A

Project Phase II Report

on

POWER CONVERTER AND CONTROL OF WIND ENERGY CONVERSION SYSTEM FOR MAXIMUM POWER EXTRACTION

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CERTIFICATE

This is to certify that the Project Phase-II report entitled

"POWER CONVERTER AND CONTROL OF WIND ENERGY CONVERSION SYSTEM FOR MAXIMUM POWER EXTRACTION",

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is a bonafide work carried out by them under the supervision of **Prof.Dr.Rahul Mapari** and it is approved for the partial fulfillment of the Project Phase II of the requirement of Savitribai Phule Pune University,Pune for the award of the degree of Bachelor of Engineering (Electronics &Telecommunication).The Dissertation work has not been earlier submitted to any other institute or university for the award of degree.

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Abstract

In this project, wind energy is recognized as a highly promising renewable energy source. Through the utilization of power electronics, wind energy is undergoing a significant transformation, evolving from a minor energy source to a prominent power supplier within the energy system. Standard power converter topologies are employed throughout the process, ranging from basic converters for turbine startup to advanced converter topologies that facilitate the flow of power through the wind energy conversion system. This system plays a crucial role in the generation of electrical power. The integration of Wind Energy Conversion Systems (WECS) with the grid presents a complex challenge in research. Various control strategies for DC-DC converters have been implemented in distributed renewable energy systems to address energy shortages and environmental concerns. Two types of double-loop controls are presented and compared: one focusing on voltage in the outer loop and current in the inner loop, while the other concentrates on current in the outer loop and voltage in the inner loop. These strategies enable independent control of active and reactive power through the manipulation of q-axis and d-axis current components in the first scheme. In the second scheme, active and reactive power control is achieved through the modulation index of the PWM converter and duty ratio of the boost converter, which are interdependent. The overall effectiveness and robustness of the WECS are determined by the superiority of the entire control system and the stability of its operation. Furthermore, the report emphasizes the significance of Maximum Power Point Tracking (MPPT) in optimizing energy extraction from wind turbines. MPPT algorithms effectively utilize available wind energy to generate maximum power output from the turbines. The power converter and control systems employed in wind energy conversion systems play a critical role in maximizing energy extraction and ensuring the efficient and reliable operation of wind turbines. The report provides a comprehensive overview of different power converter topologies and control techniques utilized in WECS, while also highlighting current research trends in this dynamic field.

Chapter 1

Introduction

1.1 Introduction

Wind energy is widely acknowledged as a highly promising renewable resource for electricity generation, primarily due to its cost competitiveness when compared to conventional energy sources. As a result, wind power has experienced a significant increase in its integration within electric power systems, and this trend is expected to continue with sustained growth in the foreseeable future. To convert wind energy into electrical energy we put a system to work between Wind Energy and Electrical energy. Wind Energy as an input and Electrical Energy is output. In wind energy conversion system power is converted from pulsating AC to pulsating DC and then DC is converted into AC. A wind turbine is an apparatus designed to transform the kinetic energy of the wind into electrical energy. Wind turbines are increasingly recognized as a prominent and growing source of intermittent renewable energy. Their utilization serves the purpose of lowering energy expenses and reducing dependency on fossil fuels. The generator, gearbox, and rotor are among the components of a wind turbine. An AC constant power supply is a power source that transmits alternating current (AC) electricity to a load. The two types of power input are AC and DC. The power needed by the load and the power supplied by the inverter and other power storage devices are usually mismatched. AC power supplies correct the electrical source's AC power to the device's necessary voltage, current, and frequency in order to address this problem. An inverter plays a vital role in solar energy systems as it facilitates the conversion of direct current (DC) electricity generated by solar panels into the alternating current (AC) electricity required by the electrical grid. While DC electricity maintains a constant voltage in a single direction, AC circuits enable the movement of electricity in both directions as the voltage alternates between positive and negative. Inverters belong to the category of power electronics, which encompasses devices responsible for managing the flow of electrical power. Among the various approaches to power conversion, sinusoidal Pulse Width Modulation (SPWM) is a popular technique used in inverters.

1.2 Research background

The use of renewable energy sources has gained widespread attention over the past few decades due to their clean and sustainable nature. Wind energy is one of the most promising renewable energy sources, with the potential to provide a significant portion of the world's electricity demand. Wind energy conversion systems (WECS) are used to harness wind energy and convert it into electrical energy. However, the performance of WECS is affected by several factors such as wind speed, wind direction, and turbine rotor speed. Therefore, power converters and control systems are essential components of WECS to ensure efficient and optimal operation.

The use of power converters in WECS is crucial to enable the conversion of the variable frequency and voltage output of the wind turbine to a fixed frequency and voltage suitable for grid connection. The power converter also ensures the maximum power extraction from the wind turbine by controlling the generator's speed and torque. The control system is responsible for monitoring the wind turbine's operating conditions and adjusting the power converter's operation to achieve maximum power extraction. This paper provides a literature review of the recent research on power converters and control systems for wind energy conversion systems.

Power Converters for Wind Energy Conversion Systems:

The power converter is a critical component of WECS as it controls the electrical energy conversion process between the wind turbine and the grid. The power converter should be designed to operate under varying wind conditions and control the generator's speed and torque to achieve maximum power extraction. Several power converter topologies have been proposed and used in WECS. The most common power converter topologies are:

1. Doubly Fed Induction Generator (DFIG) System: The DFIG system is widely used in modern wind turbines due to its low cost and high efficiency. In the DFIG system, the rotor side converter (RSC) and the grid side converter (GSC) are used to control the rotor and stator currents. The RSC controls the rotor current, while the GSC controls the stator current. The RSC is responsible for controlling the generator's speed and torque to achieve maximum power extraction from the wind turbine. The GSC is used to regulate the output voltage and frequency of the wind turbine and ensure grid compatibility. Several control strategies have been proposed for DFIG systems, such as vector control, direct power control, and model predictive control.

2. Permanent Magnet Synchronous Generator (PMSG) System: The PMSG system is another popular topology used in modern wind turbines. The PMSG system has several advantages over the DFIG system, such as higher efficiency and lower maintenance requirements. The PMSG system uses a full-scale power converter to control the generator's speed and torque and ensure maximum power extraction. The power converter regulates the generator's output voltage and frequency and ensures grid compatibility. Several control strategies have been proposed for PMSG systems, such as sliding mode control, hysteresis control, and model predictive control.

3. Full Converter System: The full converter system is a more advanced topology used in large wind turbines. The full converter system uses a full-scale power converter

to control both the rotor and stator currents. The full converter system allows for better control of the generator's speed and torque, and enables maximum power extraction from the wind turbine. The full converter system also allows for better grid compatibility and reduces the impact of grid disturbances on the wind turbine. Several control strategies have been proposed for full converter systems, such as proportional integral control, sliding mode control, and model predictive control.

Control Systems for Wind Energy Conversion Systems:

The control system is responsible for monitoring the wind turbine's operating conditions and adjusting the power converter's operation to achieve maximum power extraction. The control system should be designed to operate under varying wind conditions and ensure stable and reliable operation of the wind turbine. Several control strategies have been proposed and used in WECS. The most common control strategies

1.3 Problem Statement

"To extract maximum power by using Power converter and control of wind energy conversion system"

• Optimal power extraction from wind energy conversion systems (WECSs) is achieved through the regulation of the rotational speed of the wind turbine.

• The suggested controller for maximum power extraction exhibits a straightforward design, cost-effectiveness, and robust performance in response to changes in wind speed.

• The proposed approach enables the extraction of a greater maximum power output while exhibiting enhanced overall efficiency.

1.4 Objectives of the Study

Th objectives of the proposed works are mentioned as follow

- To extract maximum power.
  Achieving maximum power extraction from a wind energy conversion system necessitates the careful design and implementation of a highly efficient power converter and control system. These components serve a critical function in regulating the power output of the wind turbine and optimizing the overall energy conversion process. The primary objective is to maintain the wind turbine operating at the maximum power point, where the power output is at its peak for a specific wind speed and turbine configuration.

- To achieve better efficiency.
  To achieve better efficiency in a wind energy conversion system, various factors need to be considered, including the aerodynamics of the wind turbine, the mechanical design, and the power converter and control system.The mechanical design of the wind turbine is also crucial in achieving better efficiency. The mechanical design should be optimized to reduce the weight of the turbine and minimize the number of moving parts. The fewer moving parts, the less friction and wear and tear, resulting in improved efficiency and reduced maintenance costs. The tower's height is also critical in improving the turbine's efficiency, as it allows the turbine to capture higher wind speeds, which translates to higher energy output.

- To minimize the harmonics.
  Harmonics in a wind energy conversion system can be a significant issue that affects the system's performance and the quality of the electrical power generated. Harmonics are caused by non-linear loads such as power electronics, and their presence can cause distortions in the voltage and current waveforms, resulting in increased losses and decreased power quality.To minimize harmonics in a wind energy conversion system, several techniques can be employed. One of the most common techniques is the use of harmonic filters. A harmonic filter is an electronic device that is designed to attenuate harmonics in the power system. It is typically composed of a series of capacitors and inductors that create a resonant circuit at the harmonic frequency, effectively filtering out the unwanted harmonic component.

- To stabilize the output.
  Ensuring the stability and reliability of a wind energy conversion system necessitates the effective stabilization of its output. The stability of the output is influenced by various factors, such as wind speed, changes in wind direction, and system load. Multiple techniques can be employed to achieve output stabilization, one of which is the employment of Maximum Power Point Tracking (MPPT) within the control system. MPPT enables the tracking of the wind turbine's maximum power point, which is the operating point where the turbine generates the highest power output for a given wind speed. By continuously tracking the maximum power point, the control system can make necessary adjustments to the pitch angle and torque of the wind turbine, thereby maintaining a consistent power output.

- To automate the system based on availability of sufficient energy either from wind or grid.
  Implementing an automated control system in a wind energy conversion system is crucial to enable efficient and optimal operation, particularly by adapting to the availability of energy from either the wind or the grid. The automation system should possess the capability to seamlessly transition between different modes of operation, depending on the availability of energy sources. In the grid-connected mode, the wind energy conversion system is connected to the electrical grid, and its power output is synchronized with the grid's voltage and frequency. The automation system must effectively monitor the voltage and frequency of the grid and regulate the power output of the wind turbine accordingly, ensuring alignment with the grid's requirements.

1.5 Scope of the Study

Wind energy has become one of the most promising renewable energy sources due to its abundance, cost-effectiveness, and eco-friendliness. Wind energy conversion systems (WECS) are designed to harness the kinetic energy of wind and convert it into electrical energy. The performance of a WECS depends largely on the efficiency of the power converter and control system. The power converter is responsible for extracting the maximum power from the wind turbine, while the control system is responsible for ensuring stable operation and grid integration. Therefore, the scope of this study is to design, develop, and evaluate a robust and efficient power converter and control system for wind energy conversion systems to maximize power extraction and ensure reliable grid integration.

1. Analysis and Modeling of Wind Turbines:

   The first step in the development of a WECS is the analysis and modeling of the wind turbine. Different types of wind turbines are available, including horizontal axis wind turbines (HAWT) and vertical axis wind turbines (VAWT). HAWTs are the most commonly used wind turbines and have a higher efficiency compared to VAWTs. The analysis and modeling of the wind turbine involve the study of different components, such as blades, hub, gearbox, generator, and power electronics.

   The blades are responsible for capturing the kinetic energy of the wind and converting it into rotational energy. The blade design depends on various factors, such as the wind speed, wind direction, blade length, and rotor diameter. The hub is responsible for connecting the blades to the shaft and transferring the rotational energy to the gearbox. The gearbox is responsible for increasing the rotational speed of the generator to match the grid frequency. The generator converts the rotational energy into electrical energy. Finally, the power electronics are responsible for controlling the power flow and voltage regulation.

2. Power Converter Topologies:

   The power converter topology employed in a wind energy conversion system (WECS) significantly impacts its efficiency and reliability. Among the commonly utilized power converter topologies are the voltage source inverter (VSI) and the current source inverter (CSI). The VSI is widely preferred due to its high efficiency and straightforward control mechanism. It converts the DC voltage generated by the wind turbine into an adjustable AC voltage that corresponds to the grid frequency. On the contrary, the CSI exhibits lower efficiency but offers improved fault tolerance, making it suitable for high-power applications.

   Another important aspect of power converter topologies is the use of power semiconductor devices, such as MOSFETs, IGBTs, and thyristors. These devices play a critical role in the performance of the power converter. The selection of the right device depends on various factors, such as the power rating, switching frequency, and cost.

3. Control Strategies:

   The control system is responsible for ensuring stable operation and maximizing power extraction. The control system consists of various controllers, such as the pitch controller, yaw controller, and MPPT controller. The pitch controller is responsible for adjusting the pitch angle of the blades to maintain a constant rotational speed and prevent overloading. The yaw controller is responsible for adjusting the yaw angle of the turbine to ensure that the blades face the wind direction.

   The MPPT (Maximum Power Point Tracking) controller plays a critical role in maximizing power extraction from the wind turbine. It accomplishes this by dynamically adjusting the rotor speed and pitch angle to ensure that the turbine operates at the optimum point known as the maximum power point (MPP). The MPP is influenced by multiple factors, including wind speed, temperature, and blade angle. To track the MPP accurately, the MPPT controller employs different algorithms, such as perturb and observe (P and O) and incremental conductance (INC), which continuously monitor and adjust the turbine's operating parameters.

4. Simulation and Experimental Studies:

   Simulation and experimental studies play a crucial role in the development and optimization of the WECS. The simulation tools, such as MATLAB/Simulink and PSCAD, are widely used to model and simulate the WECS.

1.6 Organization of the Report

The project report is oraganized as follow:
Chapter 1 provides the information regarding introduction of area, need, relevance, problem statement, objectives and scope of the study. Further, it provides a short overview of the proposed system.

Chapter 2 gives survey of various articles on the and provides the major gaps that paves the way for the development of proposed system.

Chapter 3 In chapter 3 we put a detailed methodology of the proposed system and block diagram, circuit diagram, flowchart and algorithm etc.

Chapter 4 It gives the detailed information of hardware setup and its specifications along with results and discussion of the proposed system.

Chapter 5 In this chapter we discuss the some advantages and applications of proposed system.

Chapter 6 It gives the overall conclusion of system with proposed model of maximum power extraction. it also provides the future scope of the system.

Chapter 7 It gives the references used for the project and report.

Chapter 2

Literature Review

2.1 Literature Survey

Ali. M.Eltamaly [1] The research has presented two distinct wind energy conversion systems that utilize tracking algorithms for maximum power point tracking (MPPT). In the first scheme, a permanent magnet synchronous generator is employed, and the wind turbine (WT) is connected to the grid through a back-to-back PWM-VSC (Voltage Source Converter). On the other hand, in the second scheme, the WT is connected to the grid through a diode bridge rectifier, with an improved converter and a border PWM-VSC configuration.

Syed Naime Mohammed,Nipu kumar das and Saipat Roy [2] Over the years, a range of power converter topologies, from basic converters for turbine startup to advanced configurations, have been employed in wind energy systems. Energy plays a fundamental role in the advancement of society, serving as a key pillar for progress. The production and utilization of energy have been ongoing for many years worldwide. However, it is important to acknowledge that the world is currently grappling with a significant energy crisis despite the availability of numerous energy sources.

Lu Jiang Daming Jhang [3] Various control strategies for DC-DC converters have been implemented in distributed renewable energy systems to address energy shortages and environmental crises. These strategies involve the utilization of double-loop controls, where one loop focuses on voltage in the outer loop and current in the inner loop. The performance and effectiveness of these control strategies have been compared and evaluated.

Meyasam yousefzade ShahiHedayati Kia, Davood arab khaburi [4] The study involved the implementation and assessment of a system comprising a permanent magnet synchronous generator (PMSG) and a rectifier. This system incorporated a boost converter, wind turbine blades, and PMSG, along with a bridge diode rectifier. The models of these components were utilized in real-time simulations, enabling the evaluation of the wind turbine's performance. The primary objective of this study was to facilitate real-time analysis of the wind turbine system, particularly focusing on the passive power converters on the generator side.

Mrs.A,Santhi mary antony, Dr Godwin Immanual [5] The implementation of the bootstrap converter topology involves the replacement of the DC link capacitor positioned between the diode link rectifier and the voltage source inverter. The main purpose of the

DC link capacitor is to mitigate voltage ripple from the rectifier's output and provide a steady, modulated input voltage to the voltage source inverter. This particular topology offers the advantage of a bootstrap converter for grid-connected wind energy converter units.

M.S. Hosaain Lipu, MD Sazal Miah, Hanisf MD Saad, MD.Sultan Mahmud[6]Hybrid approaches utilizing Artificial Intelligence (AI) for wind power forecasting have gained significant attention. These approaches aim to enhance the accuracy and reliability of forecasting by combining multiple methods and techniques. It is essential to thoroughly analyze the classification structure, strengths, weaknesses, and performance of these hybrid approaches. Accurate wind power forecasting plays a vital role in ensuring the stability and dependable operation of the power grid. However, the unpredictable and variable nature of wind power poses challenges and can have adverse effects on grid operations.

Alper nabi akpolat, Erkan dursan, Ahmet emin kuzucuoglu[7]To achieve stability, reliability, and efficiency, the adoption of a deep learning aided-sensorless control approach has been implemented. This approach offers several advantages, including high accuracy by utilizing real datasets without the need for generating artificial data. Additionally, deep learning techniques have overcome various key challenges and have made significant advancements in terms of their compatibility with real-world application data.

Alireza Khosravi, Abdollah Khosravi, and Hamid Reza Karshenas (2013)[8]The authors provide a comprehensive review of control strategies for wind turbine systems, including both fixed-speed and variable-speed wind turbines. They categorize the control strategies into four main categories: aerodynamic control, electrical control, mechanical control, and integrated control. The review covers both classical control techniques and advanced control methods such as neural networks, fuzzy logic, and genetic algorithms.

D. M. Vilathgamuwa, V. G. Agelidis, and S. K. Islam (2013)[9]This paper provides an extensive review of power converter topologies for wind energy systems. The authors discuss various types of converters, including AC-DC, DC-DC, and DC-AC converters. They compare the advantages and disadvantages of different topologies, and evaluate their performance in terms of efficiency, power quality, and reliability. The paper also highlights the importance of power electronics in wind energy systems, and discusses the challenges in designing and implementing converters for this application.

Jie Yang, Weijie Zhang, and Shaohua Yang (2013)[10]This paper presents a review of maximum power point tracking (MPPT) techniques for wind energy systems. The authors discuss various MPPT algorithms such as hill-climbing, perturbation and observation, incremental conductance, and particle swarm optimization. They evaluate the performance of these algorithms in terms of tracking accuracy, convergence speed, and robustness. The paper also discusses the impact of wind turbine characteristics such as turbulence, intermittency, and partial shading on MPPT performance.

Chau Thanh Ngo, Duc Thien Nguyen, and Binh Duc Tran (2015)[11]The authors provide a review of reactive power control strategies for wind energy conversion systems. They discuss the importance of reactive power control in maintaining power quality and stability of the power grid. The paper covers various control strategies such as static VAR compensation, synchronous condenser, and STATCOM. The authors evaluate the effectiveness of these strategies in mitigating voltage fluctuations, enhancing power factor, and improving transient stability.

Jianfei Wang, Honghua Xu, and Haibo He (2015)[12]This paper presents a review of pitch angle control strategies for wind energy conversion systems. The authors discuss the importance of pitch angle control in regulating the power output and improving the stability of wind turbines. They evaluate various pitch control strategies such as proportional-integral-derivative (PID) control, adaptive control, and model predictive control. The paper also highlights the challenges in pitch angle control, such as wind gusts, tower shadow, and turbine fatigue.

Prabha Kundur, Kankar Bhattacharya, and Siddharth Joshi (2012)[13]This paper provides an overview of grid integration of wind energy conversion systems. The authors discuss the challenges in integrating wind energy into the power grid, including voltage and frequency regulation, power quality, and grid stability. The paper covers various grid integration techniques such as grid code compliance, advanced control methods, and energy storage systems. The authors also discuss the future trends and opportunities in wind energy grid integration, such as demand response.

2.2 Finding from Literature Survey

From the research papers we found that the old system is costly and difficulties in practical implementations are due to wind speed measurement.

- The reliability of a wind turbine is critical to extracting the maximum amount energy.The reliability of a wind turbine is a critical factor in extracting the maximum amount of energy from the wind. A wind turbine's reliability refers to its ability to function continuously and efficiently over a long period of time, even under harsh weather conditions. The reliability of a wind turbine depends on several factors, including the design of the turbine, the materials used in its construction, and the maintenance practices employed by the operators.

- The main drawback in the topology is higher requirements of the inductor.One of the drawbacks of certain power converter topologies is that they require relatively large inductors. The inductor size is primarily determined by the converter's switching frequency and the amount of power that needs to be transferred. The higher the switching frequency and the power level, the larger the required inductor.

- Lower efficiency, higher implementation cost, more complicated and lower reliability.Lower efficiency is a common drawback of many power electronics topologies, especially when they are operated at high frequencies or under partial load conditions. For instance, in some DC-DC converters, such as the buck-boost topology, the conversion efficiency can be lower than other topologies such as the buck or boost converters due to the additional power losses and voltage stresses on the components. This lower efficiency can lead to increased power consumption, higher operating costs, and reduced system lifetime.

- Power converters are used to convert the variable AC voltage and frequency output of the wind turbine generator into a fixed DC voltage and frequency, which can be connected to the grid. The most commonly used power converters are the back-to-back converters, which can provide reactive power support to the grid, and the full-scale converters, which can provide a variable voltage and frequency output to the grid.

- The integration of energy storage systems such as batteries and supercapacitors with wind energy conversion systems can also help to improve the power extraction efficiency. These systems can store excess energy generated by the wind turbine during periods of low demand and release it during periods of high demand, thus improving the overall efficiency of the system.

- And we found some point that we need to work on, for overcome the challenges:

  1. The Harmonics should be minimized.
     Harmonics are unwanted electrical signals that occur when the frequency of an AC waveform is a multiple of the fundamental frequency. In power electronics, harmonics can be generated by various components such as diodes, transistors, and capacitors, and they can have negative effects on the power system, including reducing power quality and causing damage to equipment.
  2. Mmaximum power extraction should be done.
     In a wind energy conversion system (WECS), maximum power extraction refers to the process of extracting the maximum amount of energy from the wind by controlling the rotational speed and torque of the wind turbine. The main objective of maximum power extraction is to optimize the power output of the wind turbine, which in turn increases the efficiency of the entire WECS.
  3. The output should be stabilized.
     In a wind energy conversion system (WECS), stabilizing the output refers to maintaining a constant output voltage and frequency despite fluctuations in the wind speed and other factors that affect the power output of the wind turbine. A stable output is essential for ensuring the efficient operation of the WECS and for ensuring that the generated power can be safely and reliably integrated into the grid.

Chapter 3

Proposed Methodolgy

3.1 Proposed System

The proposed wind energy conversion system involves the utilization of a power converter and control system to efficiently convert and regulate the power output of the wind turbine. The power converter is responsible for converting the variable voltage, variable frequency AC signal generated by the wind turbine into a fixed voltage, fixed frequency AC signal compatible with the electrical grid.

Pulse Width Modulation (PWM) techniques play a crucial role in controlling the power converter. PWM involves adjusting the duty cycle of a pulse train to control the average value of the signal. In the context of the power converter, PWM is employed to regulate the power transfer from the wind turbine to the electrical grid.

The control system employs real-time feedback from the wind turbine to dynamically adjust the PWM signal. By monitoring the turbine's performance, the control system can optimize the duty cycle of the PWM signal, ensuring that the wind turbine operates at its maximum power point. This approach allows for the extraction of the highest possible power output given the prevailing wind conditions.

Overall, the proposed system utilizing PWM techniques for wind energy conversion offers an efficient and effective means of harnessing maximum power from wind energy. Its versatility makes it suitable for various applications, ranging from small residential wind turbines to large-scale commercial wind farms.

The power converter, a vital component of the wind energy conversion system, plays a critical role in converting the wind turbine's output into a usable form for the electrical grid. Typically, it consists of a three-phase, full-wave bridge rectifier, a DC-DC boost converter, and an inverter. The rectifier converts the variable voltage, variable frequency AC signal to a DC signal. The DC-DC boost converter increases the DC voltage to the desired level for the inverter. Finally, the inverter converts the DC signal into a fixed voltage, fixed frequency AC signal that synchronizes with the electrical grid.

To maximize power output, the control system employs two main techniques: Maximum Power Point Tracking (MPPT) and PWM techniques. MPPT is utilized to track and maintain the wind turbine's operation at the maximum power point, where it operates with optimal efficiency and generates the highest power output. PWM techniques are employed to regulate the power converter, ensuring it operates efficiently and maximizes power production.

By combining MPPT and PWM techniques, the proposed system optimizes the energy conversion process, facilitating efficient power extraction from wind energy sources. It is adaptable to various scenarios, making it suitable for diverse wind energy applications.

3.2 Key Technologies

- Generator

  A wind energy conversion system (WECS) comprises essential components such as a wind turbine, a generator, a power electronics converter, and a control system. The generator within the WECS plays a vital role in converting the kinetic energy from the wind into usable electrical energy. To ensure optimal power extraction from the wind, it is crucial for the generator to operate at its maximum power point (MPP). The MPP of the generator is influenced by wind speed and continuously shifts with changing conditions.

  To extract maximum power from the wind, a control system is used to adjust the electrical load on the generator to maintain the generator operating point at the MPP. The control system uses a feedback loop to continuously measure the output voltage and current of the generator and adjust the load to maintain the operating point at the MPP.

  There are several types of generators used in WECS, including synchronous generators, induction generators, and permanent magnet generators. Each type of generator has its own advantages and disadvantages.

  Synchronous generators are typically used in large wind turbines because they are highly efficient and can produce a high amount of power. However, they require a power electronics converter to adjust the frequency and voltage of the electrical output to match the grid.

  Induction generators are commonly used in smaller wind turbines because they are less expensive and require less maintenance than synchronous generators. However, they require a reactive power compensation system to maintain a constant voltage at the generator output.

  Permanent magnet generators are becoming increasingly popular in small to medium-sized wind turbines because they are highly efficient, have a simple structure, and require little maintenance. They are also capable of producing a high amount of power, but they can be more expensive than induction generators.

  In summary, The generator within a wind energy conversion system (WECS) plays a critical role in converting the kinetic energy of the wind into usable electrical energy. To achieve maximum power extraction from the wind, a control system is employed to continuously adjust the electrical load on the generator, ensuring that its operating point remains at the maximum power point (MPP). The specific type of generator utilized in a WECS is determined by various factors, including the size of the turbine, efficiency considerations, cost considerations, and maintenance requirements.

- Power Converter

  A power converter is an essential component of a wind energy conversion system (WECS) that enables the conversion of electrical power produced by the generator to a form suitable for use in the power grid. The power converter also plays a critical role in maximizing the power output from the WECS by continuously adjusting the electrical load on the generator to maintain it at its maximum power point (MPP).

In a wind energy conversion system (WECS), the power converter plays a crucial role and is commonly implemented using power electronics technology. It consists of three main components: a rectifier, a DC-DC converter, and an inverter. The rectifier is responsible for converting the alternating current (AC) generated by the wind turbine's generator into direct current (DC). Following the rectification process, the DC-DC converter is employed to regulate and adjust the DC voltage to a level that is suitable for the subsequent stage. Finally, the inverter takes the regulated DC voltage and converts it back into AC, which is then fed into the power grid.

The power converter also includes a control system that uses feedback from the generator to adjust the electrical load on the generator to maintain it at the MPP. The control system continuously measures the electrical output of the generator and adjusts the load to maintain the generator operating point at the MPP.

One important aspect of power converter design is to minimize the losses in the conversion process, which can reduce the overall efficiency of the WECS. Losses in the power converter can result from several factors, including the switching losses in the power electronics devices, the resistive losses in the converter components, and the losses due to harmonic distortion.

To minimize losses, power converters in WECS are designed with high-efficiency devices used in power electronics, including insulated-gate bipolar transistors (IGBTs), which have low switching losses. The converter components are also designed with low resistance to reduce resistive losses. The power converter is also designed to minimize harmonic distortion by filtering out unwanted harmonic components.

In summary, the power converter in a WECS is responsible for converting the electrical power produced by the generator into a form suitable for use in the power grid. The power converter also plays a critical role in maximizing the power output from the WECS by continuously adjusting the electrical load on the generator to maintain it at the MPP. To maximize efficiency and minimize losses, power converters are designed with high-efficiency power electronics devices, low-resistance components, and harmonic filters.

- PWM Techniques
  Power converters and their associated topologies are continuously expanding with advancements in semiconductor technology. The voltage and current ratings of power converters have increased thanks to recent improvements in semiconductor technology, which have also improved their switching properties. Modern power converters primarily operate in switch mode, which allows for great efficiency, low weight, small dimensions, quick operation, and high power densities. Power converter systems use the fundamental energy processing method known as pulse width modulation (PWM). PWM approaches can range from a few kHz (motor control) to several MHz (resonant converters for power supply) depending on the rated power. PWM techniques are always changing and getting better as new technologies are created.

  1. Sinusoidal pulse width modulation (SPWM)
     To get the most power out of the wind, a wind energy conversion system

(WECS) uses Sinusoidal Pulse Width Modulation (SPWM), a modulation technique. Using the SPWM approach, the output voltage waveform's amplitude and frequency are controlled by modulating the pulse's width. The SPWM technique is used to generate a sinusoidal waveform that matches the grid voltage waveform, which is required for connecting the WECS to the power grid.

By altering the pulse width of the voltage waveform in SPWM, the amplitude and frequency of the output voltage waveform are regulated. A comparator, which contrasts a triangular carrier signal with a sinusoidal reference signal, regulates the pulse width. The reference signal is generated by a voltage controller, which adjusts the reference signal to maintain the generator operating point at the maximum power point (MPP).

The triangular carrier signal is generated by a sawtooth generator and is used to generate the switching signal for the power electronics devices in the power converter. The switching signal is used to switch the power electronics devices on and off to generate the desired output waveform.

The SPWM technique provides several advantages in WECS. It enables the power converter to generate a sinusoidal output waveform that matches the grid voltage waveform, which lowers harmonic distortion and raises the output's power quality. SPWM also enables the power converter to operate at high efficiency by minimizing the switching losses in the power electronics devices.

However, SPWM also has some limitations. One limitation is that it requires a high switching frequency, which can result in high electromagnetic interference (EMI) noise. Another limitation is that it requires a high-precision voltage controller, which can be complex and expensive.

In summary, To get the most power out of the wind, a wind energy conversion system (WECS) uses Sinusoidal Pulse Width Modulation (SPWM), a modulation technique. The output voltage waveform's amplitude and frequency are controlled by SPWM by modulating the pulse's width. The advantages of SPWM include reduced harmonic distortion, improved power quality, and high efficiency. The limitations of SPWM include high EMI noise and the need for a high-precision voltage controller.

Utilising a digital controller, the DSPic33FJ64MC802 implements the sinusoidal PWM approach. On a supply voltage of 3.3 VDC, this controller can function. Its overall full scale count is 210 = 1024 because it features a 10 bit (Analogue to Digital conversion) ADC. This indicates that 3.3V to the ADC controller pin for an analogue input produces 1024 counts. This value is taken into account as 2.5V for the implementation. Using the series connection of the step down transformer and precision rectifier depicted in Fig., the output AC voltage is converted to its linear DC value.

2. Continuous switching pulse width modulation(CSPWM)
   This scheme is somewhat similar to the hysteresis controller, only difference is that hysteresis band is used for current controlling whereas continuous switching is used here for the voltage control. When the power is ON, the output voltage of a passive boost converter is equal to the passive voltage (1.414 times the input voltage). Duty cycle must be constantly increased until target

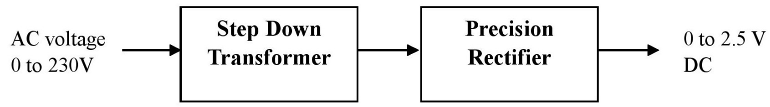


Figure 3.1: output AC voltage conversion to linear DC value

voltage is reached in order to produce desired boost voltage. The duty cycle stays constant till it reaches the optimum boost voltage level. There is a band that shows the upper and lower threshold values. The output DC link voltage changes depending on the load current and line voltage. The duty cycle starts to increase until the target voltage is reached when it hits the lower threshold, and it starts to decrease when it reaches the upper threshold. The above mentioned scheme is represent using Fig. Continuous Switching Pulse Width

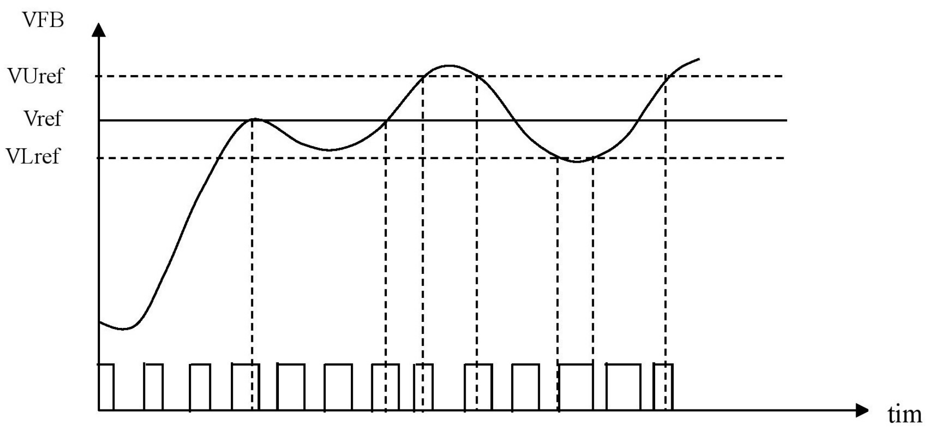


Figure 3.2: Continuous switching PWM scheme

Modulation (CSPWM) is another modulation technique used in the power converter of a wind energy conversion system (WECS) to extract maximum power from the wind. CSPWM is a technique that modulates the pulse width of the voltage waveform in a continuous manner to control the amplitude and frequency of the output voltage waveform. CSPWM is a popular modulation technique in WECS because it provides good output voltage waveform quality and is relatively simple to implement.

In CSPWM, the pulse width of the output voltage waveform is continuously adjusted by a controller that uses feedback from the generator to maintain the generator operating point at the maximum power point (MPP). The controller adjusts the pulse width by comparing the output voltage of the power converter with a reference voltage. The difference between the output voltage and the reference voltage is used to adjust the pulse width of the output voltage waveform.

The switching signal for the power electronics devices in the power converter is generated using a high-frequency carrier signal and a modulation signal. The carrier signal is typically a high-frequency sawtooth waveform, and the modulation signal is the adjusted pulse width waveform. The switching signal is used to switch the power electronics devices on and off to generate the desired output voltage waveform.

CSPWM provides several advantages in WECS. It enables the power converter to generate a continuous output voltage waveform that is free of harmonic distortion, which improves the power quality of the output. CSPWM also provides good efficiency at low switching frequencies, which reduces electromagnetic interference (EMI) noise and improves the reliability of the power converter.

However, CSPWM also has some limitations. One limitation is that it requires a high-precision voltage controller, which can be complex and expensive. Another limitation is that it can result in significant switching losses in the power electronics devices, which can reduce the overall efficiency of the WECS.

In order to maximise the power from the wind, Continuous Switching Pulse Width Modulation (CSPWM), a modulation technique, is employed in the power converter of a wind energy conversion system (WECS). To adjust the amplitude and frequency of the output voltage waveform, CSPWM continuously modulates the pulse width of the voltage waveform. Good output voltage waveform quality and good efficiency at low switching frequencies are two benefits of CSPWM. The requirement for a high-precision voltage controller and potential switching losses in the power electronics components are among the drawbacks of CSPWM.

- Control algorithm

  A key element that enables a wind energy conversion system (WECS) to obtain the most electricity from the wind is the control algorithm. The control algorithm adjusts the pitch angle of the turbine blades and the electrical load on the generator to keep it at the maximum power point (MPP) while continuously monitoring the wind speed, generator speed, and other variables. The WECS's operating point at which it produces the most power for a specific wind speed is known as the MPP.

  The electrical load control algorithm adjusts the electrical load on the generator to maintain it at the MPP. The electrical load is adjusted by the power converter, which adjusts the voltage and frequency of the electrical output from the generator. The electrical load control algorithm adjusts the electrical load by comparing the actual generator power output with the MPP power output, which is calculated based on the wind speed and turbine characteristics.

  The control algorithms used in WECS are typically implemented using a feedback control system, which continuously measures the relevant variables and adjusts the control parameters to maintain the WECS at the MPP. The control parameters include the pitch angle of the turbine blades, the electrical load on the generator, and the switching frequency and duty cycle of the power converter.

  The control algorithm in a WECS must also take into account the dynamics of the system, such as the time delay between the adjustment of the pitch angle and the resulting change in the generator output. To ensure stable and reliable operation of the WECS, the control algorithm must be designed to provide fast and accurate response to changes in wind speed and other variables.

In summary, the control algorithm in a wind energy conversion system (WECS) is responsible for adjusting the pitch angle of the turbine blades and the electrical load on the generator to maintain it at the maximum power point (MPP). The control algorithm continuously measures the relevant variables and adjusts the control parameters to maintain the WECS at the MPP. The control algorithms used in WECS are typically implemented using a feedback control system, which must take into account the dynamics of the system to ensure stable and reliable operation.

3.3 Flow Chart and algorithm

- The first step in starting the working of a wind turbine is to set up the wind turbine generator and its control system. The control system is responsible for measuring the wind speed and direction to determine the optimal positioning of the wind turbine blades to capture the maximum amount of wind energy.The wind speed is measured using an anemometer, which is a device that measures the speed of the wind. An anemometer typically consists of three or four cups that rotate in the wind. The rotation of the cups is measured and converted into wind speed.

- The wind direction is measured using a wind vane, which is a device that determines the direction of the wind. A wind vane typically consists of a flat or arrow-shaped piece of metal that is mounted on a vertical axis. The wind vane rotates in the wind and points in the direction from which the wind is blowing.The control system typically consists of a controller and a power electronics system. The controller is responsible for controlling the position of the wind turbine blades and adjusting the output of the wind turbine generator to maintain a constant voltage and frequency. The power electronics system is responsible for converting the AC output of the wind turbine generator into DC power that can be used to power homes, businesses, and other electrical loads.

- Once the power converter system has been initialized, the next step is to convert the 10 bits of digital data into analog form using a digital-to-analog converter (DAC). The DAC converts the digital data into an analog voltage that can be used to control the power electronics devices in the power converter.

- Following the creation of the analogue voltage, the power electronics components are switched using pulse width modulation (PWM) techniques. PWM is a technique that modifies the pulse width of a square wave signal to regulate the output voltage's amplitude. PWM is used to create a high-frequency square wave in a power converter system, which is then filtered to produce the correct output voltage.

- Multiple pulse width modulation (PWM) techniques are available for utilization in power converter systems, including sinusoidal pulse width modulation (SPWM), space vector modulation (SVM), and selective harmonic elimination (SHE) modulation. Each technique possesses distinct merits and demerits, which are contingent upon the specific application requirements. Once the appropriate PWM technique

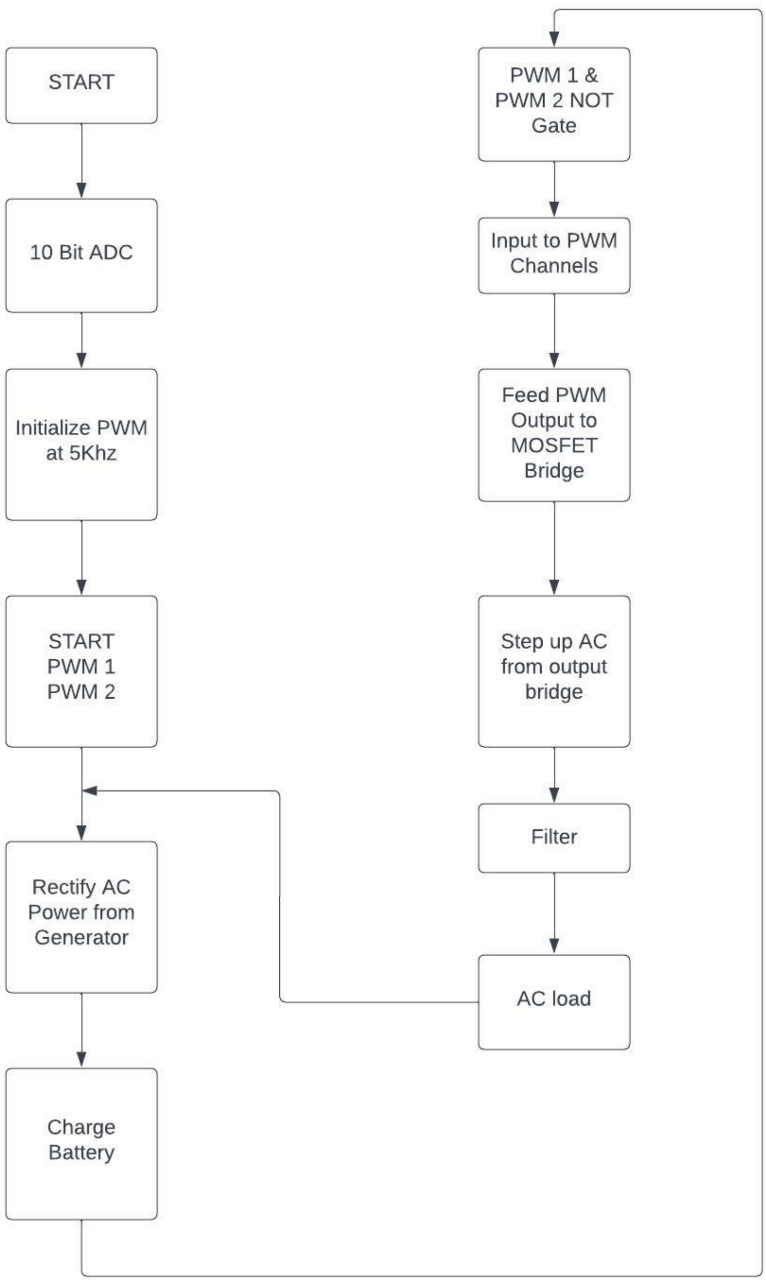


Figure 3.3: Flowchart of proposed system

is chosen, the subsequent task involves configuring the AC/DC converter. The purpose of the AC/DC converter is to convert the generator's alternating current (AC) output into direct current (DC) for charging batteries or injecting into the power grid.

- The AC/DC converter consists of a rectifier circuit, which converts the AC voltage into DC voltage, and a smoothing circuit, which filters out any remaining AC components from the DC voltage. The smoothing circuit typically consists of a capacitor that is connected across the output of the rectifier circuit.To ensure efficient and reliable operation of the AC/DC converter, it is important to select the appropriate rectifier and smoothing circuit components and to ensure that they are properly rated for the expected load conditions. The design of the AC/DC converter should also take into account the requirements of the power grid, such as the voltage and frequency of the AC output.

- Rectification is the process of converting AC voltage into DC voltage. In a WECS, rectification is typically accomplished using a rectifier circuit. A rectifier circuit consists of diodes, which allow current to flow in only one direction, and a transformer, which adjusts the voltage to the desired level. The diodes are arranged in a configuration that allows them to convert the AC voltage into a pulsating DC voltage.once the AC voltage has been rectified, the next step is to store the DC voltage in a battery. The battery acts as a storage device, allowing the electrical energy generated by the wind turbine to be stored and used later, when the demand for electricity is higher.

- To charge a battery from a rectified DC voltage, a charging circuit is typically used. The charging circuit consists of a voltage regulator, which controls the voltage and current going into the battery, and a battery management system, which monitors the battery's charge level and protects it from overcharging or undercharging.the charging circuit must be designed to match the specifications of the battery being used. Different types of batteries have different charging requirements, such as voltage and current limits, and these requirements must be taken into account when designing the charging circuit.

- Once the DC voltage has been stored in the battery, the subsequent stage in a wind energy conversion system (WECS) involves the utilization of pulse width modulation (PWM) channels for controlling the power electronics devices within the inverter circuit. The primary function of the inverter circuit is to convert the DC voltage from the battery into an AC voltage, which can be either supplied to the power grid or utilized to power electrical loads.PWM is a technique employed to manipulate the amplitude of the output voltage by varying the width of the pulse within a square wave signal. In the context of a WECS, PWM is utilized to generate a high-frequency square wave, which is subsequently filtered to produce the desired output voltage

- The PWM signals generated by the microcontroller or DSP are then fed into a MOSFET bridge, which is responsible for inverting the DC voltage from the battery into AC voltage. The MOSFET bridge consists of four or more MOSFET transistors arranged in a bridge configuration. The MOSFET transistors are switched on and off in a specific sequence to produce the desired AC waveform.the output of the

MOSFET bridge is typically fed into a filter circuit, which smooths out the square wave signal to produce a sinusoidal waveform that is suitable for feeding into the power grid or powering electrical loads. The filter circuit typically consists of inductors and capacitors that are carefully designed to filter out unwanted harmonics and ensure that the output waveform is within the desired specifications.

- The step-up AC output bridge consists of a transformer and a rectifier circuit. The transformer is an essential component in the wind energy conversion system (WECS) as it facilitates the increase of voltage level in the AC output obtained from the inverter circuit. Simultaneously, the rectifier circuit is responsible for converting the AC voltage into DC voltage.The functioning of the transformer is based on the fundamental principle of electromagnetic induction. It comprises two coils of wire referred to as the primary and secondary coils. When an AC voltage is applied to the primary coil, it generates a magnetic field, which subsequently induces a voltage in the secondary coil. The magnitude of the induced voltage in the secondary coil is directly proportional to the ratio of the number of turns in the primary and secondary coils.

- The transformer's design allows for precise control of voltage transformation by selecting the appropriate number of turns in the primary and secondary coils. This enables the transformer to step up or step down the voltage level of the AC output generated by the inverter circuit.Following the voltage transformation, the AC voltage is directed to a rectifier circuit, which converts the AC voltage into DC voltage. Typically, the rectifier circuit comprises diodes that facilitate the flow of current in a single direction.

- The resulting DC voltage can then be used to power home appliances or fed into the power grid. However, before it is used, it may need to be further filtered and regulated to ensure that it is stable and within the required specifications.

3.4 Block Diagram

1. Wind turbine
   A wind turbine is an essential component of a wind energy conversion system (WECS) utilized for harnessing the maximum power from wind resources. It comprises three main parts: the rotor, nacelle, and tower. The rotor consists of aerodynamically designed blades responsible for capturing the wind's kinetic energy and converting it into rotational energy. Housed within the nacelle are various components, including the generator, gearbox, and control systems. The tower provides structural support, positioning the rotor and nacelle at an optimal height to maximize wind capture.

   Efficiency is a key consideration when designing wind turbine blades, aiming to maximize the extraction of wind energy. Blades are typically constructed using lightweight materials like fiberglass or carbon fiber, ensuring durability and resilience against adverse weather conditions. Blade lengths can vary significantly, ranging from a few meters to well over 100 meters, depending on the size and capacity of the wind turbine.

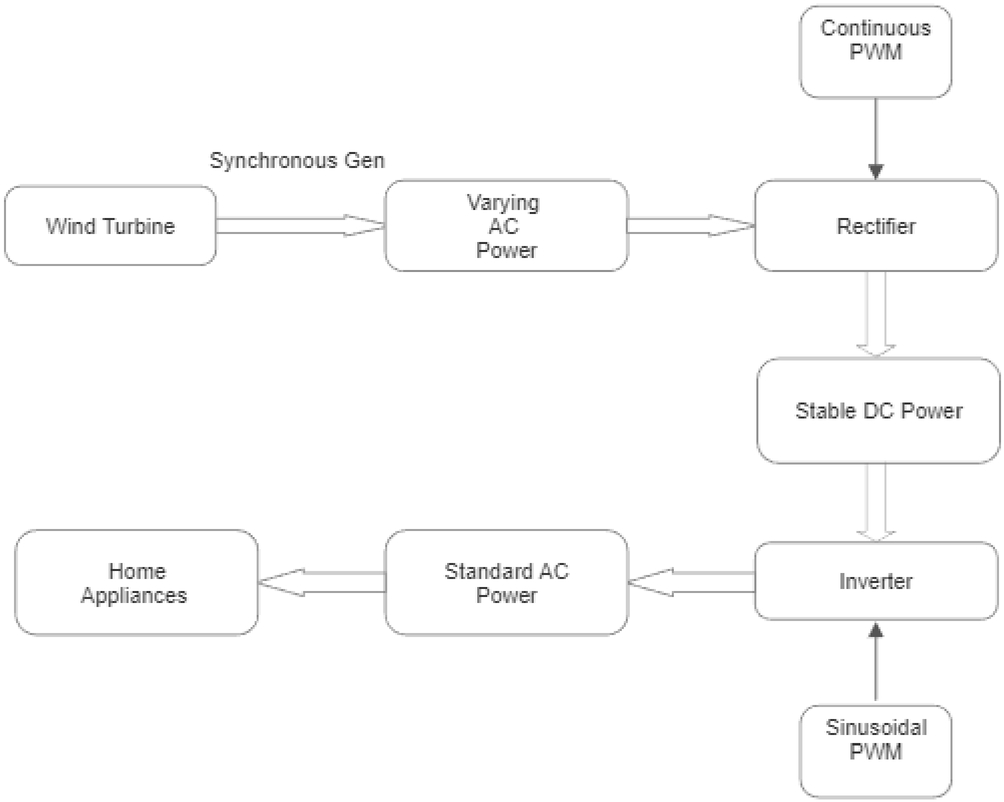


Figure 3.4: Block diagram of proposed system

The wind turbine must be positioned optimally in relation to the direction of the wind in order to generate the most power from it. This is achieved by using a yaw system, which rotates the nacelle and rotor to align them with the wind direction. The yaw system is typically controlled by the WECS control system, which uses measurements from an anemometer and wind vane to determine the direction of the wind.

To maximise the capture of wind energy, the WECS control system also modifies the pitch angle of the wind turbine blades. The tilt of the blades with respect to the plane of rotation is known as the pitch angle. The control system can optimise the quantity of wind energy captured by the blades while also maintaining the wind turbine's security under high wind situations by altering the pitch angle.

2. synchronous generator
   An electrical generator used in wind energy conversion systems (WECS) to harness the most power possible from the wind is known as a synchronous generator. It runs at a constant speed synchronised with the electrical grid's frequency, typically 50 or 60 Hz, and produces electrical power with a sinusoidal waveform.

   The construction of a synchronous generator is similar to that of a conventional generator. It is made up of a stator and a rotor. The stator is a fixed arrangement of electrical wires, whereas the rotor is a rotating electromagnet. A gearbox connects the rotor to the wind turbine, and its rotation produces a magnetic field that interacts with the stator to produce electAn electrical generator used in wind energy conversion systems (WECS) to harness the most power possible from the wind is known as a synchronous generator. It runs at a constant speed synchronised with the electrical grid's frequency.rical power.

   A synchronous generator's rotor consists of a set of electromagnets, which are mounted on a shaft and rotate inside the stator. The electromagnetic field produced by the rotor interacts with the electrical conductors of the stator, inducing an electrical current in the conductors. The speed of the rotor, which is synchronised with the frequency of the electrical grid, controls the frequency of the electrical power generated by the generator.

   The output voltage of a synchronous generator is controlled by adjusting the magnetic field of the rotor. This is achieved by varying the excitation current supplied to the electromagnets. The excitation current can be controlled by a voltage regulator that adjusts the voltage supplied to the rotor, thereby controlling the magnetic field and the output voltage of the generator.

3. Rectifier (MOSFET)
   In a wind energy conversion system (WECS), a rectifier plays a crucial role in converting the alternating current (AC) output of the generator into direct current (DC) suitable for the electrical grid. Various rectifier types are utilized in WECS, and one commonly used type is the MOSFET rectifier. The MOSFET rectifier incorporates metal-oxide-semiconductor field-effect transistors (MOSFETs) as essential components.

   The MOSFET rectifier functions by employing MOSFETs to control the conversion of the generator's AC voltage into a DC voltage. Through the manipulation of a pulse-width modulation (PWM) signal, the MOSFETs are effectively turned on or off for specific durations. By precisely regulating the PWM signal, the MOSFETs facilitate the smooth conversion of the generator's AC voltage into a steady DC voltage with minimal ripple.

The MOSFET rectifier operates in two stages: the first stage is the AC-DC conversion stage, and the second stage is the DC-DC conversion stage. In the AC-DC conversion stage, the MOSFETs are used to rectify the AC voltage of the generator into a DC voltage. The PWM signal is applied to the MOSFETs, which switch the AC voltage into a series of pulses. The pulses are then filtered by a capacitor and inductor to produce a smooth DC voltage with minimal ripple.

The smooth DC voltage is further adjusted to match the voltage of the electrical grid during the DC-DC conversion stage. A DC-DC converter is used for this, which modifies the output voltage to match the grid voltage. A maximum power point tracking (MPPT) system, which modifies the load on the generator to maximise output power, may also be included in the DC-DC converter.

4. DC Power supply

   A wind energy conversion system (WECS) needs a DC power supply since it is responsible for giving the system a consistent and dependable source of DC power. A WECS normally uses its DC power source to run its control system, sensors, and other auxiliary equipment.

   A DC-DC converter or an AC-DC converter can be used as the DC power source in a WECS. A DC-DC converter is used to transform the DC voltage from the generator into a voltage suitable for the control system and other auxiliary systems, whereas an AC-DC converter is used to transform the AC power from the generator or the electrical grid into DC power.

   The AC-DC converter is an integral part of wind energy conversion systems (WECS) that are designed to be connected to the electrical grid. In such systems, the AC power obtained from the grid undergoes rectification using a diode rectifier, followed by filtration using a capacitor to ensure a steady DC voltage. To ensure stability and consistency, a voltage regulator is employed to regulate the DC voltage and provide a reliable source of direct current.

   Conversely, the DC-DC converter finds application in standalone WECS or those not connected to the electrical grid. In these systems, the DC voltage generated by the wind turbine is rectified utilizing a diode rectifier, and subsequently filtered using a capacitor to smoothen out any voltage ripples. To guarantee a stable and constant DC power output, a DC-DC converter is employed to regulate the DC voltage and maintain a consistent power supply.

   The DC power supply in a WECS should be designed to be reliable and efficient to ensure that the control system and other auxiliary systems are powered at all times. It should also be designed to withstand the harsh environmental conditions that are typical of wind energy applications, such as high wind speeds, temperature variations, and humidity.

5. Inverter

   A wind energy conversion system's (WECS') inverter is a crucial part because it transforms the wind turbine generator's DC output into AC power that may be used by the electrical grid or the end user. By ensuring that the output power of the system matches the needed voltage and frequency of the electrical grid or the end-user, inverters play a crucial role in maximising power extraction in WECS.

Pulse-width modulation (PWM) is the underlying principle that underlies the operation of the inverter in a WECS. The wind turbine generator's DC electricity is first rectified with a diode rectifier and then filtered with a capacitor to create a steady DC voltage. The DC voltage is then fed into the inverter, which uses PWM to convert the DC voltage into a variable-frequency AC voltage.

The PWM technique involves switching the voltage waveform between a high and a low voltage at a specific frequency, known as the carrier frequency. The width of the pulses is varied based on the amplitude of the DC voltage to produce an AC waveform that closely matches the desired output waveform. The frequency of the output waveform is also varied to match the frequency of the electrical grid or the end-user.

Inverters used in WECS are typically designed to be grid-connected or standalone. Grid-connected inverters are used to convert the DC power generated by the wind turbine generator into AC power that is synchronized with the electrical grid. These inverters must comply with the grid codes and regulations to ensure the stability and reliability of the electrical grid.

Standalone inverters, on the other hand, are used in WECS that are not connected to the electrical grid. These inverters are designed to provide a stable and reliable source of AC power to the end-user or the off-grid system. They may incorporate battery storage and other control systems to ensure the stability and reliability of the system.

6. AC power supply(stable)
   AC power supply is a critical component in a method for converting wind energy ensures stable and reliable power output to the electrical grid or end-user. The stability and reliability of the AC power supply are essential for maximizing power extraction from the WECS and ensuring the safety and stability of the electrical grid.

   The AC power supply in a WECS is typically designed to operate in one of two modes: either in grid-connected or stand-alone mode. When linked to the grid, the AC power supply must comply with the grid codes and regulations to ensure that the power output is stable and reliable, and the electrical grid remains stable and secure. In standalone mode, the AC power supply must be designed to provide stable and reliable power output to the end-user or off-grid system.

   In a grid-connected mode, the AC power supply is typically a transformer-based system that steps up the voltage of the output power to match the voltage of the electrical grid. The AC power supply may also include power conditioning systems, such as filters and voltage regulators, to ensure that the output power is stable and free of harmonic distortion. The output power is also monitored and controlled by a control system to ensure that it meets the required voltage, frequency, and power factor requirements of the electrical grid.

   In a standalone mode, the AC power supply may be a simpler system that does not require compliance with the grid codes and regulations. The AC power supply may include battery storage systems to ensure a stable and reliable power output during periods of low wind speed or system downtime. The output power may also be monitored and controlled by a control system to ensure that it meets the required voltage, frequency, and power factor requirements of the end-user or off-grid system.

7. Home appliances
   Depending on the size of the system and the power needs of the appliances, a wind energy conversion system (WECS) can be used to power a variety of home appliances.

   To power home appliances with a WECS, the system must be designed and sized to meet the power requirements of the appliances. The size of the system will depend on the power consumption of the appliances, the duration of use, and the wind resource at the installation site. A WECS may also require a battery storage system to supply energy during times of low wind speed or system downtime.

   In addition to powering individual appliances, a WECS can also be used to power a home's electrical system.The system can be connected to the electrical grid, and through net metering programmes, extra electricity generated by the system can be sold back to the utility provider. This can provide additional revenue for the system owner and help to offset the cost of the system installation.

   In summary, a WECS can be used to power various home appliances, including lighting, refrigeration, air conditioning, water heating, and cooking. The system must be designed and sized to meet the power requirements of the appliances, and a battery storage system may be requiredto supply energy during times of low wind speed or system downtime. A WECS can also be connected to the electrical grid and generate revenue through net metering programs.

3.5 Circuit Diagram

1. Rotor: The windmill generator consists of a rotor, which is associated with wind turbine blades. As the wind blows, it causes the rotor to rotate.

2. Stator: The stator, a part of the generator that is stationary, is located around the rotor. A number of wire windings organised in a certain configuration make up the stator.

3. Magnetic Field: A number of electromagnets or permanent magnets are present in the rotor. The rotor produces a revolving magnetic field as it rotates.

4. Electromagnetic Induction: The circular magnetic field induces a voltage in the wire windings of the stator through the principle of electromagnetic induction. This voltage induces an alternating current (AC) in the stator windings.

5. Synchronization: The AC voltage generated in the stator windings must be synchronized with the frequency and voltage of the electrical grid or the load it is connected to. Synchronization ensures that the generator is operating in harmony with the rest of the electrical system.

6. Excitation: To maintain a stable voltage output, synchronous generators require an excitation system. This system supplies direct current (DC) to the rotor windings, either through permanent magnets or by using a separate DC power source. The

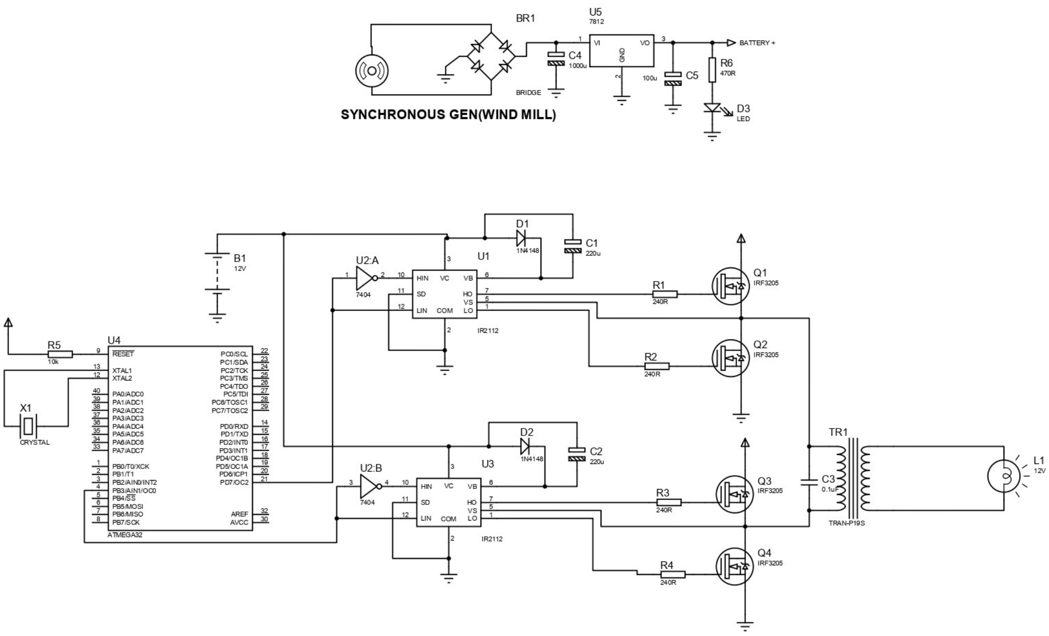


Figure 3.5: Circuit diagram of proposed system

excitation current creates a magnetic field in the rotor that remains synchronized with the rotating magnetic field generated by the wind.

7. Voltage Regulation: The excitation system also allows for voltage regulation. By adjusting the excitation current, the generator can regulate its output voltage and respond to changes in the electrical load.

8. Power Output: The synchronized AC voltage produced by the stator windings is then transferred to the electrical grid or connected to a load, where it can power various devices and systems.

9. Atmega32 Microcontroller: The Atmega32 microcontroller is responsible for controlling the operation of the inverter. It generates the control signals and PWM (Pulse Width Modulation) signals required for producing a pure sine wave output.

10. IR2110 Driver: The IR2110 is a high and low side driver that amplifies and buffers the PWM signals generated by the Atmega32. It provides the necessary voltage and current levels to drive the IRF3205 MOSFETs.

11. IRF3205 MOSFET: The IRF3205 is a power MOSFET used as a switch in the inverter circuit. The MOSFETs are driven by the IR2110 and are responsible for switching the DC input voltage on and off at high frequency to generate the AC waveform

12. DC Power Source: The DC power source, typically a battery or a rectified AC source, provides the input voltage for the inverter.

13. PWM Generation: The Atmega32 generates PWM signals with a frequency typically in the range of tens of kilohertz.The output voltage and frequency are managed by adjusting the duty cycle of the PWM signals.

14. MOSFET Switching: The PWM signals from the Atmega32 are fed to the IR2110, which amplifies and buffers them. The amplified signals then drive the IRF3205 MOSFETs to switch the DC input voltage on and off according to the PWM signal.

15. Step-up Transformer: The switched DC voltage from the MOSFETs is then applied to the primary winding of the step-up transformer. The transformer steps up the voltage to the desired level required for the AC output.

16. Load: The AC output from The transformer's secondary winding is connected to the load, which could be various appliances or electronic devices that require AC power.

17. Pure Sine Wave Output: By adjusting the duty cycle and frequency of the PWM signals, the inverter produces a smooth and continuous waveform that closely resembles a pure sine wave.

Chapter 4

Results and Discussions

4.1 Hardware Setup

1. Synchronous Generator

Figure 4.1: Synchronous Generator

When it comes to power conversion and control in a wind energy conversion system (WECS) for maximum power extraction, one commonly used technology is the synchronous generatorAn electrical device known as a synchronous generator transforms mechanical energy from a wind turbine into electrical energy. It is made up of a stator and a rotor. The rotor, also known as the field winding, is the component that rotates and is typically connected to the wind turbine shaft. The stator contains the armature windings and remains stationary.the synchronous generator operates on the principle of electromagnetic induction. A rotating magnetic field produced by the rotating rotor causes voltage in the stator's stationary armature windings. The output of electrical power is then produced from this voltage.To convert the electrical output from the synchronous generator to a usable form, a power converter is employed. In the case of a synchronous generator, the power converter is often a full-converter system. It performs the necessary conversion from the variable frequency and voltage output of the generator to a stable and grid-compatible electrical output.the control system in a WECS with a synchronous generator plays a critical part in extracting the most power possible. It typically incorporates advanced control algorithms, such as maximum power point tracking (MPPT), to continuously monitor the operating conditions and adjust the generator's parameters for optimal performance. The control system adjusts the rotor speed, field excitation, and other variables to maximize the power output based on the prevailing wind conditions.synchronous generators are commonly used in grid-connected WECS installations. They can be synchronized with the electrical grid to ensure proper integration and synchronization of power supply. Grid synchronization enables the WECS to deliver power to the grid and maintain stability during connection and disconnection.synchronous generators offer the advantage of reactive power control. By adjusting the field excitation, the generator can regulate the reactive power flow, contributing to voltage control and stability in the grid.

2. IRF3205 MOSFET

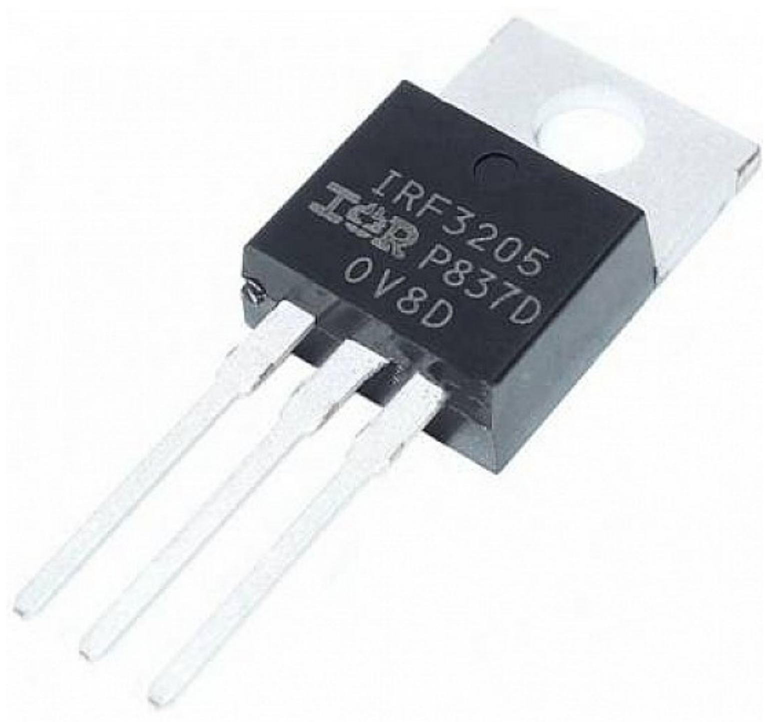


Figure 4.2: IRF3205 MOSFET

The IRF3205 is a Metal-Oxide Semiconductor Field-Effect Transistor (power MOSFET) that belongs to the N-channel enhancement-mode MOSFET family. It is designed for high-power switching applications, where it allows control over the flow of large currents with low on-state resistance (RDS(on)).the IRF3205 MOSFET is constructed using a semiconductor material, typically silicon. It consists of three terminals: the gate (G), the drain (D), and the source (S). The N-channel refers to the type of channel formed in the silicon material.the IRF3205 operates based on the principle of the field-effect transistor. Current between the drain and source terminals is controlled by the voltage applied to the gate terminal. An electric field is produced when a positive voltage, typically 10V, is applied to the gate (VGS), allowing current to go from the drain to the source.the maximum voltage that can be applied across the drain and source terminals is 55V. Exceeding this voltage can damage the MOSFET.the maximum continuous current that the MOSFET can handle is 110A. Operating beyond this limit can lead to overheating and potential failure.the IRF3205 can handle gate-source voltages ranging from -20V to +20V. The voltage applied to the gate determines the MOSFET's on-state or off-state operation.It's crucial to consult the IRF3205 datasheet and application notes for comprehensive specifications, guidelines, and recommendations specific to your application.these resources provide detailed information on electrical characteristics, thermal considerations, and suggested circuit configurations to ensure safe and optimal use.

3. IR2110 MOSFET Driver

Figure 4.3: IIR2110 MOSFET Driver

The IR2110 is a popular high-voltage, high-speed power MOSFET and IGBT driver IC (Integrated Circuit). It is commonly used to drive MOSFETs and IGBTs in various power electronic applications.the IR2110 is specifically designed to provide gate drive signals to the high-side and low-side power switches (MOSFETs or IGBTs) in a half-bridge or full-bridge configuration. It enables efficient and precise control of these switches in applications such as motor drives, power supplies, and inverters.the IR2110 consists of two independent channels: high-side (HS) and low-side

(LS). Each channel consists of an input section and an output section.the IR2110 includes undervoltage lockout circuitry to prevent insufficient gate drive voltage. It ensures that the high-side and low-side outputs remain inactive until the VCC voltage reaches a specified threshold.The TTL (Transistor-Transistor Logic) and CMOS (Complementary Metal-Oxide-Semiconductor) logic levels are both compatible with the IR2110. This allows for easy interfacing with microcontrollers, digital signal processors (DSPs), and other logic devices.propagation Delay and Dead Time Control: The IR2110 provides fast switching times and allows for precise control of the dead time (time when both high-side and low-side switches are off) between the complementary gate drive signals. This feature helps prevent shoot-through currents and improves overall system efficiency.the IR2110 offers various protection mechanisms to enhance the reliability of the power electronic system, including under-voltage lockout (UVLO), shoot-through prevention, and overcurrent protection.the IR2110 is available in different package options, including PDIP (Plastic Dual Inline Package) and SOIC (Small Outline Integrated Circuit) packages, which are widely used and easy to solder.

4. 1N4001ID to 1N4007ID Rectifiers

Figure 4.4: 1N4007 - 1A General Purpose rectifier Diode

Rectifier diodes, such as those in the 1N400xID series, are employed to transform alternating current (AC) into direct current (DC) by means of rectifying the AC voltage waveform.the main function of the 1N400xID series rectifiers is to convert the AC voltage into DC voltage. They only permit one direction of current to flow, blocking the opposite direction during the negative half-cycle of the input AC waveform.These rectifier diodes have a P-N junction configuration at their core. The P-N junction allows the diode to conduct current when a forward voltage (VF) is applied across it, and it blocks current flow when a reverse voltage is applied.the rectifier diodes have a forward voltage drop (VF) typically ranging from 0.7V to 1V, depending on the specific diode and the forward current passing through it.each diode in the 1N400xID series has a different maximum reverse voltage rating, representing the maximum voltage that can be applied in the reverse direction without causing breakdown.the forward current rating indicates the maximum continuous current that the diode can safely handle in the forward direction.the 1N400xID series rectifiers find application in various areas, including power supplies, rectification in electronic circuits, battery chargers, voltage clamping circuits, and general-purpose rectification tasks.the reverse recovery time (trr) of these diodes is relatively long, which means they have a longer delay before the diode blocks the current flow after the applied voltage changes from forward to reverse.

5. MC78XX 3-Terminal 1A Positive Voltage Regulator

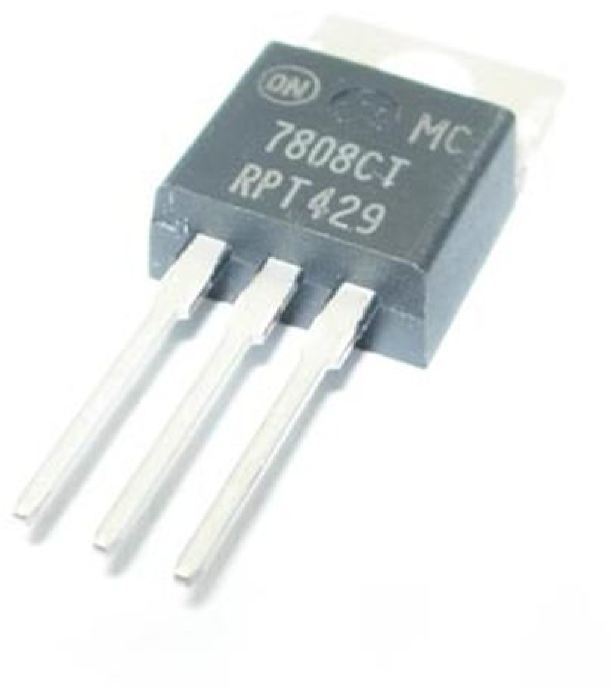


Figure 4.5: MC7808CT 3-Terminal 1A Positive Voltage Regulator

The MC78XX, LM78XX, and MC78XXA series are examples of 3-terminal positive voltage regulators commonly used in electronic circuits. These regulators are designed to provide a fixed output voltage and have a maximum output current rating of 1A. They are widely utilized in various applications to ensure a stable and regulated DC voltage output.the MC78XX, LM78XX, and MC78XXA voltage regulators are designed to take in an unregulated DC input voltage and provide a regulated and stable DC output voltage. They are commonly used to supply power to various components in electronic circuits, ensuring that the voltage remains constant despite fluctuations in the input voltage or load conditions.the regulators in this series are available with different fixed output voltage options, such as 5V (MC7805/LM7805), 12V (MC7812/LM7812), and so on. The XX in the part number represents the specific output voltage.these regulators are capable of delivering a maximum output current of 1A. However, it's important to consider the power dissipation and thermal limitations, as the regulators may require heat sinks or current limiting if higher currents are drawn.the MC78XX, LM78XX, and MC78XXA Regardless of alterations in the input voltage or variations in the load, regulators deliver a fixed output voltage. They have built-in circuitry that adjusts the output to maintain a constant voltage, compensating for fluctuations in the input and load conditions.these voltage regulators offer protection features to safeguard against overcurrent and overtemperature conditions. They have internal thermal shutdown circuitry that turns off the output when the regulator's temperature exceeds a safe limit.the regulators in this series are available in different package options, such as TO-220, TO-220FP, and TO-252. These package types facilitate easy mounting on heat sinks for efficient heat dissipation.the MC78XX, LM78XX, and MC78XXA voltage regulators find widespread use in a variety of electronic applications, including power supplies, voltage regulators for microcontrollers and integrated circuits, automotive electronics, and other low to medium power applications requiring stable and regulated voltages.

6. ATmega32

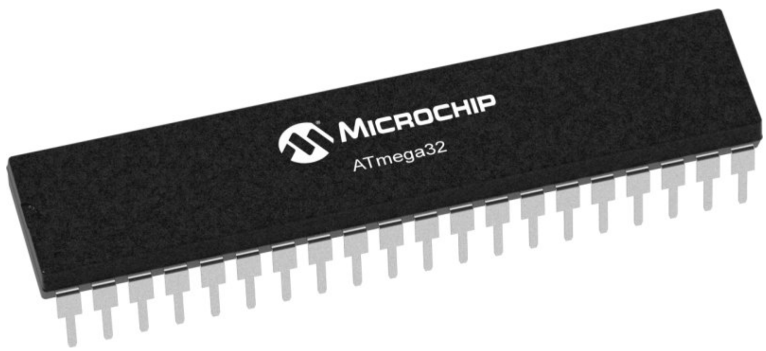


Figure 4.6: ATmega32

The ATmega32 is a popular 8-bit microcontroller from the Atmel AVR family. It offers a wide range of features and peripherals suitable for various embedded systems applications.the ATmega32 is based on the Harvard architecture, featuring an 8-bit RISC (Reduced Instruction Set Computing) CPU core. It operates at a maximum clock speed of 16 MHz, providing efficient and high-performance execution of instructions.the ATmega32 has 32KB of in-system programmable Flash memory for storing the program code.Additionally, it has 2KB of static random access memory (SRAM) for data storage and EEPROM (Electrically Erasable Programmable Read-Only Memory) of 1 KB for non-volatile data storage.the microcontroller has a total of 32 I/O pins, organized into four 8-bit ports (PORTA, PORTB, PORTC, and PORTD). These ports can be configured as inputs or outputs, allowing for interfacing with various external devices and sensors.the ATmega32 features three 16-bit timers/counters Timer/Counter0, Timer/Counter1, and Timer/Counter2 are three counters. Uses for these timers include tasks such as generating precise time delays, measuring external events, or generating PWM (Pulse Width Modulation) signals.the microcontroller supports both external and internal interrupts. It has a dedicated Interrupt Vector Table that allows the programmer to define interrupt service routines for specific events or timers.the ATmega32 offers multiple serial communication interfaces, including UART (Universal Asynchronous Receiver/Transmitter) for asynchronous serial communication and SPI (Serial Peripheral Interface) for synchronous serial communication. It also supports I2C (Inter-Integrated Circuit) communication through its dedicated TWI (Two-Wire Interface) module.the microcontroller includes an on-chip 8-channel 10-bit ADC, allowing for the conversion of analog signals into digital values. This feature is useful for reading data from analog sensors or acquiring signals from the environment.the ATmega32 has hardware support for generating PWM signals using its Timer/Counter modules. This capability is useful for controlling motor speed, dimming LEDs, and generating audio tones.

7. Step-up transformer

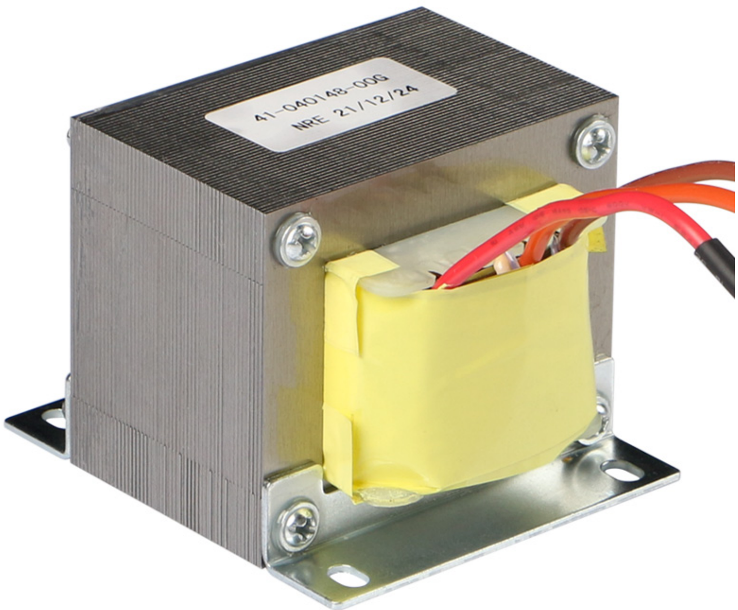


Figure 4.7: Step-up transformer

A step-up transformer is a specific type of transformer used to increase the voltage of an alternating current (AC) power supply. It achieves this by having more turns on the secondary winding compared to the primary winding, resulting in a higher output voltage than the input voltage. A transformer is an electrical device that transfers energy between coils of wire through electromagnetic induction. In the case of a step-up transformer, the primary winding is connected to the input voltage source, while the secondary winding is connected to the load.The turns ratio, represented by the ratio of the number of turns on the secondary winding (N2) to the number of turns on the primary winding (N1), determines the voltage transformation. In a step-up transformer, the turns ratio is greater than 1, indicating that N2 is larger than N1. As a result, the output voltage is increased compared to the input voltage.When an AC voltage is applied to the primary winding, it generates a changing magnetic field within the transformer core. This changing magnetic field induces a voltage in the secondary winding based on the principles of Faraday's law of electromagnetic induction. This voltage induction allows for the desired voltage transformation in the step-up transformer. The magnitude of the induced voltage in the secondary winding depends on the turns ratio.In an ideal step-up transformer, neglecting losses, the output voltage (V2) is directly proportional to the input voltage (V1) multiplied by the turns ratio (N2/N1): V2 = (N2/N1) * V1. However, it's important to note that while the voltage increases, the current decreases proportionally due to the conservation of power.transformers also provide electrical isolation between the primary and secondary circuits, allowing for safety and protection. Additionally, they can be used for impedance matching, ensuring efficient power transfer between different electrical systems.

4.2 Hardware Components and Specifications

Table 4.1: Motor Specifications

Speed	5/6pm
Motor Voltage	220V
Motor Type	Synchronous Motor
Usage/Application	The motor which runs at synchronous speed is known as the synchronous motor.
No of Phase	Single phase

Table 4.2: IRF3205 MOSFET Specifications

Drain-Source Voltage (VDS)	55V
Continuous Drain Current (ID)	110A
On-State Resistance (RDS(on))	Typically 8m ohm at VGS = 10V
Gate-Source Voltage (VGS) Range	±20V
Gate Threshold Voltage (VGS(th))	Typically 2V to 4V

Table 4.3: IR2110 MOSFET Driver Specifications

Supply Voltage	10V - 20V
Output Peak Current	Up to 2A (sink/source)
Logic Inputs	IN, INB (TTL/CMOS compatible)
Output Voltage Swing	Rail-to-rail
Propagation Delay	Typically in the range of tens of nanoseconds
Dead Time Control	Adjustable dead time between high-side and low-side signals
Under-Voltage Lockout	Disables outputs below a specified supply voltage threshold
Shoot-Through Protection	Built-in protection against simultaneous conduction
Temperature Range	-40°C to +125°C
Package Type	PDIP, SOIC, DIP, or other package options

Table 4.4: 1N4001ID to 1N4007ID Rectifiers Specifications

Rectifier Type	Maximum Average Forward Current (IFAV)	Peak Repetitive Reverse Voltage (VRRM)	Maximum RMS Voltage (VRMS)	Maximum DC Blocking Voltage (VDC)
1N4001ID	1A	50V	35V	50V
1N4002ID	1A	100V	70V	100V
1N4003ID	1A	200V	140V	200V
1N4004ID	1A	400V	280V	400V
1N4005ID	1A	600V	420V	600V
1N4006ID	1A	800V	560V	800V
1N4007ID	1A	1000V	700V	1000V

Table 4.5: MC7805 3-Terminal 1A Positive Voltage Regulator Specification

Regulator Model	MC7805
Output Voltage (VOUT)	+5V
Maximum Output Current (IO)	1A
Input Voltage Range (VIN)	7V - 25V
Dropout Voltage (VD)	2V
Line Regulation	0.2
Load Regulation	0.4
Output Voltage Tolerance	±4
Thermal Shutdown	Yes

Table 4.6: ATmega32 Specifications

Architecture	8-bit AVR
CPU Speed	Up to 16 MHz
Flash Memory	32 KB (Self-Programmable)
SRAM	2 KB
EEPROM	1 KB
Operating Voltage	2.7V to 5.5V
Digital I/O Pins	32
Analog Input Channels	8
PWM Outputs	4
USART	1

Table 4.7: Step-up Transformer Specifications

Transformer Type	Step-up Transformer
Primary Voltage	500mA
Secondary Voltage	12V
Turns Ratio	19:1
Power Rating	230V

4.3 Results and Discussions

Table 4.8: Analysis table

AC Generated	AC-DC (LOSS 0.8)	Battery (Stabilize)	DC-AC (LOSS 0.8)	Step-up AC
13.4	12.7	12 V	11.1	37.6 V
14.2	13.6	12 V	11.3	38.2 V
14.6	13.8	12 V	10.6	36.9 V
16.0	15.3	12 V	10.9	37.2 V
16.5	15.8	12 V	11.2	39.2 V

In the given analysis table, the readings of a multimeter are provided in order to convert AC to DC. First, the AC power is generated by the proposed wind turbine system. The RPM of the turbine is calculated and the initial readings are analyzed. Then,The system transforms AC power into DC to stabilize the output. A 12V battery with a capacity of 12W is used to store the DC current. While converting AC to DC, there is a loss of 0.8V due to the conversion process. The current stored in the battery is DC.

Afterwards,Using an inverter, the DC current is converted back to AC and a MOSFET bridge. During the DC to AC conversion, there is again a loss of 0.8V. The converted current remains the same for all readings due to the consistent 0.8V loss. Following the DC to AC conversion, An up-converter is used to increase the current and achieve maximum voltage. The system achieves a boosted current of approximately 35-36V.

This analysis table shows the maximum power extracted by the wind turbine in the system using PWM techniques and rectification and inversion methods. For inverting the current, a MOSFET bridge is utilized. The 12V battery stores the DC current to stabilize the voltage. To maintain a stable voltage output, synchronous generators require an excitation system. This system supplies direct current (DC) to the rotor windings, either through permanent magnets or by using a separate DC power source. The excitation current creates a magnetic field in the rotor that remains synchronized with the rotating magnetic field generated by the wind

loss in v (expected - actual)		AC Connected
42-37.6 =	4.4	13.4
42-38.2 =	3.8	14.2
42-36.9 =	5.1	14.6
42-37.2 =	4.8	16
42-39.3 =	2.7	16.5

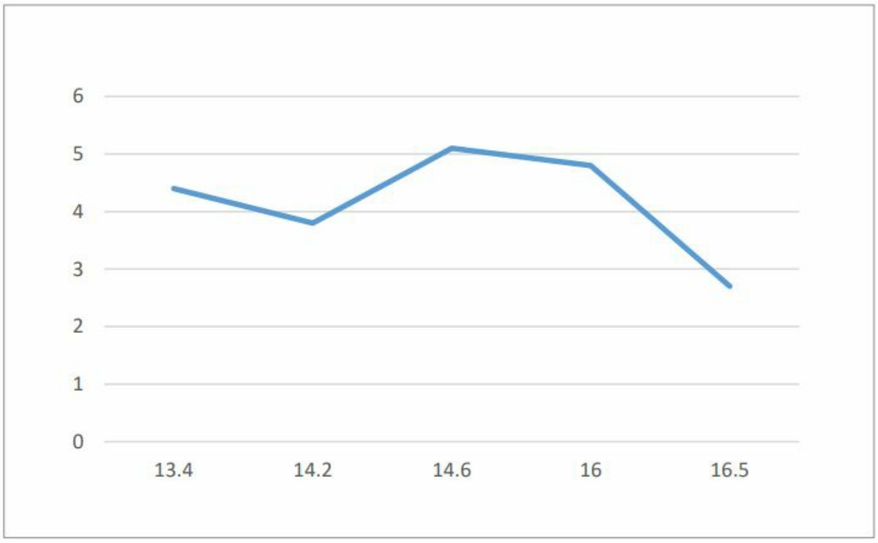


Figure 4.8: Graphical representation of analysis table

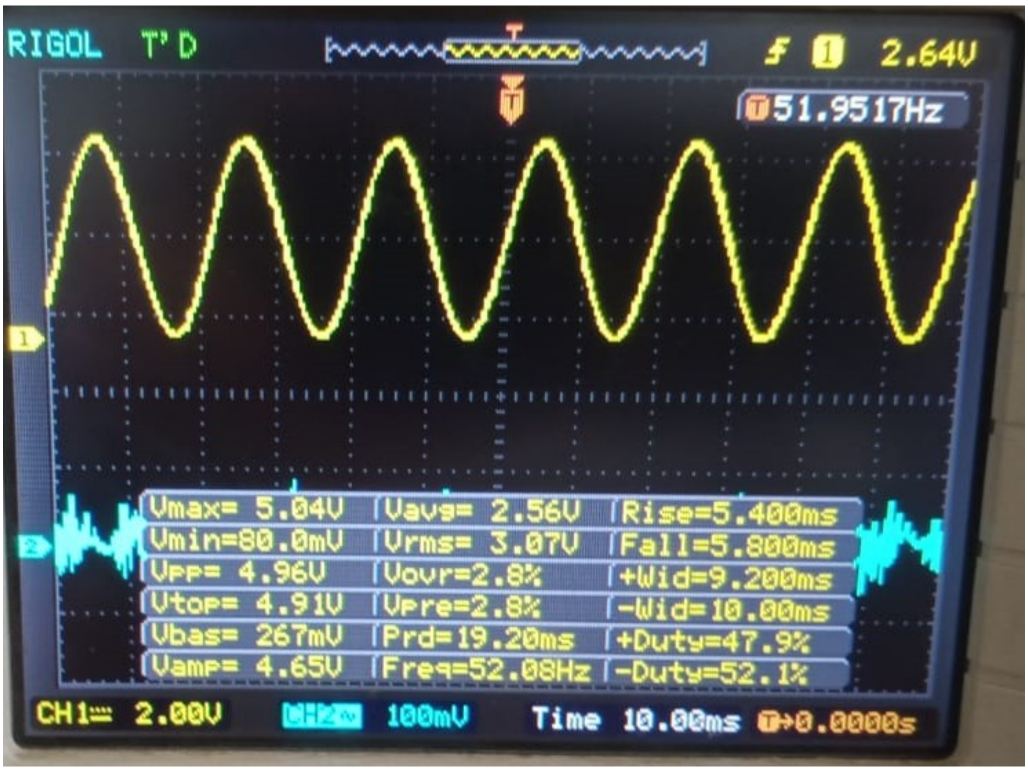
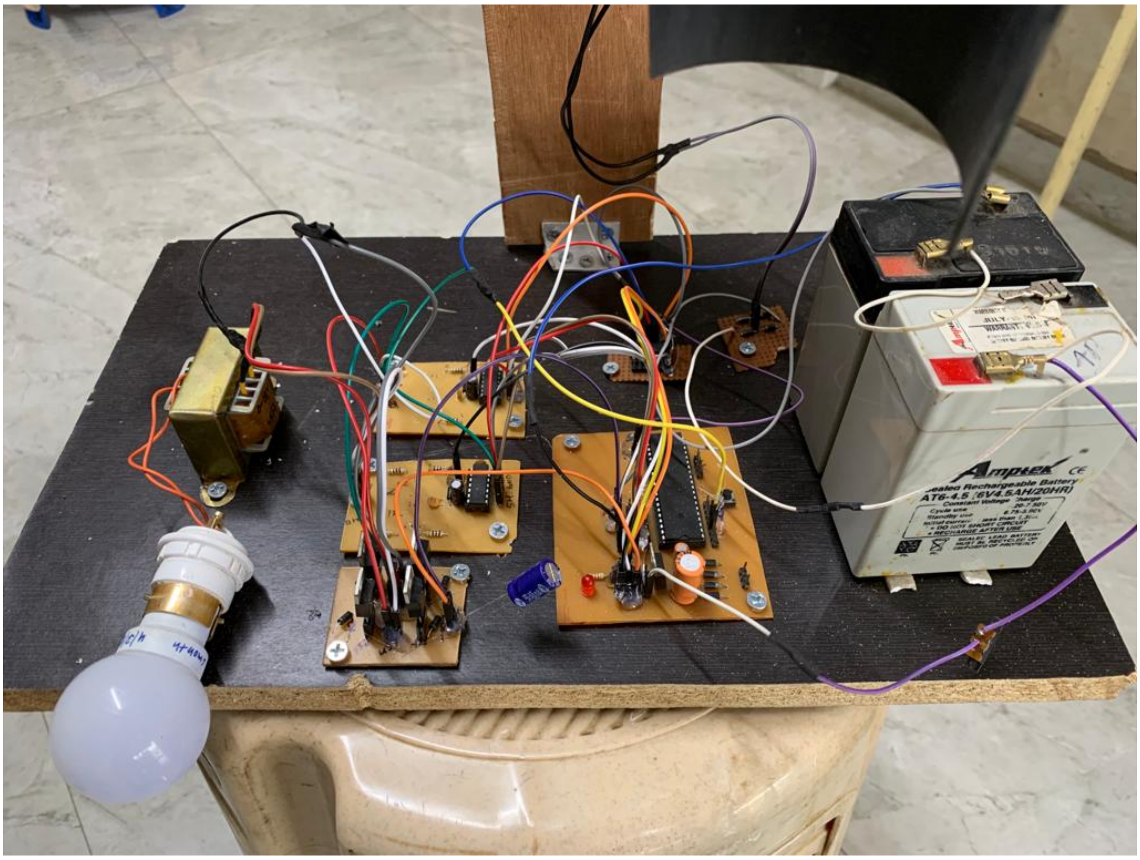
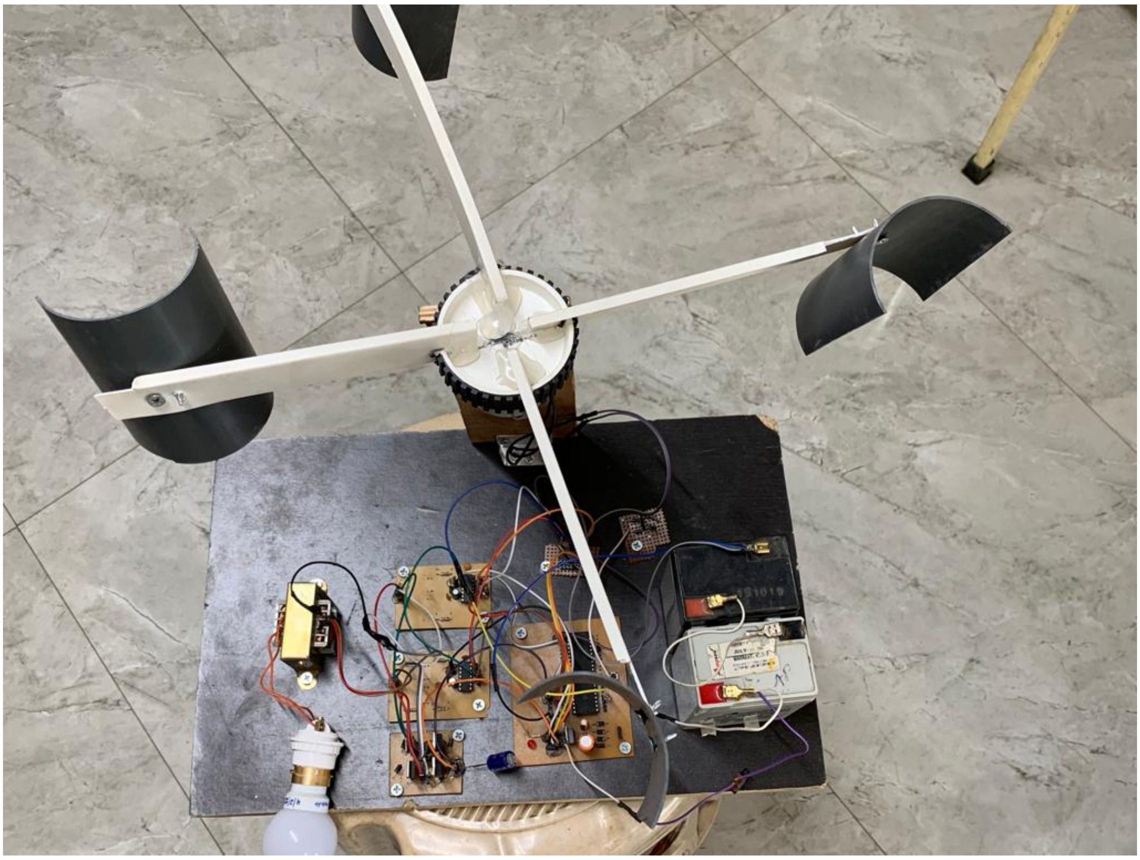


Figure 4.9: Readings in DSO


Amptek
Sealed Rechargeable Battery
AT6-4.5 (6V4.5AH/20HR)



4.4 Summary

The model's power control and extraction efficiency are enhanced by incorporating advanced control algorithms and intelligent control strategies. These algorithms continuously monitor the wind conditions, system parameters, and grid requirements, and dynamically adjust the PWM parameters accordingly. This adaptive control approach ensures that the system operates at its maximum power point (MPP), where the wind turbine extracts the maximum power available from the wind. It also facilitates efficient power transfer from the wind turbine to the grid, minimizing losses and maximizing the overall energy yield.

The successful model for wind power conversion and control described above utilizes the PWM techniques of continuous pulse width modulation (CPWM) and sinusoidal pulse width modulation (SPWM) to extract maximum power from the wind and efficiently control the power output. The incorporation of advanced control algorithms further enhances the system's performance by dynamically adapting to changing conditions and optimizing power extraction. This model represents a significant advancement in wind energy conversion technology, enabling effective utilization of wind resources and contributing to a sustainable and clean energy future.

Chapter 5

Advantage and Applications

5.1 Advantages

The power converter and control of systems for converting wind energy maximum power extraction offer several advantages in the renewable energy sector. These advantages include:

1. Increased Efficiency: By enhancing the power extraction process, the power converter and control system improves the effectiveness of wind energy conversion systems. The wind turbine's changing DC voltage is transformed into a constant AC voltage for grid integration using the power converter topology. In order to ensure effective power extraction and minimal losses, the control strategy controls the power flow between the wind turbine and the grid.

2. Improved Power Quality: By lowering harmonic distortion and raising the power factor, the power converter and control system enhance the power quality of wind energy conversion systems. The power converter architecture ensures a power factor that is close to unity and filters out harmonics produced by the wind turbine. This lowers the possibility of equipment damage and provides the grid with high-quality power.

3. Flexible Operation: The power converter and control system play a crucial role in the operation of wind energy conversion systems (WECS), allowing for adaptable and efficient power output that aligns with grid demand. The control strategy implemented in these systems is responsible for managing the power flow between the wind turbine and the grid, ensuring stability and flexibility in the generation process. This capability enables WECS to operate effectively under diverse wind conditions and respond to dynamic changes in the grid environment.

4. Fault Tolerance: The power converter and control system in wind energy conversion systems (WECS) contribute to the overall fault tolerance of the system by offering safeguards against grid faults and other potential failures. The control strategy implemented is designed to identify and isolate faults within the WECS, mitigating the risk of equipment damage. This emphasis on fault detection and prevention enhances the reliability, availability, and overall performance of wind energy conversion systems.

5. Reduced Costs: By streamlining the power extraction procedure and lowering equipment costs, the power converter and control system can lower the overall costs of wind energy conversion systems. Lower operating expenses are obtained as a result of efficient power extraction and reduced losses provided by the power converter architecture and control technique. In addition, other parts of the wind energy conversion system, including the transformer and switchgear, can be made smaller and less expensive by using the power converter and control system.

6. Environmental Benefits: By enabling the grid integration of renewable energy sources and lowering greenhouse gas emissions, the power converter and control system provide environmental benefits. Power converter and control system-powered wind energy conversion systems lessen reliance on fossil fuels and help cut greenhouse gas emissions. This encourages sustainable development and lessens the negative effects of energy generation on the environment.

7. Scalability: The power converter and control system are scalable and can be employed in both small-scale and large-scale wind energy conversion system designs. Wind energy conversion systems can be used in a variety of contexts by adapting the power converter topology and control technique to the unique requirements of various applications.

8. Maximum Power Extraction: The power converter and control system play a crucial role in optimizing power extraction from the wind turbine by effectively managing the turbine's speed and controlling the power flow. This ensures that the wind energy conversion system operates at its maximum capacity, resulting in enhanced energy production and greater financial returns. By employing efficient control strategies, the power converter and control system enable the wind turbine to harness the maximum available wind energy, maximizing the system's overall performance and revenue generation.

9. Low Noise Emissions: By regulating the wind turbine's speed, the power converter and control system can lessen the noise emissions of the wind energy conversion system. As a result, the operation is quieter, which has a less negative effect on the environment and adjacent residents.

10. Improved Control: The power converter and control system can improve the control of the wind energy conversion system by regulating the speed of the turbine and the power flow. This results in improved stability and reliability, reducing the likelihood of faults and other disruptions.

11. Remote Monitoring and Control: The power converter and control system can be remotely monitored and controlled, enabling real-time monitoring and optimization of the wind energy conversion system. This results in improved efficiency and reliability, reducing the need for on-site maintenance and repair.

12. Rapid Response to Grid Disturbances: The power converter and control system can respond rapidly to grid disturbances, such as voltage and frequency fluctuations. This enables the wind energy conversion system to operate reliably and stably, reducing the likelihood of power outages and other disruptions.

5.2 Applications

Applications for power converters and wind energy conversion systems that maximise power extraction are important in the renewable energy sector. The creation and improvement of wind energy conversion systems is a result of the rising demand for renewable energy sources and the requirement for sustainable development. Some of the uses for power converters and control systems in wind energy conversion systems are listed below.

1. Grid Integration: The power converter and control system play a crucial role in the grid integration of wind energy conversion systems. The power converter topology and control strategy ensure efficient power extraction and smooth grid integration. Offshore wind energy is a promising source of renewable energy that has gained significant attention in recent years. The power converter and control system are crucial for the efficient and reliable operation of offshore wind energy conversion systems.

2. Hybrid Energy Systems: In hybrid energy systems, the power converter and control system play a key role. For a dependable and effective power supply, hybrid energy systems combine two or more renewable energy sources.

3. Microgrid Systems: Microgrid systems are small-scale power systems that can operate independently or in parallel with the main grid. The power converter and control system are crucial for the efficient and reliable operation of microgrid systems.

4. Remote Power Systems: Remote power systems are small-scale power systems that operate in remote locations with limited access to the main grid. The power converter and control system have significant applications in remote power systems.

5. Industrial Applications: The power converter and control system have significant applications in various industrial processes. The efficient and reliable operation of industrial processes requires a stable and reliable power supply.

6. Utility-Scale Wind Farms Large-scale wind energy conversion systems that are connected to the grid and supply energy to the utility companies are known as utility-scale wind farms. These wind farms can use the power converter and control system to increase power output and boost system effectiveness overall.

7. Distributed Generation Distributed generation is a system where the energy is generated close to the point of consumption. This system can reduce the dependence on the central grid and improve the energy security of the system.

8. Hybrid Systems Hybrid systems are systems that combine two or more sources of energy, such as wind and solar. The power converter and control system can be used in hybrid systems to regulate the power flow and optimize the power extraction process.

Chapter 6

Conclusion and Future Scope

6.1 Conclusion

The DC-to-DC Conversion process is widely used in the power electronics. This paper proposes a method, which is for the maximum power extraction for wind turbine by using an CSPWM (Continuous Switching pulse width modulation) and SPWM (sinusoidal pulse width modulation). By using control system and PWM techniques the power conversion and extraction of wind turbine is controlled. In rectifier and inverter using the methodology of continuous pulse width modulation (CSPWM) and sinusoidal pulse width modulation (SPWM) maximum power is extracted and stabilized efficiently. Wind energy system extracted by regulating the wind turbine's rotational speed, maximum power.In conclusion, an efficient power converter and a well-designed control system are essential for maximizing power extraction is a system for converting wind energy. The selection of an appropriate converter and the implementation of advanced control strategies are significantly improved the overall efficiency and performance of the system, contributing to the increased utilization of wind energy as a sustainable power source.

6.2 Future Scope

The power converter and control of wind energy conversion system for maximum power extraction has already demonstrated its significant impact on the renewable energy sector. As the demand for renewable energy continues to increase, there is a need for more efficient and reliable wind energy conversion systems. The power converter and control system have shown promise in meeting these demands and have several future scopes:

1. Integration with Energy Storage:
   Integration with energy storage systems is one of the power converter and control system's prospective application areas. Batteries and supercapacitors are examples of energy storage devices that can store extra energy produced by wind turbines and release it when there is a lack of wind or a heavy demand on the grid. The power converter and control system may govern the power flow between the grid, energy storage devices, and wind turbines to ensure optimal energy use.

2. Artificial Intelligence and Machine Learning:
   The power converter and control system can benefit from the use of artificial intelligence and machine learning algorithms. These algorithms can optimize the control

strategy of the power converter and improve the power extraction process. Additionally, machine learning algorithms can detect and predict faults in the wind energy conversion system, enabling early detection and preventive maintenance.

3. Advanced Control Strategies:
   Advanced control strategies, such as model predictive control, can enhance the performance of the power converter and control system. Model predictive control can predict the future behavior of the wind energy conversion system and optimize the control strategy accordingly, improving the power extraction process and reducing losses.

4. Offshore Wind Energy:
   Offshore wind energy is a promising sector for the power converter and control system. Offshore wind turbines generate larger amounts of energy than onshore turbines, but their operation is more challenging due to harsh environmental conditions. The power converter and control system can regulate the power flow between the offshore wind turbine and the grid, ensuring efficient power extraction and reducing losses. Additionally, the power converter and control system can provide fault detection and isolation, ensuring reliable and safe operation.

5. Microgrid and Hybrid Energy Systems:
   The power converter and control system can be used in microgrid and hybrid energy systems, combining renewable energy sources with traditional energy sources. The control strategy can optimize the power flow between the different energy sources and the grid, ensuring reliable and efficient operation. Additionally, the power converter topology can be customized to match the specific requirements of different energy sources, enabling flexible operation and efficient power extraction.

6. Smart Grid Integration:
   When integrating wind energy conversion systems into smart grids, the power converter and control system may be of utmost importance. Advanced communication and control technologies are used by smart grids to optimise energy utilisation and lower losses. The power converter and control system has the ability to govern the power flow between the smart grid and the wind turbine, ensuring steady operation and effective energy utilisation.

7. Modular Design:
   The power converter and control system can benefit from modular design approaches. Modular design enables the power converter and control system to be easily scalable and customized to match the specific requirements of different applications. Additionally, modular design can reduce the size and cost of the power converter and control system, enabling its use in smaller-scale wind energy conversion systems.

8. Multi-Level Converters:
   Multi-level converters can enhance the performance of the power converter and control system by reducing harmonic distortion and improving the power quality. Multi-level converters use multiple voltage levels to generate a sinusoidal voltage waveform with reduced harmonic content. This results in a high-quality power supply to the grid and reduces the risk of equipment damage.

9. Power Electronics and Wide Bandgap Devices:
   Power electronics with wide bandgap components like silicon carbide (SiC) and gallium nitride (GaN) can help the power converter and control system. In comparison to conventional silicon-based devices, power electronics and wide bandgap technologies have higher switching frequencies, higher efficiency, and higher temperature tolerance.

10. Fault Tolerant Control:
    The power converter and control system can benefit from fault-tolerant control strategies, which enable the system to operate despite the occurrence of faults in the wind turbine or the power converter. Fault-tolerant control strategies can detect and isolate faults and reconfigure the system to maintain stable operation. This can result in increased reliability and reduced downtime of the wind energy conversion system.

11. Condition Monitoring:
    Condition monitoring can provide real-time information about the performance and health of the wind energy conversion system. Condition monitoring techniques can include vibration analysis, temperature measurement, and oil analysis. The power converter and control system can use this information to optimize the control strategy and detect and predict faults in the system, enabling preventive maintenance and reducing downtime.

12. Power Flow Control:
    Power flow control can optimize the power extraction process of wind energy conversion systems. Power flow control can regulate the power flow between the wind turbine, the power converter, and the grid, enabling optimal power extraction and reducing losses. Additionally, power flow control can mitigate the effects of grid disturbances and ensure stable operation of the wind energy conversion system.

13. Predictive Maintenance:
    Predictive maintenance can detect and predict faults in the wind energy conversion system, enabling preventive maintenance and reducing downtime. Predictive maintenance can use machine learning algorithms and condition monitoring techniques to predict the remaining useful life of components and identify potential faults before they occur.

14. Voltage Regulation:
    Voltage regulation can optimize the power extraction process of wind energy conversion systems. Voltage regulation can regulate the voltage level of the wind turbine, the power converter, and the grid, enabling optimal power extraction and reducing losses. Additionally, voltage regulation can ensure stable operation of the wind energy conversion system and mitigate the effects of grid disturbances.

15. Electromagnetic Interference:
    Electromagnetic interference can affect the operation of the wind energy conversion system and other electronic devices. The power converter and control system can implement electromagnetic interference (EMI) filters and shielding to reduce the effects of electromagnetic interference. Additionally, the power converter and control system can use EMI detection and mitigation techniques, enabling reliable and efficient operation.

Chapter 7

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Appendices

Appendix A

Project Outcomes

A.1 Plagiarism Report

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4.	Class and description of the work	Literary/ Dramatic Work
5.	Title of the work	Power Converter and Control of Wind Energy Conversion System for Maximum Power Extraction
6.	Language of the work	English
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8.	Whether the work is Published or Unpublished	Unpublished
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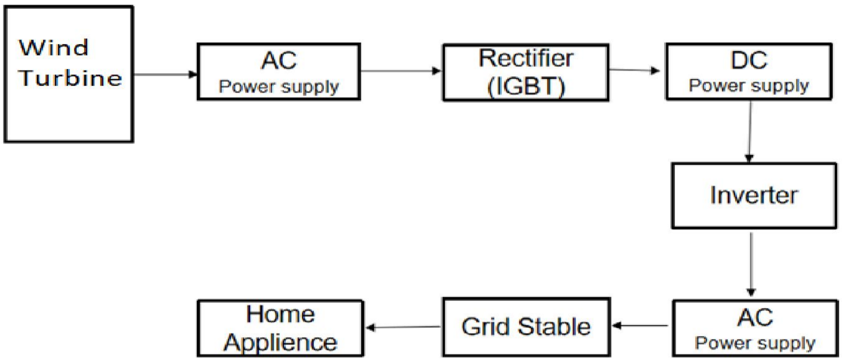
Diary No.: 23202/2022-CO/L

TITLE: Power Converter and Control of Wind Energy Conversion System for Maximum Power Extraction

INTRODUCTION:

We know wind energy is most important renewable energy sources for producing electricity, because of its cost is very low as compared to other conventional kind of energy sources. Wind power greatly increases in the electric power systems and it is anticipated to keep constant growth in the upcoming years. To convert wind energy to electrical energy we put a system to work between Wind Energy and Electrical energy. Wind Energy as an input and Electrical Energy is output. In wind energy conversion system power is converted from pulsating AC to pulsating DC and then DC is converted into AC. In this project we discuss the most important and favourable renewable power source origin, wind energy, from that we can say that the power electronics is convert from being a small energy source to be provisional as an important power source in the energy system and the general power converter chorography from the simple converters for starting up the turbine to advanced power converter chorography, where the whole power is flowing through the converter. Wind Energy conversion system is very prevalent in the era of electrical power. The combination of Wind energy conversion system (WECS) with the is a challenging type in research areas. Several DC-to-DC converter control plan have been applied in assign renewable energy tackling with the energy short and eco problem. We use here duel-loop control, one for voltage in outsider loop and current in inner loop. As the current and voltage presented in looping, we are trying to balancing it. From that we got Active and reactive energy via managing to axis power components, for the given strategy where, active power can be managed via be in control of modulation of the PWM converter and (DC) duty cycle ratio of the boost converter for the second point.

BLOCK DIAGRAM:



Block diagram of proposed system

APPLICATIONS:

1. Electrical energy production: With the help of wind turbines, the kinetic energy can be converted to mechanical energy and converted to the electrical power. And we can use that energy as we want.
2. Pumping water: Wind energy can be used to bring out water from the earth using wind power, which are turbines useful for pumping up to three hundred liters per hour, which can be fulfilled our requirements for farms.
3. Home appliances**:** We can use maximum power for home appliance.

CONCLUSION:

By using maximum power point tracking theorem and PWM techniques the power conversion and extraction of wind turbine is controlled. In rectifier and inverter using the methodology of continuous pulse width modulation (CSPWM) and sinusoidal pulse width modulation (SPWM) maximum power is extracted and stabilized efficiently. Wind energy system extracted maximum power by controlling the wind turbine rotational speed.

APPLICANTS:

Sr. No.	Name	Address
	Sanket Kale	**A/P Vaduj, Tal-Khatav, District- Satara, Pin-415506.**
2	**Kapil Waghmare**	**Ravet, Pune, Bhondve corner, sec. no. 28, Pin-412101**
3	**Kiran Throat**	**Ambegaon, Tal-Gangapur Dist. Aurangabad Pin-431002**
4	**Dr. Rahul Mapari**	**502, Bhondve orchid, ravet, Pimpri Chinchwad, Pune - 412101**

A.3 Research Paper

POWER CONVERTER AND CONTROL OF WIND ENERGY CONVERSION SYSTEM FOR MAXIMUM POWER EXTRACTION

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Kapil Waghmare, Student, Department of E&TC Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, MH, India
Kiran thorat, Student, Department of E&TC Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, MH, India
Dr. Rahul G. Mapari, Professor, Department of E&TC Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, MH, India

Abstract:
In this paper the most emerging renewable energy source, wind energy, which by means of power electronics is changing from being a minor energy source to be acting as an important power source in the energy system and the standard power converter topologies from the simplest converters for starting up the turbine to advanced power converter topologies, where the whole power is flowing through the converter wind Energy conversion system is very predominant in generation of electrical power. The integration of Wind energy conversion system (WECS) with the grid is a challenging phenomenon in research areas. Several DC-DC converter control. strategies have been implemented in distributed renewable energy harnessing system for coping with the energy shortage and environmental crisis. Double-loop controls, one being with voltage in outer loop and current in inner loop and the other being current in outer loop and voltage in inner loop are presented and compared. Active and reactive power control is achieved independently via controlling q-axis and d-axis current components, respectively for the first scheme, whereas, active and reactive power control is achieved dependently via controlling modulation index of the PWM converter and duty ratio of the boost converter for the second scheme. The effective and powerful WECS is determined via the whole control system superiority and the system operation stability.
Keywords:
Wind Energy, Bidirectional Converter, Power electronics, Renewable Energy

I. Introduction

We know wind energy is one of the most promising renewable energy sources for producing electricity, due to its cost competitiveness compared to other conventional types of energy resources. Wind power penetration greatly increases in the electric power systems and it is anticipated to keep steady growth in the upcoming years. To convert wind energy into electrical energy we put a system to work between Wind Energy and Electrical energy. Wind Energy as an input and Electrical Energy is output. In wind energy conversion system power is converted from pulsating AC to pulsating DC and then DC is converted into AC. A wind turbine is a device that converts kinetic wind energy to electrical energy. Wind turbines are becoming into a more major source of intermittent renewable energy as a means of reducing energy costs and reducing reliance on fossil fuels. The generator, gearbox, and rotor are among the components of a wind turbine. An AC constant power supply is a power source that transmits alternating current (AC) electricity to a load. The two types of power input are AC and DC. The power needed by the load and the power supplied by the inverter and other power storage devices are usually mismatched. AC power supplies correct the electrical source's AC power to the device's necessary voltage, current, and frequency in order to address this problem. One of the most crucial components of a solar energy system is an inverter. It is a device that transforms solar panels produced direct current (DC) electricity into the alternating current (AC) electricity needed by the electrical grid. DC keeps the voltage of the electricity constant in one direction. As the voltage shifts from positive to negative in an AC circuit, electricity moves in both directions. One type of power electronics—a class of devices that control the flow of electrical power—includes inverters. A popular Pulse width modulation approach is sinusoidal Pulse width modulation (SPWM).

II. Research Background

A power converter is a device that converts the direct current (DC) output of the generator into alternating current (AC) which can be fed into the power grid. The power converter is also responsible for controlling the speed of the generator to maintain a constant output power despite variations in wind speed. This is accomplished using a control algorithm which monitors the power output and adjusts the generator speed accordingly. The control algorithm used for maximum power extraction from the WECS can be based on different control strategies. One popular approach is the maximum power point tracking (MPPT) algorithm, which continuously tracks the maximum power point of the WECS and adjusts the generator speed to maintain the maximum power output. Another approach is the droop control, which adjusts the generator speed based on the frequency deviation from a reference frequency.

Current Technology

Wind energy conversion systems (WECS) use power electronics converters to interface the variable frequency output of the wind turbine generator with the grid. The power converter and control system of a WECS are crucial components that ensure efficient and reliable operation of the system. The current technology for power converters in WECS is based on voltage source converters (VSCs) and current source converters (CSCs). VSCs use pulse width modulation (PWM) techniques to control the output voltage and frequency of the generator. CSCs, on the other hand, use PWM techniques to control the output current and voltage of the generator. The control strategy of a WECS aims to maximize the power extraction from the wind turbine by adjusting the generator torque and blade pitch angle. The control system uses feedback from sensors to adjust the generator torque and blade pitch angle in real-time.

Proposed System

Wind energy conversion systems typically include a power converter and a control system that work together to extract the maximum possible power from the wind turbine. The power converter converts the variable-frequency AC power generated by the wind turbine into fixed-frequency AC power that can be fed into the grid. The control system regulates the power converter to ensure that the maximum amount of power is extracted from the wind turbine. Two commonly used modulation techniques for power converters are carrier-based pulse width modulation (CPWM) and space vector pulse width modulation (SPWM) CPWM involves generating a high-frequency carrier signal and varying the width of the pulses in the carrier signal to control the amplitude of the output waveform. In wind energy conversion systems, CPWM is typically used to control the output voltage of the power converter. SPWM involves generating a three-phase sinusoidal reference waveform and comparing it to a triangular carrier waveform to generate the pulse width modulation signal. SPWM is typically used to control the output current of the power converter. Both CPWM and SPWM have their advantages and disadvantages. CPWM is simpler to implement and has lower harmonic distortion, but it can result in higher switching losses and lower efficiency. SPWM is more complex to implement but offers better control of the output waveform and can result in higher efficiency.

Fig 1: Flowchart of proposed system.

1. To start the working of wind turbine first step is to set up the wind turbine generator and its control system. It measures the wind speed and direction.
2. After initializing it convert the 10 bits into analog to digital. After this setup initialized the PWM techniques in proposed system of power converter and created the setup for AC/DC converter.
3. In the system of power converter two PWM techniques started working for rectifying continuous pulse width modulation is used.
4. The AC power is rectified from the generator and the energy that created from wind turbine is saved in the battery and the battery is charged.
5. PWM techniques which used in rectifying and inverting the current for better efficiency after they form waveforms for the current and voltage which is formed in the process of rectifying and inverting. It shows the waveform graph for the system.
6. Then it gives the input to PWM channels for the maximum power extraction from the wind turbine and then output is feed to the MOSFET bridge to inverting the current from DC to AC.
7. For maximize the power from given system step up AC output bridge is required and it filters the current and voltage and forms the stable AC load for the home appliances.

Key Technology

- Generator: This component converts the mechanical energy from the wind turbine into electrical energy.
- Power Converter: This component converts the direct current (DC) output of the generator into alternating current (AC) which can be fed into the power grid.
- Control Algorithm: This component is responsible for controlling the speed of the generator to maintain a constant output power despite variations in wind speed. The control algorithm can be based on different strategies such as maximum power point tracking (MPPT) or droop control. Overall, the proposed system for power converter and control of wind energy conversion systems for maximum power extraction is designed to ensure that the maximum

amount of energy is extracted from the wind and fed into the power grid, making wind energy a more viable source of renewable energy.

Block Diagram

Wind Turbine: A wind turbine is a device that converts the kinetic energy of wind into electrical energy. Wind turbines are an increasingly important source of intermittent renewable energy, and are used in many countries to lower energy costs and reduce reliance on fossil fuels. Wind Turbine contains some components which are Rotor, Gear box, Generator.

AC power supply(unstable): From wind turbine we get AC power supply and that AC power supply is not continuous with the help of CSPWM (continuous pulse width modulation) we stabilize that power. and further we sent it to the rectifier. Alternating current (AC) is the way electric power is transmitted from generating facilities to end users. It is used for power transportation because electricity needs to be transformed several times during the transportation process.

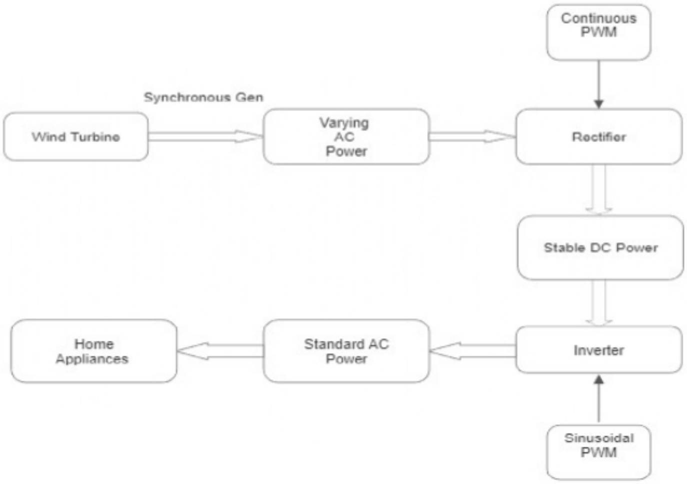


Fig 2: Block diagram of proposed system.

Rectifier (MOSFET): In energy harvesters, full wave rectifiers using diodes are frequently used. The traditional harvester circuit consists of an AC/DC rectifier with a full wave bridge and high voltage charges. These rectifier circuits based on diodes are not suited for obtaining current. In the typical circuit, diodes are replaced by n-channel switches to create a viable single- and double-stage energy harvesting module. An n channel MOSFET is added to the existing diode-based rectifier circuit in order to achieve the ideal voltage. The suggested MOSFET rectifier circuit is thought to be able to increase current and overcome voltage drop. A boost converter has been added to the energy harvesting circuit in order to double the voltage obtained at the rectifier's output. DC Power supply: From Rectifier we got Stabilize DC power and that DC power is supplied to the Inverter.

Inverter: An inverter is one of the most important pieces of equipment in a solar energy system. It is a device that converts direct current (DC) electricity, which is what a solar panel generates, to alternating current (AC) electricity, which the electrical grid uses. In DC, electricity is maintained at constant voltage in one direction.

AC power supply(stable): An AC stable power supply is a type of power supply used to supply alternating current (AC) power to a load. The power input may be in an AC or DC form. The power supplied from inverter and various power storage devices is oftentimes incompatible with the power needed by the load. To address this problem, AC power supplies transform and fine-tune AC power from the electrical source to the voltage, current, and frequency needed by the device. Home appliances: we can use that power for home appliance.

III. Applications

1. Electrical energy production: With wind turbines, the wind's kinetic energy can be transformed into mechanical energy and this, in turn, into electrical energy.
2. Pumping water: Wind energy can be used to extract water from the ground using wind pumps, which are turbines capable of pumping up to six hundred litters per hour, which is enough to meet the needs of a small farm.
3. Home appliances: We can use power for home appliance.
4. Renewable hydrogen: Wind energy is used to produce the continuous electrical current that the needed to produce renewable hydrogen. This type of hydrogen is used, for example, to produce synthetic fuels or eco-fuels.

IV. Results

Table 1: Analysis table.

Sr. No.	AC Generated	AC-DC (Loss 0.8 V)	Battery (Stabilize)	DC-AC (Loss 0.8 V)	Step-up AC
1	13.4	12.7	12 V	11.1	37.6 V
2	14.2	13.6	12 V	11.3	38.2 V
3	14.6	13.8	12 V	10.6	36.9 V
4	16.0	15,3	12 V	10.9	37.2 V
5	16.5	15.8	12 V	11.2	39.2 V

	loss in v (expected - actual)	AC Connected
42-37.6 =	4.4	13.4
42-38.2 =	3.8	14.2
42-36.9 =	5.1	14.6
42-37.2 =	4.8	16
42-39.3 =	2.7	16.5

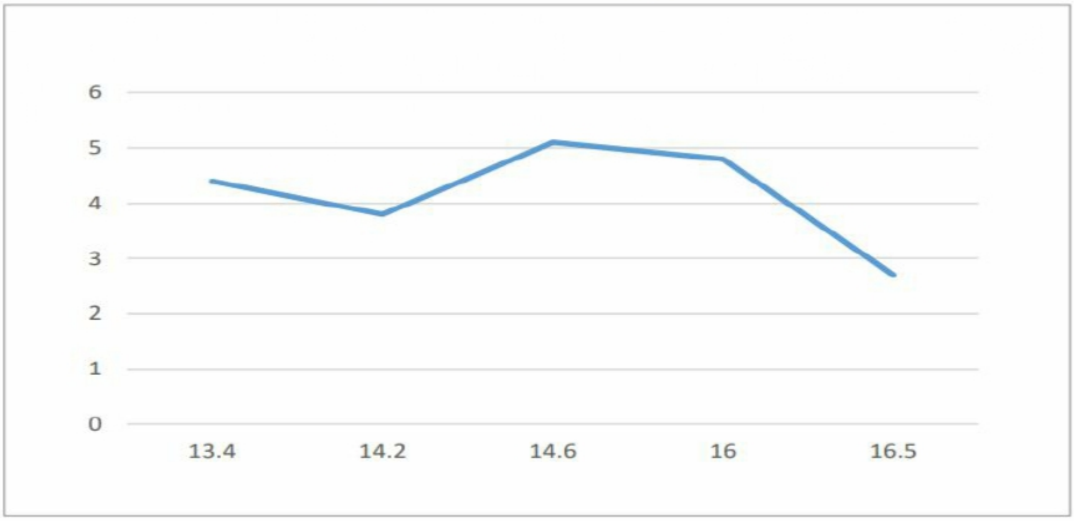
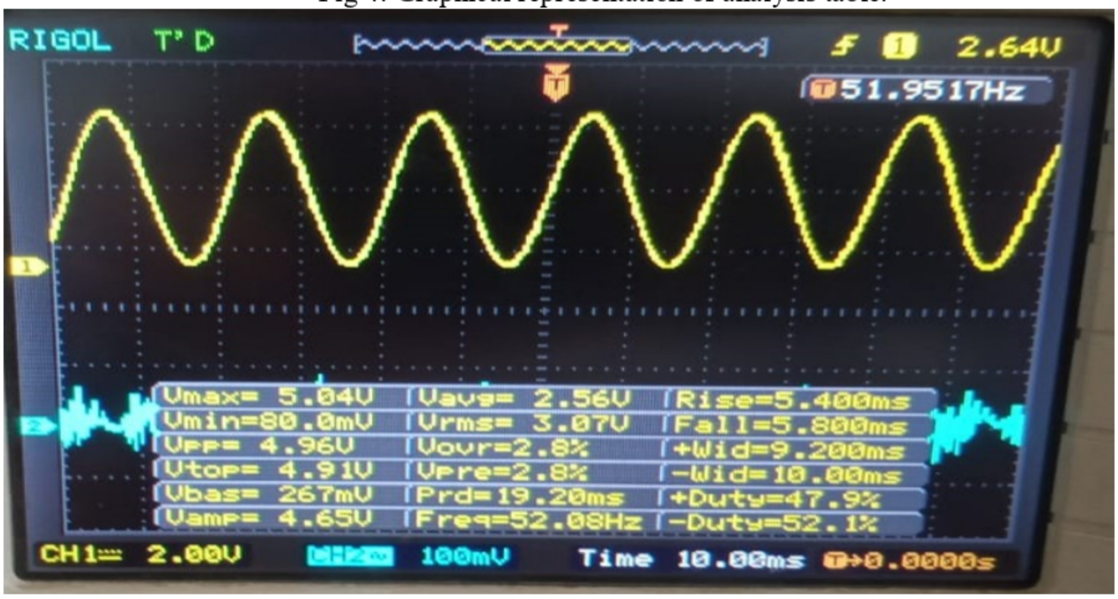


Fig 4: Graphical representation of analysis table.



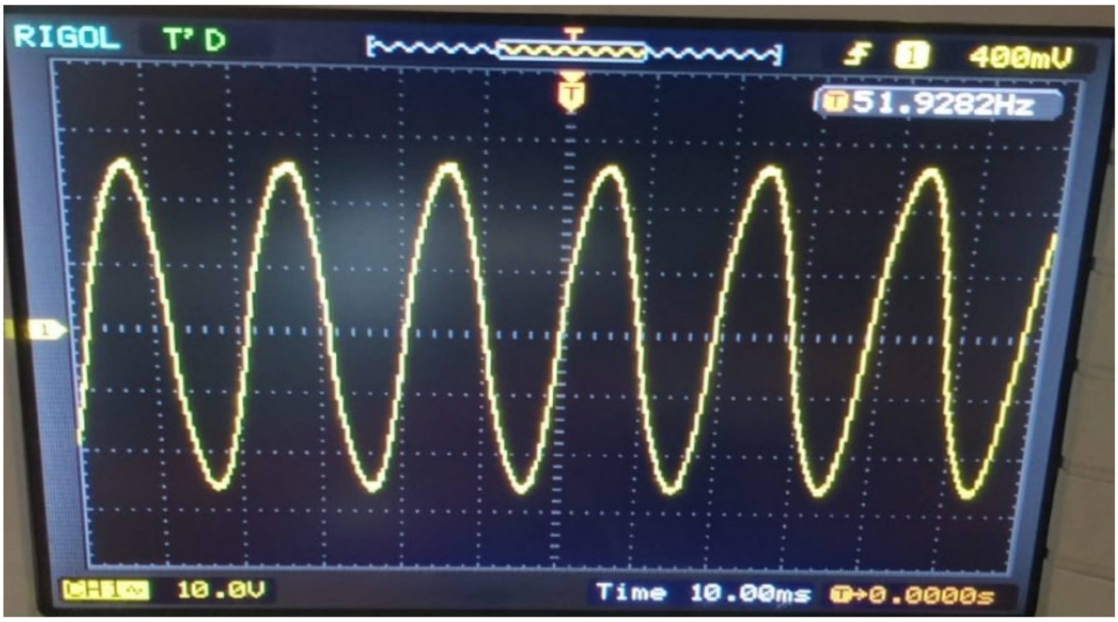
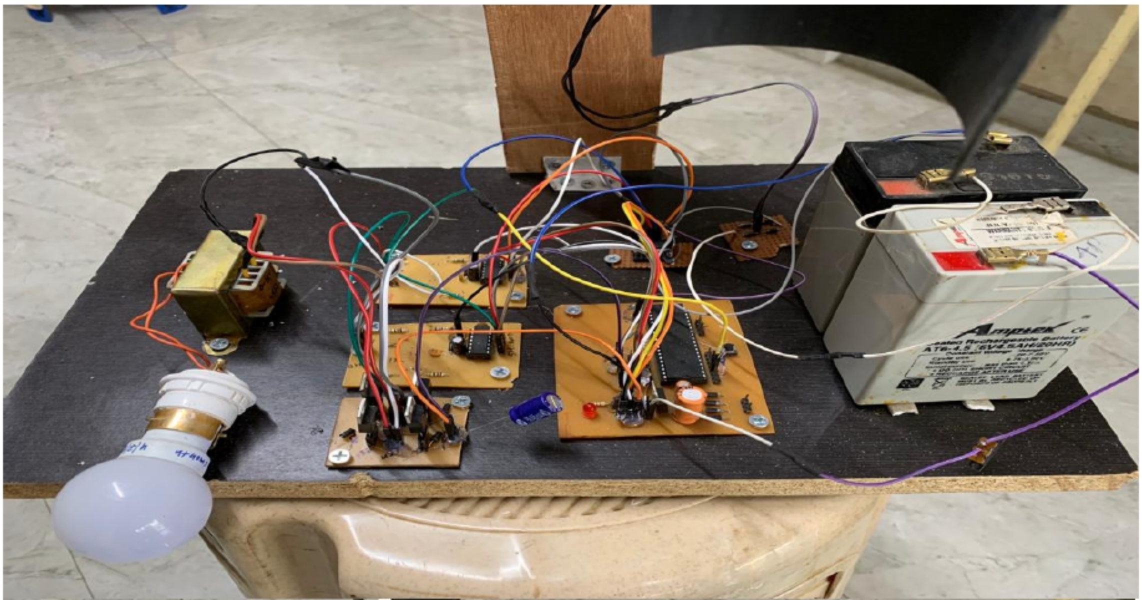
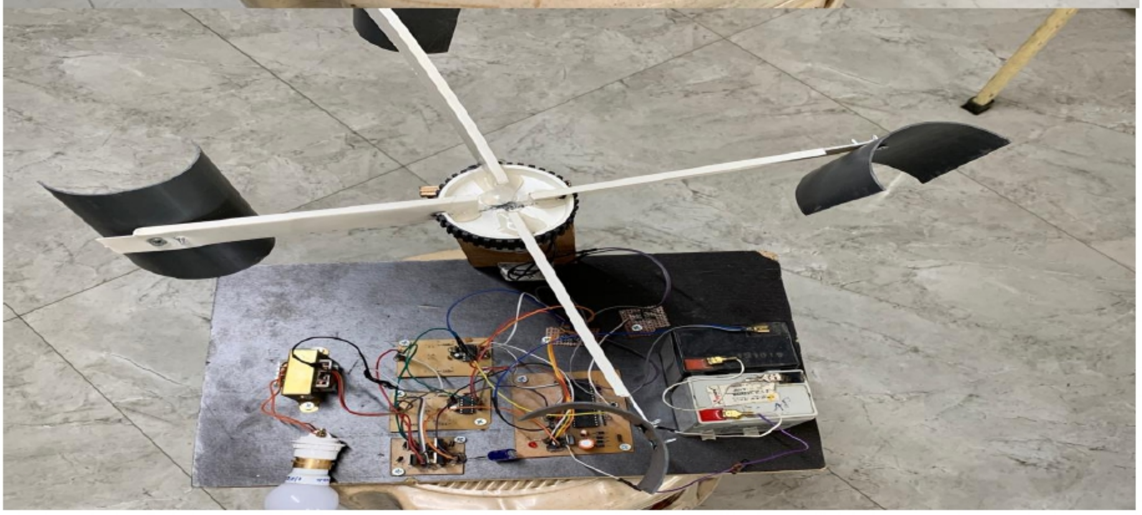


Fig 5: Readings in DSO

V. Conclusion

The DC-to-DC Conversion process is widely used in the power electronics. This paper proposes a method, which is for the maximum power extraction for wind turbine by using an CSPWM (Continuous Switching pulse width modulation) and SPWM (sinusoidal pulse width modulation). By using maximum power point tracking theorem and PWM techniques the power conversion and extraction of wind turbine is controlled. In rectifier and inverter using the methodology of continuous pulse width modulation (CSPWM) and sinusoidal pulse width modulation (SPWM) maximum power is extracted and stabilized efficiently. Wind energy system extracted maximum power by controlling the wind turbine rotational speed.





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A.4 Publication Certificates

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Authored By

Sanket Kale,
Student, Department of E&TC Engineering, PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune, MH, India

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A.5 Project presentation competition Certificates

PCET's Pimpri Chinchwad College of Engineering and Research, Ravet, Pune

Department of Electronics and Communication

Certificate of Appreciation

This Certificate is presented to **Sanket Kale** of **BE (E&TC)** for successfully presenting the project on **Power converter and control of wind energy using maximum power extraction** in the Project Presentation Competition held on 11th April 2023 at Department of Electronics and Communication.

Mr. Kishor Bhangale

Project Coordinator

Dr. Rahul Mapari

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Mr. Kishor Bhangale	Dr. Rahul Mapari
Project Coordinator	**HOD (E&TC)**