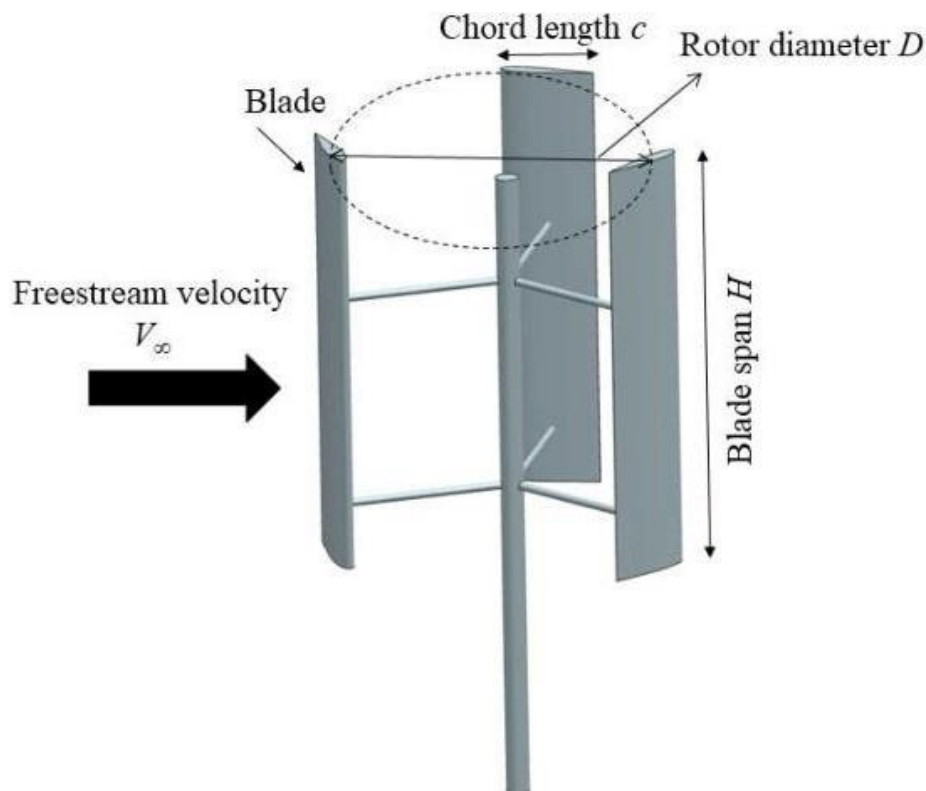


Fig.4.13: VAWT

One of the prime commodity in modern civilization is energy. The amount of energy consumption has become the indicator for the standard of living and the degree of industrialization. At present, nearly ninety percent of the world's energy come from the combustion of fossil fuels, i.e. coal, petroleum oils, natural gas, etc. People use fossil fuels to meet nearly all of their energy needs, such as powering vehicles, producing electricity for light and heat, and running factories. On the other hand, energy resources from earth's fossil energy are limited and also the global production of petroleum oils will come beyond their peak in the next decades. The population growth will make the need of energy becomes higher and also the price of fossil fuels. At the same time there is a problem with the global climate change as a result of carbon-dioxide and sulfur-dioxide emission from the burning of fossil fuels. Using renewable energy as a cost-effective and reliable low carbon energy sources is becoming an important objective of energy policy in the world. Renewable energy is a climate-friendly energy due to the absence of emission detrimental to the environment. The International Energy Agency reported that only a very small proportion of the energy comes from nuclear and hydro-power, and a much smaller portion from renewable energy sources such as solar, wind, biomass, geothermal and tidal waves. Wind is an environment friendly source of energy that has got huge potential to satisfy energy needs for people and also to mitigate the climate change from greenhouse gasses emitted by the burning of fossil fuels. It was estimated that roughly 10 million MW of energy are available in the earth's wind. The International Energy Agency (IEA) showed the global cumulative wind power capacity worldwide in Fig. 1 based on the projection in the 2004 World Energy Outlook report. Wind turbine is used to change wind energy into mechanical energy (such as wind mill and moving height) and generate electricity. The turbines are classified to two categories, horizontal axis wind turbines (HAWTs) and vertical axis wind turbines (VAWTs). If HAWT has a horizontal axis of rotation, then VAWT has a vertical axis of rotation. VAWT has more simple structure and installation than that HAWT. The generator of VAWT is placed at the bottom of central shaft on the ground and the tower do not need to support it. The turbines are useful in different speed and direction of wind. In contrast, VAWTs have low pressure coefficients, therefore the scope for major research on VAWT rotors is to improve their performance. VAWT rotors have different types, such as Savonius rotor, and (eggbeater) Darrieus

4.4.1 Vertical Axis Wind Turbine

Vertical axis wind turbines are wind turbines whose rotors rotate around a vertical shaft with vertically oriented blades. They produce electricity by utilizing wind power the same way horizontal axis wind turbines do: Wind drives the rotor to turn, the rotation connects to the generator, and the generator converts the mechanical energy into electricity. Vertical axis wind turbines are the oldest form of wind turbines. Now viewed as a product for a niche market, vertical axis wind turbines are in fact the earliest recorded wind turbines. The use of such mechanical models dates as far back as the Persian times in the 7th century for milling and pumping. In 1887, Scottish electrical engineer and academic, James Blyth, built one of the first recorded electricity-generating wind turbines, also using the vertical axis structure. What's special about vertical axis wind turbines is the variety of possible designs blades, structures, shapes which then determines the operational principle, performance, and applications. Vertical axis wind turbines come in many shapes, but technically, they can be categorized into two groups based on their operational principles: There are 2 types of vertical axis wind turbines: The Savonius model and the Darrieus model.

Wind Turbine Icons created by Lluïsa Iborra from the Noun Project.

Savonius wind turbines: the resistance runner Savonius wind turbines have blades built around the vertical shaft in a helix form, which basically looks like DNA or fusilli pasta. Wide, solid wind-receiving area of the blades is one of the most significant features. When in operation, Savonius wind turbines rely on the flow resistance mechanism to turn their rotors. In simple words, the dynamic pressure of the wind against the blades pushes the rotor into rotation. At the same time, the opposite side of the blades encounters a force of aerodynamic resistance or "drag." This is just like what we experience when cycling or running: There's always the air flow coming against us. Because of this, Savonius wind turbines can only turn as fast as the wind speed.

Darrieus: The Uplift Runner Often called the "egg-beater" and named after the French inventor Georges Darrieus, classic Darrieus turbines have long, curved wings with each end attached to the top and bottom of the rotor shaft. In terms of operation, Darrieus utilizes the "lift" aerodynamic force to rotate. By flowing around the structure, the wind creates a suction on the front side of the turbine, driving the wings to rotate. Because of the shape of the wings, they do not experience as much drag as Savonius turbines do. Once the rotation starts, Darrieus

wind turbines are able to accelerate to rotate faster than the wind speed. Due to certain structural characteristics, vertical axis wind turbines are typically smaller than horizontal axis wind turbines. This adds to the number of advantages such as low noise emission and high turbulence endurance that make them perfect for electricity generation in populated or urban areas as well as in unstable, gusty wind. Since vertical axis wind turbines have less energy efficiency and power output, it is common to group multiple turbines into a wind power plant or use them as one of many electricity sources of a building or campus. It is possible to connect a vertical axis wind turbine into the local power grid or with an external storage battery. Although not as common as horizontal axis wind turbines, vertical axis wind turbines are also used on offshore platforms to support various industrial activities. In the past, the wind power industry has always been focused on the development and construction of horizontal axis wind turbines because they are the most powerful wind turbine models. Vertical axis wind turbines remain relatively underdeveloped and even a bit experimental. When you compare a vertical axis wind turbine with a horizontal axis wind turbine, the answer is clear: Vertical axis wind turbines cannot compete with horizontal axis wind turbines, particularly regarding power output and efficiency. The question is, why should they be comparable or competitive against each other. As a company dedicated to the development of vertical axis wind turbines, we believe these two types of turbines are to co-exist in the wind power industry because they are designed for completely different applications. There are situations where horizontal axis wind turbines thrive excellently, and also areas where vertical axis wind turbines, on the other hand, are more geographically flexible and not restricted as much by governmental policies. This makes them great alternatives for conditions unsuitable for horizontal axis models. For LuvSide, as wind power supporters and sustainability advocates, it is more important to utilize all possible solutions than to create competition when the expansion of renewable energy is an increasing need for our society. That is why we and many engineers around the world devote our resources and knowledge into research, development, and innovation of vertical axis wind turbines.

4.4.2 Savonius Wind Turbine

Savonius wind turbines are vertical-axis wind turbines (VAWTs) that convert wind energy into torque on a rotating shaft. The turbine is made up of a number of

aerofoils that are typically, but not always, vertically mounted on a rotating shaft or framework, which can be ground-based or airborne. The Savonius turbine is one of the most basic. Aerodynamically, it is a drag device with two or three funnels. In cross section, a two-scoop machine may mimic the letter "S" when viewed from above. The scoops experience less drag when moving against the breeze than when moving with the wind due to the curvature. The Savonius turbine spins due to differential friction. Savonius turbines produce much less wind power than similar-sized lift-type turbines because they are drag-type devices. In reality, because of the lower wind speed, much of the swept area of a Savonius rotor may be close to the ground if it has a short mount without an extended post, making overall energy extraction less effective. When cost or reliability are more essential than efficiency, Savonius turbines are used. Because efficiency is irrelevant to the purpose of measuring wind speed, most anemometers are Savonius turbines. Much larger Savonius turbines have been used to produce electricity on deep-water buoys that require very little power and receive very little maintenance. The design is simplified because, unlike horizontal axis wind turbines (HAWTs), no pointing mechanism is needed to allow for wind direction changes, and the turbine is self-starting. Savonius and other vertical-axis machines are best suited for pumping water and other high torque, low rpm uses, and are typically not connected to power grids. Risto Joutsiniemi invented a helix rotor in the early 1980s.

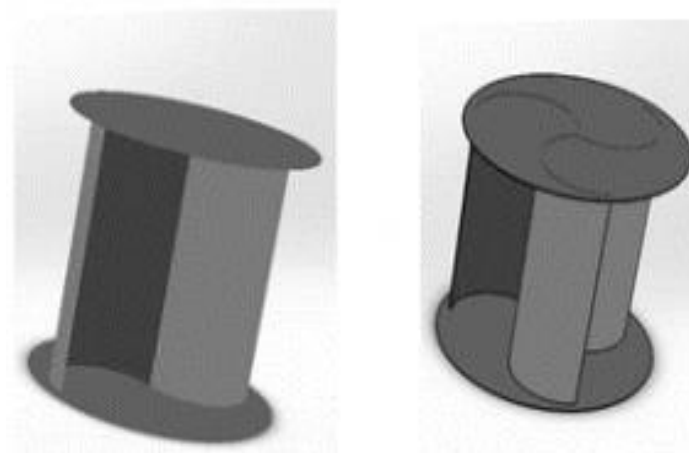


Fig.4.14:Savonius Blade

The device in a similar way to a cup anemometer. The savonius wind turbine working principle can be easily explained because this is considered as the most streamlined turbine when compared with other turbines. This is a dragging kind of instrument where it consists of some 2 – 3 cups. From the above portion, when the rotor is seen, it appears in the shape of “S” in the form of a cross-section. Due to this curvature shape, the cups will have minimal dragging when they move in the opposite direction of the wind, whereas they experience maximum drag while moving in the same direction of the wind. This variation in the dragging creates the spinning movement of the savonius turbine. As these instruments are drag type, they grab minimal wind power when compared with that of other same-sized lift kinds of turbines. Most of the brushed section of savonius rotor is close to the ground level when the device has minimal mount having no stretched post thus delivering low energy extraction because of the fewer wind speeds observed at lesser heights. The cups in the savonius wind turbine will not have faster rotational speeds when compared with the wind speed and this creates a tip speed proportion of either one or less than one. This states that the device has minimal rotational speed but produces a higher amount of torque. So, these instruments are not exactly suitable for the production of electricity as they require higher RPMs for the generation of higher current and voltage values. For this, a gearbox can be inserted to minimize the torque and enhance the generator RPM level, and this corresponds that the turbine does not hold the ability to start by itself. Savonius Wind Turbine Power Output. As per Betz’s principle, the high range of power that is received by the rotor is **$P_{max} = (16/27) (1/2) \cdot \rho \cdot d \cdot h \cdot v^3$**

Where ‘ ρ ’ corresponds to the density of the air

‘ d ’ and ‘ h ’ corresponds to the height and diameter of the rotor

‘ v ’ corresponds to the speed of the wind

Whereas in the practical scenarios, the received power is only half which is given by

$$P_{max} = 0.18 \text{ kg/m}^{-3} d \cdot h \cdot v^3$$

Power output defines the higher power level which can be extricated from the airflow. Due to the mass and momentum conservation, there will be no complete energy extraction from the wind. With Betz’s law, it was demonstrated that the higher amount of kinetic energy that was received from the wind should not go beyond 60%. So as per this principle, none of the turbines extracts the entire energy from

wind. The below picture is the curve that is plotted against the turbine's power coefficient to the ratio of before and after passage across the turbine. The Betz's threshold is based on the wind turbine's horizontal axis and is not directly applicable to the vertical kind of turbines. A similar statement contends that the theoretical threshold might be enhanced by the application of a standard VAWT method. Though, it is stated that VAWT's have minimal efficiency than that of HAWT's and are less probable in the present state to move across the threshold for the turbine's horizontal axis.

4.4.3 Darrieus Wind Turbine

The Darrieus wind turbine is a type of vertical axis wind turbine (VAWT) used to generate electricity from wind energy. The turbine consists of many curved aerofoil blades mounted on a rotating shaft or framework. The curvature of the blades allows the blade to be stressed only in tension at high rotating speeds. Several closely related wind turbines use straight blades. This design of the turbine was patented by Georges Jean Marie Darrieus, a French aeronautical engineer; filing for the patent was on October 1, 1926. There are major difficulties in protecting the Darrieus turbine from extreme wind conditions and in making it self-starting. In the original versions of the Darrieus design, the aerofoils are arranged so that they are symmetrical and have zero rigging angle, that is, the angle that the aerofoils are set relative to the structure on which they are mounted. This arrangement is equally effective no matter which direction the wind is blowing in contrast to the conventional type, which must be rotated to face the wind. When the Darrieus rotor is spinning, the aerofoils are moving forward through the air in a circular path. Relative to the blade, this oncoming airflow is added vectorially to the wind, so that the resultant airflow creates a varying small positive angle of attack to the blade. This generates a net force pointing obliquely forwards along a certain "line of action". This force can be projected inwards past the turbine axis at a certain distance, giving a positive torque to the shaft, thus helping it to rotate in the direction it is already travelling in. The aerodynamic principles which rotate the rotor are equivalent to that in autogiros, and normal helicopters in autorotation. As the aerofoil moves around the back of the apparatus, the angle of attack changes to the opposite sign, but the generated force is still obliquely in the direction of rotation, because the wings are symmetrical and the rigging angle is zero. The rotor spins at a rate unrelated to the windspeed, and

usually many times faster. The energy arising from the torque and speed may be extracted and converted into useful power by using an electrical generator. The aeronautical terms lift and drag are, strictly speaking, forces across and along the approaching net relative airflow respectively, so they are not useful here. The forces at play are rather tangential force, which pulls the blade around, and radial force, which acts against the bearings. When the rotor is stationary, no net rotational force arises, even if the wind speed rises quite high the rotor must already be spinning to generate torque. Thus the design is not normally self-starting. Under rare conditions, Darrieus rotors can self-start, so some form of brake is required to hold it when stopped. One problem with the design is that the angle of attack changes as the turbine spins, so each blade generates its maximum torque at two points on its cycle (front and back of the turbine). This leads to a sinusoidal (pulsing) power cycle that complicates design. In particular, almost all Darrieus turbines have resonant modes where, at a particular rotational speed, the pulsing is at a natural frequency of the blades that can cause them to (eventually) break. For this reason, most Darrieus turbines have mechanical brakes or other speed control devices to keep the turbine from spinning at these speeds for any lengthy period of time. In this configuration, the Darrieus design is theoretically less expensive than a conventional type, as most of the stress is in the blades which torque against the generator located at the bottom of the turbine. The only forces that need to be balanced out vertically are the compression load due to the blades flexing outward (thus attempting to "squeeze" the tower), and the wind force trying to blow the whole turbine over, half of which is transmitted to the bottom and the other half of which can easily be offset with guy wires. By contrast, a conventional design has all of the force of the wind attempting to push the tower over at the top, where the main bearing is located. Additionally, one cannot easily use guy wires to offset this load, because the propeller spins both above and below the top of the tower. Thus the conventional design requires a strong tower that grows dramatically with the size of the propeller. Modern designs can compensate most tower loads of that variable speed and variable pitch.

The features of the Darrieus wind turbine include the following.

- These turbines are eggbeater shaped which includes high efficiency, but, they are not consistent.

- In order to utilize this turbine, you should have an exterior power source to start them
- This turbine includes two blades so it is the best choice to select instead of selecting a three-blade wind turbine.
- This wind turbine can be supported by using a superstructure that will fix it close to the pinnacle bearing.
- A Darrieus wind turbine spins many times than the wind hitting speed. Therefore, a Darrieus wind turbine produces low torque as compared to a Savonius turbine however it turns very fast. So, this turbine rotates very fast to generate electricity instead of water pumping as well as related activities. This turbine generates centrifugal forces which are extremely large & performs on the turbine blades. But the bearings & generator are generally lower as compared to a Savonius. The design of the Darrieus wind turbine can be done using a number of curved aerofoil blades which are arranged on a rotary framework or shaft. The Darrieus wind turbine is a type of vertical axis wind turbine, used to produce electricity using wind energy. The blade curve of this turbine allows being stressed only in anxiety at high rotary speeds. There are numerous closely related wind turbines that utilize straight blades.

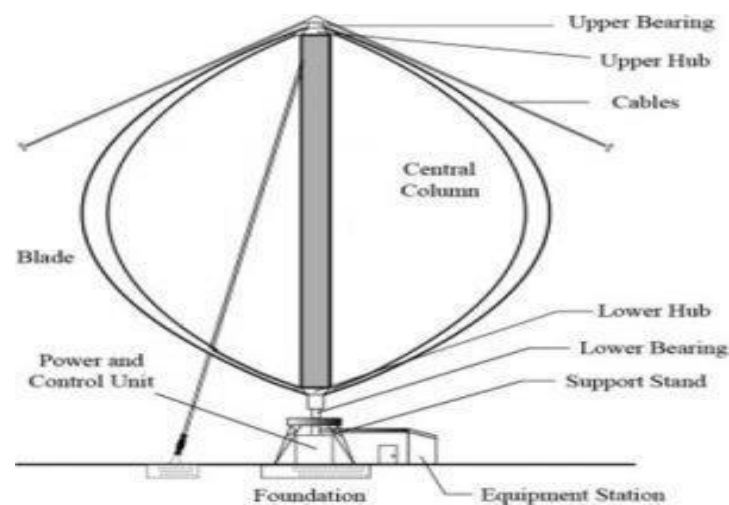


Fig.4.15:Darrieus Blade

The Darrieus Wind Turbine Design was patented by a French aeronautical engineer namely Georges Jean Marie Darrieus and filing for the copyright was done on 1st Oct in 1926. There are many troubles while protecting this turbine from severe wind

situations and also in designing it as self-starting. These turbines are not self-starting but it requires a motor which is small powered to begin the revolution. Once it has sufficient speed then the wind flows across the aerofoils starts to produce torque & the rotor can be driven in the region of the wind. In the Darrieus turbine, two mini Savonius rotors are placed on the shaft to start a revolution. These reduce the Darrieus turbine once it gets going but they make the complete device very simpler as well as easier to keep. The efficiency of the Darrieus Wind Turbine is less as compared to the horizontal axis wind turbine (HAWT) due to the operational characteristics and design. Generally, the efficiency of a HAWT (horizontal axis wind turbine) ranges from 40 % to 50 % which means the turbine is capable of converting 40% – 50 % of the KE (kinetic energy) it obtains into real electrical power. Alternatively, the efficiency of a Savonius vertical axis wind turbine ranges from 10 % to 17 %, whereas the Darrieus vertical axis wind turbine achieves 30 % to 40 %. A Savonius wind turbine can generate sufficient power to hold yearly utilization of a usual two-person family. The power of wind turbines can be calculated by estimating two values like accessible wind power as well as the wind turbine efficiency. So by multiplying these two values we can get the output power of the turbine. The sweep area of the wind turbine can be calculated like the following. To calculate the wind power, we need to find out the swept region of the wind turbine based on the following equations:

For HAWT, $A = \pi * L^2$

For VAWT, $A = D * H$

From the above equations, 'L' is the blade length

'H' is the turbine's height

'D' is the diameter. The available power of wind can be calculated like the following.

If we know the sweep area, we can discover the accessible wind power based on the following formula.

$$P_{\text{wind}} = 0.5 * \rho * v^3 * A$$

From the above equations, 'A' is the sweep area

' ρ ' is the density of air

'v' is the wind speed

' P_{wind} ' is the accessible wind power.

The **turbine efficiency** can be calculated like the following.

$$\mu = (1 - k) * (1 - k_e) * (1 - k_{e,t}) * (1 - k_t) * (1 - k_w) * C$$

Where,

'kw' is the wake of losses

'k_e' is the electrical losses of the wind turbine

'k_{e,t}' is the electrical losses of transmission to the grid

'k_t' is the % of the time out of order because of failure

'μ' is the real efficiency

To find out the power of the wind turbine, simply multiply the efficiency through the available wind power

$$P_{\text{output}} = \mu * P_{\text{wind}}$$

4.5 Analysis

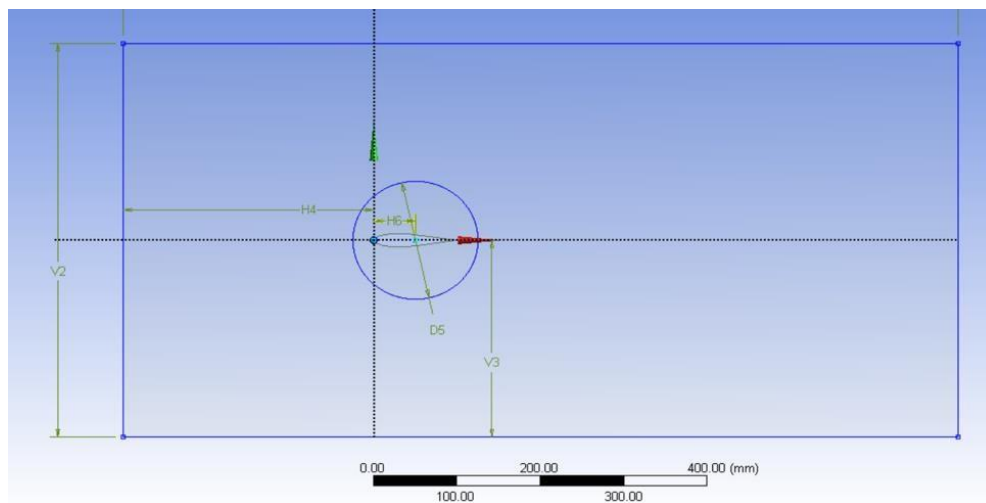


Fig.4.16: Airfoil geometry

To perform an analysis of the S1046 airfoil, we can start by looking at its basic geometric properties. The airfoil has a maximum thickness of 12.5% of its chord length, which is relatively thin compared to some other airfoils. Its maximum camber is 2.5% of its chord length, which means that it has a relatively flat upper surface. We can also analyze the lift and drag characteristics of the airfoil using computational fluid dynamics (CFD) simulations or wind tunnel tests. These tests can give us an idea of the airfoil's performance at different angles of attack and Reynolds numbers. One important performance metric for airfoils is the lift coefficient (C_l), which is a measure of the amount of lift generated by the airfoil at a given angle of attack. The S1046 airfoil has a maximum lift coefficient of around 1.5, which is relatively low compared to some other airfoils. This means that it may not be as

effective at generating lift at high angles of attack. Another important performance metric is the drag coefficient (C_d), which is a measure of the amount of drag generated by the airfoil at a given angle of attack. The S1046 airfoil has a relatively low drag coefficient, which means that it is efficient at generating lift with minimal drag. Overall, the S1046 airfoil is a relatively simple and efficient airfoil that is well-suited for use in small aircraft and gliders. Its low drag coefficient and moderate lift coefficient make it a good choice for applications where efficiency is important. However, it may not be as effective at generating lift at high angles of attack as some other airfoils.

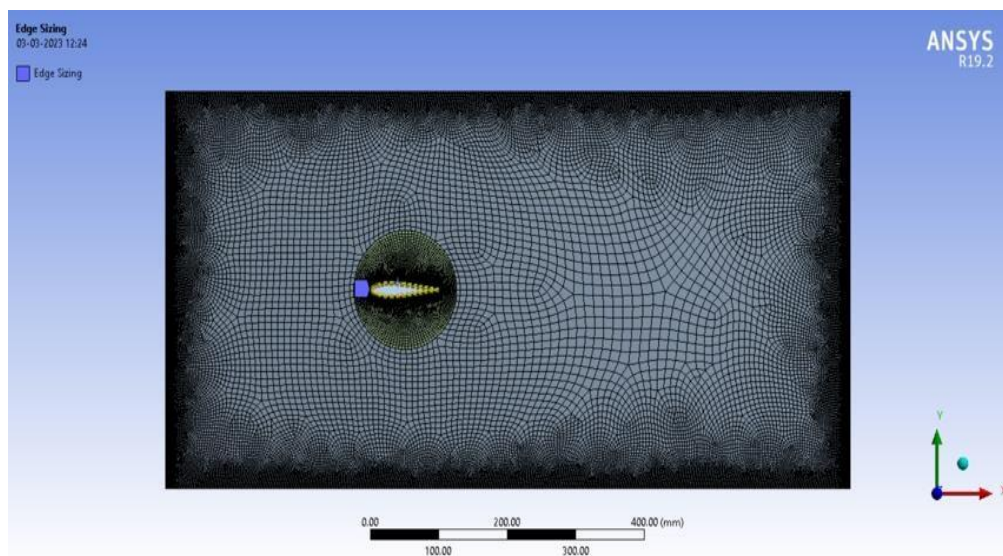


Fig.4.17: Meshing

Meshing is the process of dividing a complex geometry into smaller elements in order to solve mathematical equations that describe the behavior of the flow around it., meshing is the process of dividing the surface of the airfoil into small elements so that the flow can be accurately analyzed. The S1046 airfoil is a popular choice for a range of applications, including wind turbines and aircraft wings. The meshing process for an airfoil like the S1046 typically involves the following steps:

- Import the airfoil geometry into a meshing software.
- Define the domain around the airfoil where the mesh will be generated.
- Determine the appropriate size and shape of the mesh elements based on the desired level of accuracy and computational resources available.

- Use the meshing software to generate the mesh by dividing the airfoil surface into small elements, typically triangles or quadrilaterals.
- Refine the mesh in areas of high flow gradients or other regions of interest to increase the accuracy of the analysis.
- Export the meshed airfoil geometry for use in a computational fluid dynamics (CFD) simulation.

The quality of the mesh is an important factor in the accuracy of the CFD simulation. A poorly meshed airfoil can lead to inaccurate results, while a well-meshed airfoil can provide valuable insight into the behavior of the flow around the airfoil.

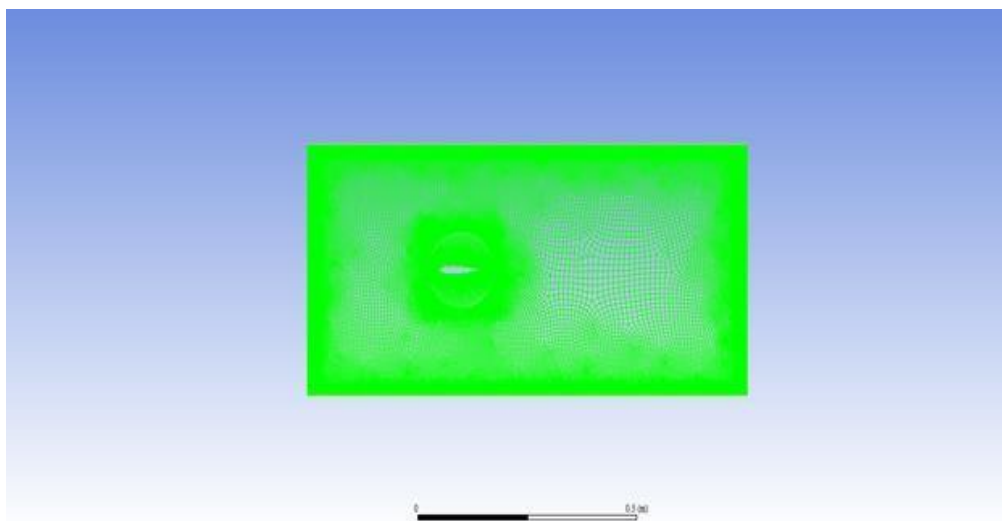


Fig.4.18:Mesh geometry

4.5.1 Boundary Conditions

Some algebraic equations are obtained after discretizing the governing equations. To solve these equations, the flow conditions must be solved within the computational domain's boundaries. In the 2D simulations, the boundary conditions were velocity inlet for the inlet boundary, walls for the blades, and pressure outlet for the rest of the domain. The boundary conditions in the 3D simulations are similar; however, the boundaries in the 3D simulations are surfaces rather than lines. In this study, the fluid flow was simulated using ANSYS Fluent software, and all equations were discretized using the second-order upwind discretization method. Because turbulent modelling method produces accurate results in fluid flows with separation and adverse pressure gradient and has good performance in terms of stability and

convergence, this model was developed.

4.6 Composition And Classification Of Energy Storage Systems

Energy Storage Systems allow power to be taken from a source (such as the power grid), stored and then released back into the system as and when required. The method used for energy storage will differ depending on the technology being used; however, most energy storage systems will include the following four main components; Storage Medium (the device which will store the energy until it is required) Charging System: the method of allowing energy flow from the external system into the storage medium Discharging System: the method used to release stored energy back into the power system Control: Governing the operation of the storage system According to, energy storage systems can be broadly classified into three groups based upon their response characteristics as follows; short term energy storage (seconds to minutes) – used for power quality applications; long term energy storage (minutes to hours) – used for grid congestion management and frequency response; and real long term energy storage (hours to days) – used for supply and demand matching over long periods. In addition to classification based on response characteristics, energy storage systems can also be classified based upon the form in which the energy is stored. Using this method, storage systems can be classified into groups such as mechanical storage, electrochemical storage, electrical storage and thermal storage.

4.6.1 Overview Of Electrical Energy Storage Technologies

The number of technologies which exist for the storage of electrical energy is vast. Such technologies include:

- Flow battery energy storage
- Superconducting magnetic energy storage
- Capacitors (Super-capacitors, electrolytic double layer capacitor)
- Batteries (Lead-Acid, Nickel Cadmium, Sodium Sulphur, Lithium Ion)

In this section, a review of several technologies relating to the direct storage of electrical energy, technologies where electrical energy is obtained directly from the device will be presented. Information such as operating principles, system components and device characteristics will be provided.

4.6.2 Flow Battery Energy Storage (Fbes)

Like conventional batteries, Flow Battery Energy Storage works by converting chemical energy into electrical energy. Unlike conventional batteries, FBES uses two aqueous electrolytic solutions contained in separate tanks. During normal operation, each of the aqueous solutions are pumped through an electrochemical cell, where a reversible electrochemical redox reaction occurs and electricity is generated. FBES technology is relatively young, and three main types of commercially developed flow battery exist; Vanadium Redox Battery, Polysulphide Bromide Battery and Zinc Bromine Battery. Due to a low self discharge (because electrolytes are stored in separate tanks) and the ability to withstand full discharge without damage, FBES systems have both a long lifespan and low maintenance requirement, making the technology suitable for long term energy storage.

4.6.3 Battery Energy Storage Systems (Bess)

Battery energy storage systems store electrical energy in the form of chemical energy. When discharged, chemical energy within the battery is converted into electrical energy for supply to an external circuit. During charging, the reverse is true and electrical energy is converted to chemical energy within the battery. BESS covers a number of storage technologies referred to as batteries. Examples of such battery technologies include;

- Lithium-Ion batteries
- Lead Acid batteries
- Nickel batteries
- Sodium Sulphur batteries

Batteries are comprised of multiple cells, containing either a solid or liquid electrolyte and a positive and negative electrode. Despite being one of the oldest technologies for storage of electrical power, factors such as ease of use and reliability mean that it is still a widely used and favoured technology for energy storage. A wide ranging power storage capability (100W – 20MW) means that battery energy storage can be suited to many different applications. The modular nature of batteries allows multiple devices to be connected together as required to increase power capacity. Lead acid is considered to be the oldest and most mature battery energy storage technology, having been in existence since 1859. Despite this, Lead

Acid is still a widely used battery energy storage technology due to advantages including; low cost, negligible maintenance requirement, and low self-discharge rates. Lead Acid technology is still considered to be popular for applications such as Uninterruptable Power Supplies (UPS) . Factors such as high toxicity, increased weight due to lead content, and low power density do however mean that for certain applications such as energy management, use of lead acid batteries has been hindered. Newer battery technologies such as Lithium-Ion have now achieved a significant penetration into the field of consumer electronics, and are also beginning to transition into hybrid and electric vehicle applications. Factors such as very high energy densities and high efficiencies make this battery technology attractive, and have also led to its application as a power source within medical devices. Sodium-Sulphur is another battery technology which is considered to show promise, with this type of battery having advantages such as high energy density, high efficiency and deep discharge tolerance. This technology is currently employed in large scale energy storage applications such as renewable energy management and integration. A high operating temperature (300°C – 350°C) and the highly corrosive nature of the sodium polysulfide discharge products does however mean that this technology is primarily suitable only for large-scale, non-mobile applications.

4.6.4 Control Strategies

The primary focus of the energy management strategy is to limit the wind power fluctuations to a level that is acceptable to the time frame of interest. However, we need to be conscious of the upper and lower limitations of the device and any margin that one may want to maintain. Furthermore, the questions as to how we can combine features related to normal operation and those associated with transients (say for LVRT enhancement) need to be addressed in the management algorithm. There are, of course, a number of different ways that one can meet these constraints, each with its own merits. In analysis of the different options, it is useful to consider the following: A deterministic analysis of the problem is useful for gaining an appreciation of the different issues: wind characteristics, impact of fluctuations, storage characteristics. Extending the deterministic approach to one which weights various deterministic formulations with corresponding probabilities can lead to an optimized overall solution, providing the greatest trade off between risk aversion and sizing. However, due to the dimensionality of the stochastic approach to the

problem, this needs to be contained in some realistic form for on-line scheduling. Nonlinear control or knowledge-based systems may be particularly useful when trying to develop a storage management structure that can be readily applied in industry. The flexible structure and wide range of toolboxes for prototyping make these especially attractive for this application. As an example, fuzzy logic can be used to characterize the state-of-charge of the energy storage device. Through extension of the structure, both additional storage levels and coordination with other energy sources can be achieved. It is important to emphasize that the original design of the management structure should be based upon a rigorous formulation of the problem, the knowledge-based system then serves as a modern tool to translate this information into a usable format. If properly developed, issues such as location of the storage and sizing can be included in the model and whose optimal values will be products of the solution. This process, if followed with discipline, should lead to a storage management system that is truly optimized, in the sense of its sizing, siting, and how it is operated. Here we consider the practical issues for implementing an energy storage system that includes: power electronic converters, converter control, power scheduling algorithm. The focus is on the latter item; the power electronic converters and controls are standard and will not be touched on here. The objective of the present work is to develop a modular structure that allows for scheduling of one or more storage levels. The control strategy of the overall storage-wind system has been defined to supply the moving average of the wind power over the period under consideration. Although this strategy is likely not optimal, it was deemed appropriate for validation of the control structure. Numerous energy storage technologies are currently in existence. Some are now highly developed, with others still in their infancy. Existing energy storage technologies allow energy to be stored in a variety of forms, for a variety of timescales, and with varying capacities. Application of specific technologies differs, with technologies such as Supercapacitors and SMES being suitable for short-period, fast response applications, and technologies including CAES and PHS being more suited to long term, long discharge applications. Increased use of intermittent energy sources such as wind and solar will act as a stimulus for increased energy storage implementation within power systems. The correct application of energy storage technologies within power systems allows the potential of renewable energy sources to be realised to a greater extent, enabling disadvantages such as voltage and frequency fluctuation

and mismatching of supply and demand peaks to be reduced, with grid stability being increased as a result. Future developments in energy storage technology such as the application of Carbon Nanotube technology to Supercapacitor design and the introduction of low-loss bearings for flywheel systems look set to bring further improvements in terms of device efficiency, energy density and extended component lifecycles. An energy storage system is introduced to land hydraulic wind turbine, which is a closed pump-control-motor hydraulics system. With Micon 600 kW wind turbine as a test object, the hydraulic principle diagram is designed, and the calculation and selection of the main components are completed. The mathematical model of the whole hydraulic system is constructed. A double closed-loop control method of the motor speed and the accumulator pressure is employed to satisfy the demand on the constant speed of the synchronous generator regardless of the fluctuation of wind speed. The responses under step and sine wind wheel speeds are simulated and analysed. The simulation results demonstrate that the constant speed control system of land hydraulic wind turbine with an energy storage system has fast response and very little steady-state error. Meanwhile, the accumulator working pressure is kept at around 200 bar throughout by adjusting the proportional valve opening and the motor displacement. In this way, the energy storage system is always ready to provide hydraulic energy to the motor without wind, which significantly improves the quality and stability of electric energy from wind turbine. Moreover, a parameter tuning method under high-order systems is proposed. Through simulation analysis, the system output power is effectively controlled. At the same time, under the fluctuating wind speed, the smoothness of the output power is greatly improved, and the power smoothing control effect is remarkable.

4.7 Other Energy Storage Technologies In Hydraulic Wind Turbines

While hydraulic accumulators and compressed air energy storage are widely applied to hydraulic wind turbines, some scholars have also applied pumped hydroelectric storage, battery energy storage, and flywheel energy storage to hydraulic wind turbines. This section will specifically introduce the application of several other energy storage technologies in hydraulic wind turbines. That has been implemented in various countries for the development of the hydraulic wind turbines.

4.7.1 Pumped Hydroelectric Storage

To increase the penetration rate of grid-connected wind power generation, Tonio Sant et al. designed a special offshore hydraulic wind turbine. The system uses sea water as the working fluid and connects pumped hydroelectric storage directly to the hydraulic transmission system in order to solve the problem of mismatch between supply and demand. There is no need for electric energy conversion in this process, which greatly reduces the conversion loss and simplifies the system. In addition, it also avoids the capacity loss of protects the system components from the destructive impact of localized high-pressure fluids. The hydraulic circuit contains a specific volume of the hydraulic fluid, which is distributed between hydraulic motors using a proportional valve. At the same time, a battery is equipped at the end of the auxiliary motor, which is used to store the excess energy in the battery through the transmission device when the wind speed is high. When the wind speed drops below the threshold, the energy stored in the battery is released back into the system and transmitted to the main generator in order to maintain the rated frequency. This section summarizes the application of several rare energy storage methods in hydraulic wind power systems, specifically involving the application of pumped hydroelectric storage, battery energy storage and flywheel energy storage in hydraulic wind power systems. The main reason for the lack of research results in this research at this stage is that the technology is not yet mature. The research of pumped hydroelectric storage focuses on evaluating the feasibility of several schemes through simulation. The research of battery energy storage focuses on the verification of the proposed structure and control algorithm. The research of flywheel energy storage focuses on evaluating the performance of different flywheel-based storage configurations. The role of energy storage technology in hydraulic wind turbines. On one hand, introducing the energy storage system into hydraulic wind power solves the problems caused by the randomness and volatility of wind energy on achieving the unit's own functions, such as speed control, power tracking control, power smoothing, and frequency modulation control. On the other hand, it can provide a solution to the problem of unsustainable and instable power supply of wind turbines caused by intermittent wind energy. Energy storage systems play an irreplaceable role in optimizing resource allocation and improving power grid security and the economy. Aimed at the above points, this chapter will introduce the

specific functions of energy storage technology in hydraulic wind turbines in detail in order to provide ideas for scholars' follow-up research.

4.7.2 Stable Output Speed

Grid-connected speed control is the premise of grid-connected wind turbine generation. However, because hydraulic wind turbines have no rectifier or inverter device, they require a hydraulic main drive system to complete. At the same time, due to stringent grid-connected requirements, time-varying hydraulic systems and external disturbances, how hydraulic wind turbines can achieve high-precision grid-connected speed control is still a technical problem. Therefore, many scholars have studied generator speed control under changes in the wind speed and generator load and the strive to keep it stable in grid frequency. The energy storage system has the ability to store energy and absorb pulsation, which can assist the hydraulic main drive system. controlling the displacement of the motor and the opening area of the proportional valve. This method verifies the accuracy of the control strategy on a 600 kW wind power generation system prototype. The dual closed-loop speed control strategy based on the accumulator working pressure and motor speed is, and the control effect The flywheel energy storage system has also received attention from scholars due to its advantages in terms of speed and economy and has been used in research on stabilizing speed. The principle of achieving its energy storage function Carrillo et al. aimed at the variable speed flywheel wind power generation system based on hydrostatic transmission, using the PID algorithm to control the pump in the system to meet the standard value of the diesel generator when working.

4.7.3 Conventional Accumulator Characteristics

The conventional accumulator can reduce the fluctuation of pipeline oil pressure. the oil pressure curve of highpressure pipeline with and without conventional accumulators in the system. When the system is not equipped with conventional accumulator, the fluctuation of pipeline oil pressure is relatively violent, and the fluctuation range is between 1:0, 107 and 3:0, 107Pa. When conventional accumulator exists in the system, the pipeline oil pressure is stable, and the fluctuation amplitude is very small. Compared with non conventional accumulator condition, the fluctuation amplitude of oil pressure decreases significantly, which

shows the necessity of setting the conventional accumulator in the hydraulic circuit. The most competitive advantage of hydraulic system with accumulator is that it can use the accumulator to store and release energy to smooth the power output fluctuation. The changes of gas pressure and volume in the conventional accumulator, respectively. It can be seen that when the system is in stable operation, the change relationship between them conforms to the theoretical calculation. Thus, the volume decreases as the gas pressure increases, and increases as the gas pressure decreases. The changes of gas pressure and volume fluctuate respectively in the range of 2.0107 Pa-2.08107 Pa and 48.5 L-50 L, which are relatively stable. It displays the flow change in the conventional accumulator. When the flow is positive, the oil enters into the conventional accumulator, which compresses gas and stores energy. When the flow is negative, the oil flows out of the conventional accumulator, which expands gas and releases energy. The product of instantaneous pulsating flow and pressure is the power change of the conventional accumulator. Turbulent wind speed condition The time-domain curve of the turbulent wind speed measured in a wind farm is plotted. average wind speed is 12.8 m/s and the turbulence intensity is 10.9%. The wind speed increases sharply during the period of 160 s-230 s. Furthermore, during the period of 360 s-402 s, the wind speed decreases sharply.

4.7 Importance Of Low Manufacturing Cost Of Wind Turbine

The importance of low manufacturing cost of wind turbines is crucial for the following reasons: Cost-competitive renewable energy: As wind energy continues to grow as a source of clean energy, the cost of producing wind power needs to remain competitive with fossil fuels. Lower manufacturing costs of wind turbines make wind energy more cost-effective, which in turn makes it more competitive with traditional energy sources. Increased adoption: Lower costs of manufacturing wind turbines make wind energy more accessible and affordable, which can increase its adoption rate worldwide. This can lead to a greater reduction in greenhouse gas emissions and a more sustainable energy future. Improved return on investment: For wind energy projects, the return on investment is a key factor in determining the viability of the project. Lower manufacturing costs can improve the return on investment by reducing the upfront costs of building the turbines. Job creation: With lower manufacturing costs, more wind turbines can be produced, leading to increased job

creation in the renewable energy sector. Technological advancements: Lower manufacturing costs can also incentivize research and development in wind energy technology, leading to improvements in turbine design and efficiency. In summary, low manufacturing cost of wind turbines is crucial for the growth and sustainability of the wind energy industry, and for achieving a cleaner, more sustainable energy future.

4.8 Importance Of Turbulent Wind Technique

The turbulent wind technique is a method used in the aviation industry to simulate real-life flight conditions in a controlled environment. It involves generating random air movements, or turbulence, around an aircraft during ground tests. This technique is important for several reasons: Safety, Efficiency and Cost Effectiveness. Safety: Turbulence is a natural occurrence during flight, and testing the aircraft's ability to handle it is essential for safety. By subjecting the aircraft to simulated turbulence, engineers can identify any potential weaknesses and make necessary adjustments before the aircraft takes to the skies. Efficiency: Aircraft designers use the data gathered from the turbulent wind technique to optimize the aircraft's design for efficiency. By understanding how the aircraft behaves in turbulence, they can adjust the shape of the wings, tail, and other components to minimize drag and improve fuel efficiency. Cost-effectiveness: Testing an aircraft in real-life turbulence conditions can be costly and dangerous. The turbulent wind technique allows engineers to simulate these conditions in a controlled environment, saving time and money. Overall, the turbulent wind technique plays a crucial role in the development and testing of aircraft, helping to ensure their safety, efficiency, and cost-effectiveness.

CHAPTER 5

RESULT AND DISCUSSIONS

5.1 Result

One benefit of the proposed hydraulic transfer system is having one central generation unit. The key point in this system is the usage of a proportional valve to make this design a possibility. In a conventional wind power plant, individual gearboxes in each wind tower interface the low- and high-speed shafts of the turbine and the generator and provide an amplified linear speed follower mechanism. In the new design, hydraulic energy transfer in the form of pressurized fluid replaces the gearbox compartment, allowing for energy collection from multiple turbines. This technique utilizes hydraulic pumps and hydraulic motors connected through high-pressure pipes to transfer the energy from the wind turbine to a central ground level generator. Hydraulic valves are utilized to control and regulate the hydraulic flows while propelling a loaded generator at the desired frequency. Multiple-turbine configuration requires multiple hydraulic pumps driven by individual turbines. The energy from each turbine in this system is transferred through pipes and is collected in a fluid combiner unit at the central ground level power generation unit. In the central power generation unit, there are two sets of main and auxiliary generators. The total fluid generated from the multiple turbines is regulated and sent to the main generators.

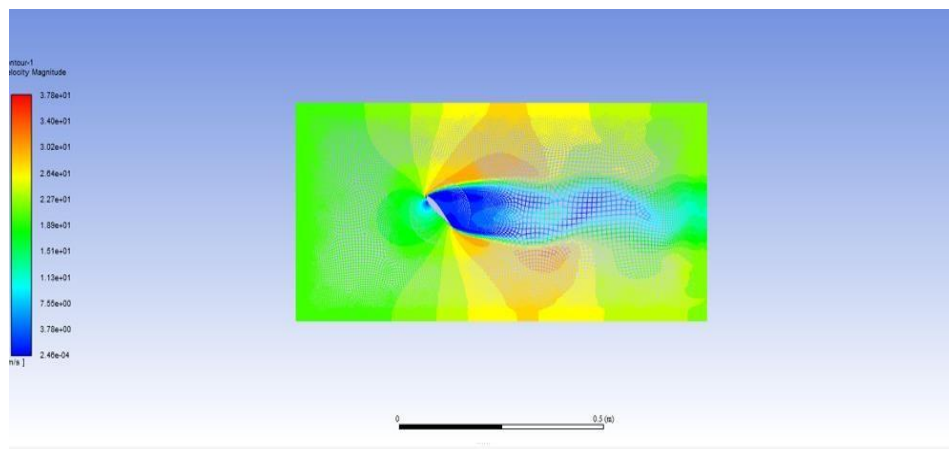


Fig.5.1: Result and analysis

The analysis of an airfoil such as the S1046 typically involves using computational fluid dynamics (CFD) software to simulate the flow around the airfoil under different conditions, such as different angles of attack and airspeeds. The results of the simulation can provide insight into the lift and drag characteristics of the airfoil, as well as its stall behavior and other important performance metrics. One common metric used to evaluate the performance of an airfoil is the lift coefficient (C_L), which is a measure of the amount of lift generated by the airfoil at a given angle of attack. The drag coefficient (C_D) is another important metric, which measures the amount of drag produced by the airfoil. In the case of the S1046 airfoil, CFD simulations have shown that it has a high lift coefficient and relatively low drag coefficient compared to other airfoils with similar applications. This makes it a popular choice for use in wind turbines and other applications where high lift is desirable. However, the S1046 airfoil also exhibits some limitations. At high angles of attack, it is prone to stall, which can cause a significant decrease in lift and an increase in drag. Overall, the performance of the S1046 airfoil is highly dependent on the specific application and operating conditions. By carefully analyzing the results of CFD simulations, designers can optimize the airfoil shape and geometry to achieve the desired performance characteristics for a particular application.

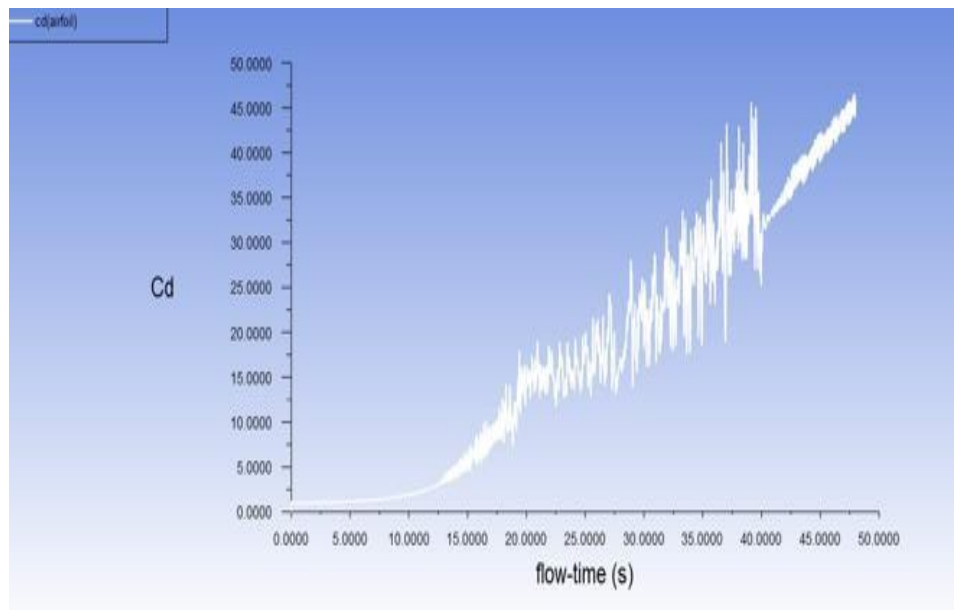


Fig.5.2:cd rplot

The drag coefficient (C_D) of an airfoil like the S1046 is an important performance metric that can be determined through computational fluid dynamics (CFD) simulations. The drag coefficient is a measure of the amount of drag produced by the airfoil relative to its size and speed. The drag coefficient of the S1046 airfoil can vary depending on several factors, including the angle of attack, airspeed, and Reynolds number. However, CFD simulations have shown that the drag coefficient of the S1046 airfoil is generally low compared to other airfoils with similar applications. For example, at an angle of attack of 5 degrees and a Reynolds number of 1 million, CFD simulations have shown that the S1046 airfoil has a drag coefficient of approximately 0.009. This is relatively low compared to other airfoils with similar lift coefficients and applications. However, at higher angles of attack, the drag coefficient of the S1046 airfoil can increase significantly due to the onset of flow separation and other flow phenomena. At an angle of attack of 20 degrees, for example, the drag coefficient of the S1046 airfoil can increase to approximately 0.2. Overall, the drag coefficient of the S1046 airfoil is an important consideration for designers and engineers who are interested in optimizing the performance of wind turbines, aircraft wings, and other applications. By carefully analyzing the results of CFD simulations, designers can optimize the shape and geometry of the airfoil to achieve the desired lift and drag characteristics for a particular application.

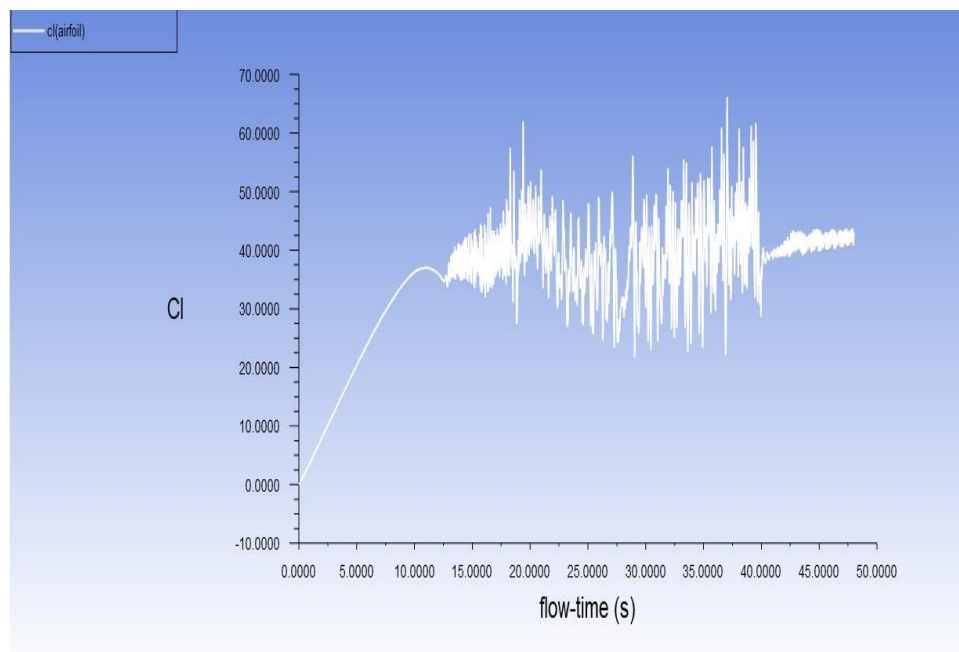


Fig.5.3:Cl rplot

The lift coefficient (CL) is an important performance metric for an airfoil like the S1046, which is commonly used in applications such as wind turbines and aircraft wings. The lift coefficient is a measure of the amount of lift produced by the airfoil relative to its size and speed. The lift coefficient of the S1046 airfoil can vary depending on several factors, including the angle of attack, airspeed, and Reynolds number. However, CFD simulations have shown that the S1046 airfoil has a high lift coefficient compared to other airfoils with similar applications. For example, at an angle of attack of 5 degrees and a Reynolds number of 1 million, CFD simulations have shown that the S1046 airfoil has a lift coefficient of approximately 1.4. This is relatively high compared to other airfoils with similar drag coefficients and applications. At higher angles of attack, the lift coefficient of the S1046 airfoil can increase further, peaking at around 1.8 at an angle of attack of approximately 15 degrees. However, at angles of attack beyond this, the airfoil can experience significant flow separation and stall, which can result in a decrease in lift and an increase in drag. Overall, the lift coefficient of the S1046 airfoil is an important consideration for designers and engineers who are interested in optimizing the performance of wind turbines, aircraft wings, and other applications. By carefully analyzing the results of CFD simulations.

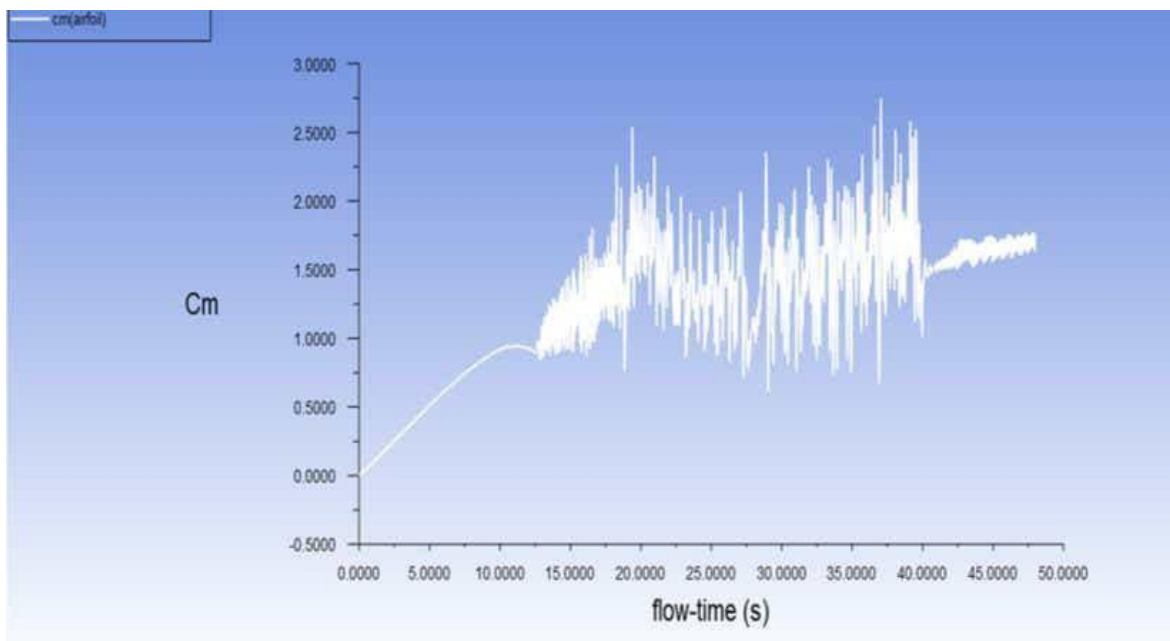


Fig.5.4:Cm rplot

The pitching moment coefficient (CM) is a measure of the tendency of an airfoil like the S1046 to pitch or rotate around its center of gravity in response to changes in the angle of attack. The pitching moment coefficient is an important consideration for designers and engineers who are interested in optimizing the stability and control characteristics of an airfoil. The pitching moment coefficient of the S1046 airfoil can vary depending on several factors, including the angle of attack, airspeed, and Reynolds number. CFD simulations have shown that the S1046 airfoil has a relatively low pitching moment coefficient compared to other airfoils with similar applications. For example, at an angle of attack of 5 degrees and a Reynolds number of 1 million, CFD simulations have shown that the S1046 airfoil has a pitching moment coefficient of approximately -0.04. This indicates that the airfoil has a slight tendency to pitch nose-down at this angle of attack. At higher angles of attack, the pitching moment coefficient of the S1046 airfoil can become more negative, indicating a stronger tendency to pitch nose-down. However, this can be mitigated through careful design of the airfoil shape and geometry, such as the addition of camber or other features to control the flow over the airfoil. Overall, the pitching moment coefficient of the S1046 airfoil is an important consideration for designers and engineers who are interested in optimizing the stability and control characteristics of wind turbines, aircraft wings, and other applications. By carefully analyzing the results of CFD simulations and adjusting the airfoil shape and geometry, designers can optimize the pitching moment coefficient to achieve the desired stability and control characteristics for a particular application. In the case of the S1046 airfoil, CFD simulations have shown that the CM is relatively low or negative at low angles of attack, indicating a slight tendency to pitch nose-down. As the angle of attack increases, the CM becomes more negative, indicating a stronger tendency to pitch nose-down. At high angles of attack, the airfoil can experience significant flow separation and stall, which can result in a decrease in lift and an increase in drag, and can also significantly affect the pitching moment coefficient. To optimize the pitching moment coefficient of the S1046 airfoil, designers can adjust the shape and geometry of the airfoil, such as by adding camber or other features to control the flow behavior. This can help to achieve the desired stability and control characteristics for specific applications, such as wind turbines or aircraft wings.

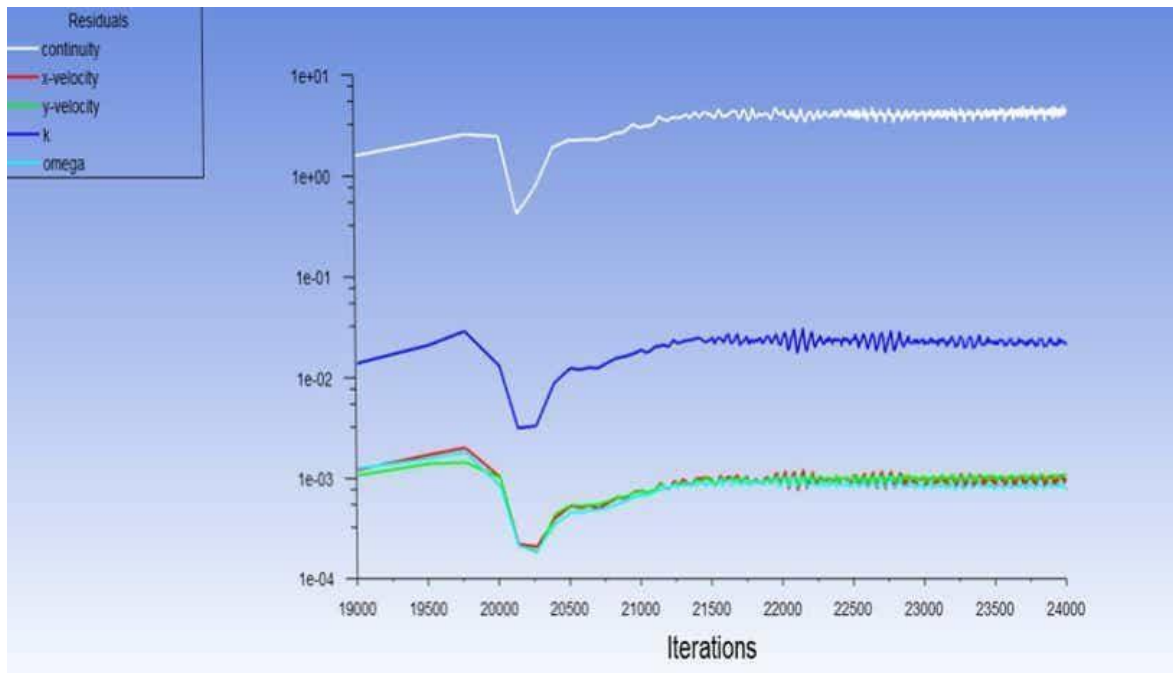


Fig.5.5: Scaled Residuals

Scaled residuals are a measure of the convergence of a computational fluid dynamics (CFD) simulation. They provide an indication of whether the solution has reached a steady state, and whether the numerical errors are acceptable. In a CFD simulation of an airfoil like the S1046, scaled residuals are typically monitored for various parameters, such as velocity, pressure, and turbulence. The residuals are scaled to account for differences in the magnitudes of the variables being solved for, and are plotted as a function of the iteration number. In general, the scaled residuals for a CFD simulation of the S1046 airfoil should decrease over time as the simulation approaches a steady state. The rate at which the residuals decrease depends on several factors, including the quality of the mesh, the numerical methods used, and the convergence criteria set by the user. Ideally, the scaled residuals should reach a plateau or steady state after a certain number of iterations, indicating that the solution has converged. However, in practice, some residual oscillations may occur, especially near the walls of the airfoil where the flow behavior can be complex. To ensure the accuracy and reliability of the simulation results, designers and engineers should carefully monitor the scaled residuals during the CFD simulation of the S1046 airfoil. If the residuals do not converge or plateau after a sufficient number of iterations, adjustments to the mesh or numerical methods may be necessary.

5.2 Discussion

The S1046 airfoil is a popular choice for a wide range of applications, including wind turbine blades, aircraft wings, and hydrofoils. Its design features a relatively thin and symmetrical airfoil shape, which makes it suitable for use in both horizontal and vertical axis wind turbines. One of the advantages of the S1046 airfoil is its relatively low drag coefficient, which makes it efficient at converting the kinetic energy of the wind into rotational energy for wind turbines. The low drag also makes it suitable for use in aircraft wings, where it can help to reduce fuel consumption and increase range. In terms of lift characteristics, the S1046 airfoil has a relatively high maximum lift coefficient, which makes it suitable for use in applications where high lift is required, such as takeoff and landing in aircraft. The airfoil's symmetric shape also means that it has a relatively low pitching moment coefficient, which can help to improve stability and control. However, one potential limitation of the S1046 airfoil is its susceptibility to flow separation and stall at high angles of attack. This can result in a decrease in lift and an increase in drag, which can reduce the efficiency of wind turbines and aircraft wings. To mitigate this, designers may incorporate features such as camber or other airfoil shapes to control the flow behavior and improve the airfoil's performance at high angles of attack. Overall, the S1046 airfoil is a versatile and widely used airfoil design that can be optimized for a variety of applications. By carefully analyzing the airfoil's performance characteristics, designers and engineers can optimize the airfoil's shape and geometry to achieve the desired performance and efficiency for specific applications.

A hydraulic system is a type of power transmission system that uses pressurized fluid, typically oil or water, to transmit power from one location to another. Hydraulic systems are widely used in a variety of industrial, construction, and transportation applications, where they provide a high level of power and precision control. One of the key advantages of hydraulic systems is their ability to transmit large amounts of power over long distances with relatively small energy losses. This makes them suitable for use in applications such as heavy machinery, construction equipment, and transportation vehicles, where high power and precise control are required. Another advantage of hydraulic systems is their ability to provide precise and proportional control of the power output. By adjusting the flow rate and pressure of the hydraulic fluid, operators can precisely control the motion and force of hydraulic cylinders, motors,

and other hydraulic components. This allows for precise control of heavy machinery, such as excavators or cranes, and can also be used for precision control of manufacturing equipment, such as injection molding machines. In addition, hydraulic systems are generally robust and reliable, requiring relatively little maintenance compared to other types of power transmission systems. However, they do require regular monitoring and maintenance to ensure proper operation and prevent leaks or other malfunctions. One potential disadvantage of hydraulic systems is the potential for fluid leaks or spills, which can cause environmental contamination and pose a safety hazard. To mitigate this, hydraulic systems should be designed and maintained to minimize the risk of leaks, and operators should be trained to properly handle and dispose of hydraulic fluids. Overall, hydraulic systems offer a high level of power and precise control for a wide range of industrial, construction, and transportation applications. By carefully designing and maintaining hydraulic systems, operators can ensure reliable and efficient operation while minimizing environmental and safety risks.

CHAPTER 6

OUTLOOK AND CONCLUSION

6.1 Outlook

Leakage is a major problem in hydraulic wind turbines and even hydraulic systems as a whole. Liquid transmission media in hydraulic systems are inevitably prone to leaks. Additionally, hydraulic fluids are not completely incompressible, so hydraulic systems should not be used if precise conversion is required. To overcome these problems, the manufacturing precision of hydraulic components must be high. However, this leads to high costs for wind turbines. Poor performance and maintenance issues are other limitations to address. There are some common problems in the application of hydraulic drives in wind turbines. Firstly, the leakage, especially when developing offshore wind turbines, will pollute the marine environment. Secondly, the development status of hydraulic components is limited. The actual saving in weight is achieved by the omission of the power electronics and voltage transformer. Key components, which are suitable for wind turbines, are relatively few, especially the pumps or motors with low speed and large displacement. At present, most pumps or motors exhibit limited range when the wind speed fluctuates in a large range. Thirdly, the temperature will influence the performance of the hydraulic system. It is a problem whether the wind power unit can work properly in the harsh installation environment. Fourth, the vibration problem cannot be avoided. When wind power systems utilize hydraulic systems, the system flexibility is increased. Fifth, considering the water-based hydraulic offshore wind power, the problem is that the water hydraulic pump has not yet achieved the megawatt level, and internal leakage is more serious, so the efficiency will be lower. Compared with mechanical systems, hydraulic systems feature large power to volume ratio, adjustable transmission ratio, so when replacing the gear transmission, the hydraulic system can be directly connected to a synchronous generator, which can largely reduce the weight of the nacelle, and the power electronic converters can be omitted.

6.2 Conclusion

Many countries around the world have conducted theoretical research and prototype experiments on the main hydraulic transmission control system of the hydraulic wind turbine, but this research field is still in its infancy in China. It would be very costly to fully introduce foreign hydraulic wind turbine technology, and domestic users could have a hard time mastering its core technology. Therefore, research on localized models is recommended to develop hydraulic transmission control systems for hydraulic wind turbines with improved efficiency and flexibility. The system can be connected to a network via an electrically excited synchronous generator. The system can achieve power generation, optimal power tracking, and low-voltage drive. Gearbox and Rectifier Eliminates the use of inverter equipment, reduces wind turbine weight, and reduces installation costs. The hydraulic wind turbine will be the new development direction of the wind turbine. Currently, energy storage technology for hydraulic wind turbines mainly consists of hydraulic accumulators and compressed air energy storage. Compressed air storage has produced some research results, but has not yet been funded. It has very few practical engineering applications. Pumped storage power plants, battery storage, flywheel storage, and other technologies are gradually being applied to hydro-wind turbines. Due to the low threshold of battery energy storage technology, battery energy storage will occupy the market of hydro-wind energy storage technology, second only to hydraulic accumulators and compressed air energy storage. the application of battery energy storage in hydro-wind power is mainly used for onshore power generation, while offshore hydro generator sets continue to be dominated by compressed air storage. under the stable wind speed condition, the characteristics of impeller torque, hydraulic drive, and conventional accumulator are studied. which can stabilize the power output effectively. When the wind speed changes sharply, the controllable accumulator opens intermittently. It stores energy as the wind speed increases rapidly and releases energy for the system as the wind speed drops suddenly. The application of the multi- accumulator effectively reduces the torque fluctuation of the generator, increases the system stability, and improves the quality of power generation.

REFERENCES:

- [1]. Afshin Izadian, Sina Hamzehlouia, Majid Deldar, and Sohel Anwar, A Hydraulic Wind Power Transfer System: Operation and Modeling Senior Member, IEEE, 2014
- [2]. Anil C. Mahato, Sanjoy K. Ghoshal a, Arun K. Samantaray, Reduction of wind turbine power fluctuation by using priority flow divider valve in a hydraulic power transmission.
- [3]. Ayana Pusha, and Sohel Anwar, Member, Sina Hamzehlouia, Afshin Izadian, Senior Member, IEEE,
- [4]. B. Skaare, B. Hornsten, F.G. Nielsen, Modeling, simulation and control of a wind turbine with a hydraulic transmission system, Wind Energy 16 (2013).
- [5]. C. Ai, L.J. Chen, X.D. Kong, Efficiency analysis of main hydraulic transmission system in a 30 kVA hydraulic wind turbine simulation experimental platform, China Mach Eng (2016).
- [6]. C. Ai, W.J. Bai, T.Y. Zhang, X.G. Kong, Active control of pressure resonance in long pipeline of bottom founded hydraulic wind turbines based on multi objective genetic algorithm, IEEE Access 6 (2018).
- [7]. Castillo A, Gayme DF. Grid-scale energy storage applications in re-newable energy integration: a survey. Energy Convers Manage 2014.
- [8]. Chad Abbey, John Chahwan & Geza Joos (2008) Energy Storage and Management in Wind Turbine, EPE Journal.
- [9]. Chao Ai, Jiawei Guo, Wei Gao, Lijuan Chen, Guangling Zhou, Zengrui Han, Xiangdong Kong, Active Disturbance Rejection Control with Linear Quadratic Regulator for Power Output of Hydraulic Wind Turbines.
- [10]. Chao Ai, Lin Zhang, Wei Gao , Guisheng Yang, Die Wu c , Lijuan Chen c , Wenting Chen, Andrew Plummer, A review of energy storage technologies in hydraulic wind turbine .
- [11]. Chao Ai, Wei Gao, Qinyu Hu, Yankang Zhang, Lijuan Chen, Jiawei Guo and Zengrui Han, Application of the Feedback Linearization in Maximum Power PointTracking Control for Hydraulic Wind Turbine, 2020
- [12]. Chengbing He a, Jianchong Wang b , Runze Wang a , Xiaoxiang Zhang, Research

on the characteristics of hydraulic wind turbine with multiaccumulator,2020.

- [13]. Christopher A , Moofik Al-Tai,A Review of the Technology and Its Application in Power Systems Jamie C Beardsall Staffordshire University.
- [14]. Engguang Liu, Guolai Yang, Liejiang Wei and Daling Yue, Variable speed and constant frequency control of hydraulic wind turbine with energy storage system,2017
- [15]. Francisco Rubio¹ , Carlos Llopis-Albert, viability of using wind turbines for electricity generation in electric vehicles.
- [16]. Gao Y, Ma S, Wang T, Wang T, Gong Y, Peng F, et al. Assessing the wind energy potential of China in considering its variability/intermittency. Energy Convers Manage 2020.
- [17]. Jiang R, Wang J, Guan Y. Robust unit commitment with wind power and pumped storage hydro. IEEE Trans Power Syst 2012
- [18]. Kong Y, Kong Z, Liu Z, Wei C, Zhang J, An G. Pumped storage power stations in China: the past, the present, and the future. Renew Sust Energ Rev 2017.
- [19]. Kose F, Kaya MN, Ozgoren M. Use of pumped hydro energy storage to complement wind energy: a case study. Therm Sci 2018.
- [20]. Liu X, Li N, Mu H, Li M, Liu X. Techno-energy-economic assessment of a high capacity offshore wind-pumped-storage hybrid power system for regional power system. J Energy Storage 2021
- [21]. M. Deldar, A. Izadian, M. Vaezi, Modeling of a hydraulic wind power transfer utilizing a proportional valve, IEEE Trans. Ind. Appl. 51 (2) (2015).
- [22]. M. Saadat, F.A. Shirazi, P.Y. Li, Modeling and control of an open accumulator Compressed Air Energy Storage (CAES) system for wind turbines, Appl. Energy 137 (2015).
- [23]. M.L. Cai, Y.X. Wang, Z.X. Jiao, Review of fluid and control technology of hydraulic wind turbines, Front. Mech. Eng. 12 (3) (2017).
- [24]. Maolin CAI, Yixuan WANG, Zongxia JIAO, Yan SHI, Review of fluid and control technology of hydraulic wind turbines,2017.

- [25]. Masoud Vaezi, Aryan Asgharifard, and Afshin Izadian , Control of Hydraulic Wind Power Transfer System under Wind and Load Disturbances, Senior Member.
- [26]. R. Dutta, F. Wang, B.F. Bohlmann, K.A. Stelson, Analysis of short-term energy storage for midsize hydrostatic wind turbine, J Dyn Syst.(2010).
- [27]. Sayga S, Szabowski U, Badyda K. Comparison of constant volume energy storage systems based on compressed air. Int J Energy Res 2021.
- [28]. T. Sant, D. Buhagiar, R.N. Farrugia, Evaluating a new concept to integrate compressed air energy storage in spar-type floating offshore wind turbine structures, Ocean Eng. 166 (2018) .
- [29]. Venkataramani G, Parankusam P, Ramalingam V, Wang J. A review on compressed air energy storage - A pathway for smart grid and polygeneration. Renew Sustain Energy Rev 2016.
- [30]. Wenlong Tian, Zhaoyong Mao, Xinyu An, Baoshou Zhang, Haibing Wen, Numerical study of energy recovery from the wakes of moving vehicles on highways by using a vertical axis wind turbine,2017
- [31]. Wenting Chen, Xiaoyun Wang, Fusen Zhang, Hongwei Liu¹, Yonggang Lin, Review of the application of hydraulic technology in wind turbine,2019.
- [32]. Whitby, R David Tribology & Lubrication Technology ,Hydraulic fluids in wind turbines, 2010
- [33]. Wu S, Zhou C, Doroodchi E, Moghtaderi B. Thermodynamic analysis of a novel hybrid thermochemical-compressed air energy storage system powered by wind, solar and/or off-peak electricity ScienceDirect. Energy Convers Manage 2019.
- [34]. Xie Fangwei ¹ & Xuan Rui¹ & Sheng Gang¹ & Wang Cuntang, Flow characteristics of accelerating pump in hydraulic-type wind power generation system under different wind speeds, 2017
- [35]. Y.M. Bian, X.M. Xu, X. Niu, Research on the wind power generation system based on hydraulic conduction, Mech Sci Technol for Aerospace Eng 32 (2013).
- [36]. YaJun Fan, AnLe Mu ^b , Tao Ma, Modeling and control of a hybrid wind-tidal turbine with hydraulic accumulator ,2016

- [37]. Yang T, Han Z, Gao J. Optimal Configuration Method of Distributed Hybrid Energy Storage Systems in Distribution Network with Large Scale of Wind Power Generation. In: International seminar of purple mountain forum academic forum; 2020.
- [38]. Ying-Yuan Liu , Yi-Ran Li, and Le-Qin Wang , Experimental and theoretical studies on the pressure fluctuation of an internal gear pump with a high pressure,2018
- [39]. Ying-Yuan Liu , Yi-Ran Li, and Le-Qin Wang ,Experimental and theoretical studies on the pressure fluctuation of an internal gear pump with a high pressure,2018.
- [40]. Zhiyu Jianga Limin Yangd, Zhen Gao, Torgeir Moan, Numerical Simulation of a Wind Turbine with a Hydraulic Transmission