National Conference on Sustainable Engineering And Management (NCSEM24) ISSN 2349-6002

Conversion Comprehensive Review Wind Energy Systems and Analysis

Sagin J
Assistant Professor, Department of Electrical and Electronics Engineering, Sivaji College of Engineering and Technology

Abstract: Wind power now represents a major and growing source of renewable energy. Large wind turbines (with capacities of up to 6-8 MW) are widely installed in power distribution networks. Increasing numbers of onshore and offshore wind farms, acting as power plants, are connected directly to power transmission networks at the scale of hundreds of megawatts. As its level of grid penetration has begun to increase dramatically, wind power is starting to have a significant impact on the operation of the modern grid system. Advanced power electronics technologies are being introduced to improve the characteristics of the wind turbines, and make them more suitable for integration into the power grid. Meanwhile, there are some emerging challenges that still need to be addressed. This paper provides an overview and discusses some trends in the power electronics technologies used for wind power generation. First, the state-of-the-art technology and global market are generally discussed. Several important wind turbine concepts are discussed, along with power electronics solutions either for individual wind turbines or for entire wind farms. Some technology challenges and future solutions for power electronics in wind turbine systems are also addressed.

INDEX TERMS: Grid, Power Electronics, Wind Turbines, wind power.

I. INTRODUCTION

In recent years, wind energy has become one of the most economical renewable energy technologies. Today, electricity generating wind turbines employ proven and tested technology, and provide a secure and sustainable energy supply. At good, windy sites, wind energy can already successfully compete with conventional energy production. Many countries have considerable wind resources, which are still untapped. The technological development of recent years, bringing more efficient and more reliable wind turbines, is making wind power more cost-effective. In general, the specific energy costs per annual kWh decrease with the size of the turbine not withstanding existing supply difficulties. Many African countries expect to see electricity demand expand rapidly in coming decades. At the same time, finite natural resources are becoming depleted, and the environmental impact of energy use and energy conversion have been generally accepted as a threat to our natural habitat. Indeed, these have become major issues for international policy. Many developing countries and emerging economies have substantial unexploited wind energy potential. In many locations, generating electricity from wind energy offers a cost-effective alternative to thermal power stations. It has a lower impact on the environment and climate, reduces dependence on fossil fuel imports and increases security of energy supply. For many years now, developing countries and emerging economies have been faced with the challenge of meeting additional energy needs for their social and economic development with obsolete energy supply structures. Overcoming supply bottlenecks through the use of fossil fuels in the form of coal, oil and gas increases dependency on volatile markets and eats into valuable foreign currency reserves. At the same time there is growing pressure on emerging newly industrialised countries in particular to make a contribution to combating climate change and limit their pollutant emissions. In the scenario of alternatives, more and more developing countries and emerging economies are placing their faith in greater use of renewable energy and are formulating specific expansion targets for a 'green energy mix'. Wind power, after having been tested for years in industrialised countries and achieving market maturity, has a prominent role to play here. In many locations excellent wind conditions promise inexpensive power generation when compared with costly imported energy sources such as diesel. Despite political will and considerable potential, however, market development in these countries has been relatively slow to take off. There is a shortage of qualified personnel to establish the foundations for the exploitation of wind energy and to develop projects on their own initiative. The absence of reliable data on wind potential combined with unattractive energy policy framework conditions deters experienced international investors, who instead focus their attention on the expanding markets in Western countries.

Wind power can play a major role in meeting USA's increasing demand for electricity, according to a ground-breaking technical report, 20% Wind Energy by 2030: Increasing Wind Energy's Contribution to US Electricity Supply, prepared by the US Department of Energy with contributions from the National Renewable Energy Laboratory, the AWEA, Black & Veatch and others from the energy sector To implement the 20% Wind Scenario, new wind power installations would increase to more than 16,000 MW per year by 2018, and continue at that rate through 2030, as shown in Fig 3 Wind plant costs and performance are projected to improve modestly over the next two decades, but no technological breakthroughs are needed In the 20% wind scenario, 46 states would experience significant wind power development

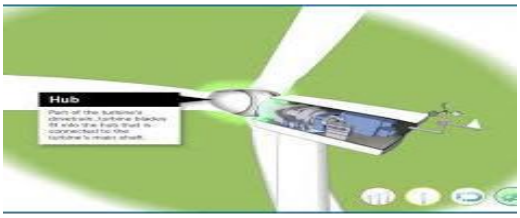
The report finds that during the decade preceding 2030, the US wind industry could:

(a) support roughly 500,000 jobs in the United States, with an annual average of more than 150,000 workers directly employed by the wind industry;
(b) support more than 100,000 jobs in associated industries (egg accountants, lawyers, steel workers and electrical manufacturing);
(c) support more than 200,000 jobs through economic expansion based on local spending;
(d) increase annual property tax revenues to more than $15 billion by 2030 and
(e) increase annual payments to rural landowners to more than $600 million in 2030

The report explores one scenario for reaching 20% wind electricity by 2030 and contrasts it to a scenario in which no new US wind power capacity is installed It examines costs, major impacts and challenges associated with the 20% Wind Scenario It investigates requirements and outcomes in the areas of technology, manufacturing, transmission and integration, markets, environment and siting The report finds that the Nation possesses affordable wind energy resources far in excess of those needed to enable a 20% scenario [15]

Wind power is a well-proven and cost-effective technology and expected to be the main way in which industry responds to the Government's targets – so becoming an important source of electricity in years to come

Wind farms are created when multiple wind turbines are placed in the same location for the purpose of generating large amounts of electric power Due to rising energy prices and the resultant search for



alternatives, there are now thousands of wind farms in many countries around the world There is still a lot of controversy surrounding the pros and cons of wind power and its local impact The articles listed on this page explore news and information about wind farms Now major electric companies are going green and proudly proclaiming it too from rooftops

II.COMPONENTS OF WIND ENERGY SYSTEM

Wind energy systems harness the kinetic energy of wind to generate electricity. They consist of several key components that work together to achieve this goal. Here's a breakdown of the essential elements:

A. Tower: The towering structure that supports the entire wind turbine. Made of steel or concrete, with heights ranging from 50 to 150 meters for onshore turbines and even taller for offshore turbines. Provides a stable platform for the nacelle and rotor to capture wind energy at higher altitudes where wind speeds are stronger

Fig: 1 Wind turbine tower

B. Nacelle: The housing at the top of the tower that encloses the main components of the wind turbine. Rotates to keep the rotor facing into the wind for optimal energy capture. Contains critical components like the drivetrain, generator, and control systems.

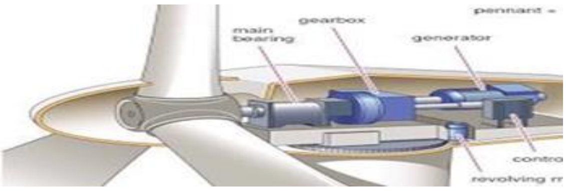


Fig: 2 Wind turbine nacelle

C. Rotor**:** The set of blades that spin in the wind to capture its kinetic energy. Typically made of fiberglass or reinforced plastic for strength and flexibility. Number of blades varies, with 3 being the most common due to efficiency and cost considerations. Blade design and pitch angle are crucial for maximizing energy capture under various wind conditions.Fig : 3 Wind turbine rotor

D. Drivetrain**:** The system that transfers the rotational energy from the rotor to the generator. May include a gearbox to increase the rotational speed for efficient electricity generation. Modern turbines increasingly use direct-drive systems for simpler design and lower maintenance.

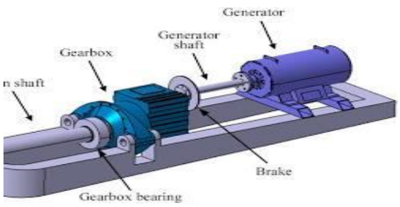


Fig: 4 Wind turbine drivetrain

E. Generator**:** The heart of the wind turbine, converting the rotational energy from the drivetrain into electricity. Uses magnets and coils to create an electric current as the shaft spins. Type of generator (induction or synchronous) depends on specific turbine design and grid requirements.

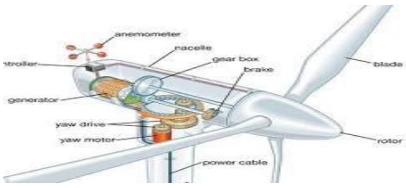


Fig: 5 Wind turbine generator

F. Control Systems**:** The brains of the wind turbine, monitoring and regulating its operation for optimal performance and safety. Sensors measure wind speed and direction, adjusting the blade pitch and nacelle orientation to maximize energy capture. Safety systems ensure automatic shutdowns in case of high winds or other emergencies.

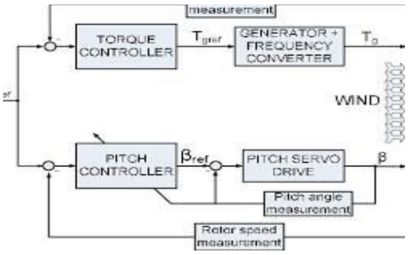


Fig : 6 Wind turbine control systems

G. Electrical Collection System: The network of cables and transformers that transmit the generated electricity from the turbine to the grid. May involve voltage conversion depending on the distance and connection to the grid. Includes safety features to protect against electrical hazards.

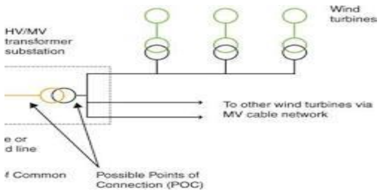


Fig : 7 Wind turbine electrical collection system

H. Foundation: The base that anchors the wind turbine to the ground. Designed to withstand the weight of the turbine and the forces exerted by wind. Can be concrete, steel, or a combination depending on soil conditions and site requirements.

Fig: 8 Wind turbine foundation

III.TYPES OF WIND ENERGY

A Onshore Wind Energy:

Wind farms located on land, typically in areas with strong and consistent winds like hills, plains, and coastlines. More mature and cost-effective technology with widespread adoption. Can have visual and noise impacts on nearby communities, requiring careful planning and mitigation strategies.

Fig : 9 Onshore wind farm

B: off shore Wind Energy:

Wind farms located in bodies of water, usually at sea where wind speeds are stronger and more consistent. Newer technology with higher capacity turbines, offering significant potential for future growth. Faces challenges like higher installation and maintenance costs, and requires specialized technology and infrastructure.

Fig : 10 Offshore wind farm

There are several ways to graphically represent wind power generation, depending on the specific information you want to convey. Here are a few options:

C. Wind Turbine Schematic:
This diagram illustrates the key components of a wind turbine and how they work together to generate electricity. It typically includes:Tower: Supports the turbine and rotor.
Nacelle: Houses the gearbox, generator, and other critical components.
Rotor: Consists of blades that capture wind energy.
Drivetrain: Transfers rotational energy from the rotor to the generator.
Generator: Converts mechanical energy into electrical energy.
Transmission lines: Carry the generated electricity to the grid.

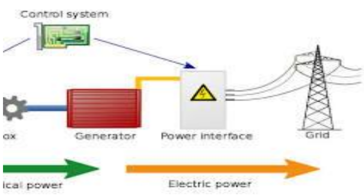


Fig : 191Wind Turbine Schemata

D .Wind Farm Layout:

This map shows the arrangement of multiple wind turbines within a wind farm. It can reveal factors like:Number and spacing of turbines: Influences land use and energy production potential.Terrain and wind patterns: Affect turbine placement for optimal wind capture.Connection to power grid: Shows how generated electricity is integrated into the system.

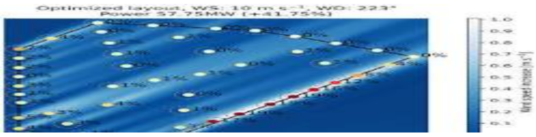


Fig : 12Wind Farm Layout

E. Power Generation Graph:

This chart displays the amount of electricity generated by a wind turbine or farm over time. It can show:Fluctuations in power output: Reflecting variations in wind speed and direction.

Average power generation: Indicating overall performance and contribution to the grid.

Comparison with other energy sources: Highlighting the role of wind energy in the power mix.

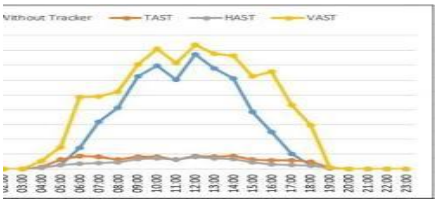


Fig : 13 Power Generation Graph

F. Global Wind Power Map:

This interactive map visualizes global wind power capacity and generation. It allows you to explore:Geographical distribution of wind farms: Highlighting areas with strong wind resources.Contribution of different countries: Comparing their wind power generation capacity.Growth trends over time: Demonstrating the increasing role of wind energy in the global energy mix.

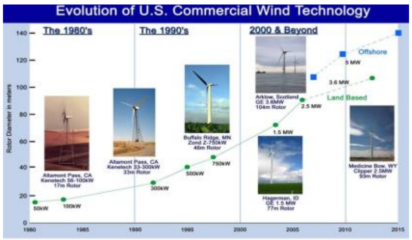


Fig14: Evaluation of wind energy technology

V. CLASSIFICATION OF WIND TUBINES

A. Micro wind Turbines: Small-scale turbines for individual homes or businesses, generating electricity for on-site use.

Fig 15: Micro wind turbine

B. Horizontal-Axis Wind Turbines (HAWT): Horizontal axis wind turbines (HAWTs) are the most common type of wind turbine, and they're the ones you probably picture when you think of wind turbines in general. They have two or three long blades that spin around a horizontal axis, much like a giant propeller. The wind blowing over the blades creates lift, which turns the rotor and generates electricity. These are the most common type, resembling giant propellers with blades rotating on a horizontal axis. Typically have 3 blades, but some designs can have 2 or even more. Offer high efficiency and are suitable for a wide range of wind speeds and locations. Dominant technology in wind farms globally.

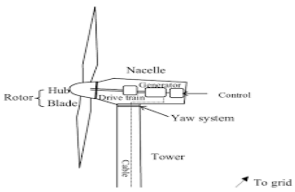


Fig 16: Horizontal axis wind turbine

Here are some of the advantages of HAWTs:

High efficiency: HAWTs can convert a large amount of wind energy into electricity. Large power output: The size of HAWTs allows them to generate a lot of electricity. Mature technology: HAWTs have been around for many years, and the technology is well-developed. However, there are also some disadvantages to HAWTs: High cost: HAWTs are expensive to manufacture and install. Visual impact: The large size of HAWTs can make them visually obtrusive. Noise**:** HAWTs can generate noise, which can be a nuisance to nearby residents.rid and bat mortality: HAWTs can kill birds and bats that fly into the bladesDespite these disadvantages, HAWTs are a valuable source of renewable energy, and they are likely to continue to play a major role in the future of energy production.

C. Vertical-Axis Wind Turbines (VAWT): Less common than HAWTs, with blades rotating on a vertical axis, resembling an eggbeater or windmilling design. Offer advantages like omnidirectional wind capture and potentially lower noise emissions. Still under development and typically smaller in size compared to HAWTs.

Fig 17: Vertical axis wind turbine

Certainly! Vertical axis wind turbines (VAWTs) are quite different from their horizontal counterparts. As the name suggests, their main rotor shaft is set transverse to the wind, meaning the blades rotate around a vertical axis. This design offers several advantages and disadvantages compared to HAWTs:

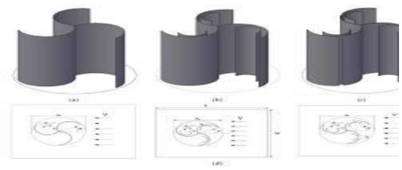


Fig 18: Types of VAWT

These have airfoiled blades that utilize lift forces for higher efficiency. However, they experience pulsating torque, requiring complex drivetrain components.

Fig 19 :H-rotor: These are a variation of the Darrius design with improved structural stability and lower torque pulsations.

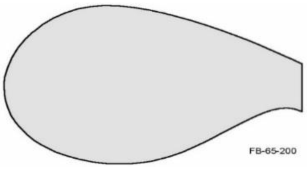


Fig 20: VAWT:

V.WIND TECHNOLOGIES OF THE FUTURE

The European Wind Energy Technology Platform[5] envisions that "in 2030, wind energy will be a major modern energy source, reliable and cost competitive in terms of cost per kWh." In addition, they foresee that wind energy will contribute 21% to 28% of the European Union (EU) electricity demand, which is similar to the scenario described previously for the United States. The European Wind Energy Technology Platform describes a long series of research and development improvements that will be necessary to make wind cost competitive by 2030. The reader interested in this challenging multi-disciplinary research program is referred to reference 5. There is no "big technology breakthrough" envisioned for wind technology in the United States or in Europe. However, many evolutionary steps executed with technical skill can cumulatively bring about a 30% to 40% improvement in the cost effectiveness of wind technology over the next two decades.

VII. CONCLUSION

Wind energy presents a powerful and cost-effective solution for combating climate change and achieving energy security. Continuous technological advancements and strategic policy frameworks can pave the way for wind power to become a leading force in the global energy mix. The use of wind energy was an old practice since thousands of years ago However, this technology has revived due to the shortage of fuels and the environmental problems generated by the traditional energy resources The last decade has seen a sharp increase in wind turbine generated electricity globally and is now well accepted with a large industry manufacturing and installing thousands of MWs of new capacity each year Although there are exciting new developments, particularly in very large wind turbines, and many challenges remain, there is a considerable body of established knowledge concerning the science and technology of wind turbines This book is intended to present some of this knowledge and to present it in a form suitable for use by students and by those involved in the design, manufacture or operation of wind turbines

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