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State of the Art in Wind Turbine and Photovoltaic Panels

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Abstract. This paper functions as an instructional resource for budding researchers in the field of electrical engineering engaged in generating electrical power from renewable energy sources. It will provide insights into wind turbines, listing their constituent parts and fundamental operational principles. Additionally, the paper will delve into the operational principles of photovoltaic panels, their various categories, and their significance within the realm of renewable energy. By perusing this material, readers can develop a comprehensive grasp of these state-of-the-art technologies, ultimately fostering the progress of the field and advocating for a more sustainable future.

Keywords – Wind Turbine, Photovoltaic Panels, Renewable energy sources

1. Introduction

The purpose of this paper is to emphasize the essentiality and significance of producing electric power through the utilization of wind turbines and photovoltaic panels. In contemporary times, the origin of electric energy has evolved into a focal point of discourse and deliberation, prompted by escalating environmental apprehensions and the issue of climate changes[1], [2]. Within this framework, wind turbines and photovoltaic panels have assumed a substantial role in fulfilling our progressively mounting electricity requisites in an environmentally responsible and sustainable approach[1], [2]. Wind turbines harness the power of wind to produce electricity through the rotation of their blades, transforming kinetic energy into electrical power[3]. Conversely, photovoltaic panels utilize semiconductor materials, specifically solar cells, to convert solar energy into electricity. These renewable technologies provide environmental benefits by diminishing greenhouse gas emissions. Wind turbines and photovoltaic panels alike offer hope for a sustainable energy landscape, diminishing our reliance on fossil fuels and ameliorating the effects of climate changes[3], [4].

2. Wind turbines

Wind energy technology captures kinetic energy from moving air. Wind power measures the rate of extracting this energy and the kinetic energy flow in the air. Efficient wind power extraction balances slowing down the wind while maintaining a sufficient flow. This section quantifies these key concepts and explores the nature of wind[5], [6], [7], [8]. Global attention has increasingly focused on global energy and environmental protection. Wind power technology, a mature and commercially viable option, has witnessed rapid global development, exemplified by China's doubling wind power market since 2006, making it the world leader in installed capacity with 41.827GW in 2010, surpassing the

United States[9], [10]. In this part of the article, it is a must to mention about both concepts of „onshore” and „offshore” wind power. It is one of the foundations on which Europe and it`s member states will implement the Green Deal, giving society a carbon neutral future. Also, offshore wind power is a formidable challenge for a new generation and opportunity in Romania. According to the European Commission, Europe needs between 230 and 450 GW offshore wind energy capacities by 2050. Europe leads the world in offshore wind technology with substantial annual investments of around 10 billion euros. Romania, the leader in onshore developments in Southeast Europe with 3GW installed capacity, aims to double it within the next decade per the National Integrated Energy and Climate Change plan 2021-2030 submitted to the European Commission. However, offshore potential along the Black Sea coast remains relatively unexplored[11], [12], [13].

2.1. Operating principles of wind turbines

To exemplify the conversion of kinetic energy into electric energy, it will be used a benchmark system, HIWF, located in Ontario, Canada. It is known as the largest windfarm comprising 87 vestas 3.45 MW wind turbines and other infrastructure. Figure 1 shows the wind turbine conversion system, and electrical connection in the HIWF. The turbine is equipped with a low voltage (800V) induction generator decoupled from the collector grid using two fully rated voltage source converters (VSC’s). The generator side VSC performs a vector control over the induction generator (IG) for maximum power point tracking (MPPT), while the grid side converter maintains a fixed DC-link voltage and controls the power flow. The output of grid side converter is 720V, which is stepped-up to 34.5 kV and connects the turbine to the windfarm collector grid[14].

Figure 2 shows wind turbine characteristics. The turbine starts delivering power at cut-in-velocity of 3 m/s and reaches its nominal 3.45 MW power at 11.5 m/s. Beyond the cut-out velocity of 22.5 m/s the turbine output power in zero, however, it is on standby and as soon as the wind velocity returns to below 20,5 m/s, referred to as recut-in velocity, it starts generating power. The grid side VSC always maintains a DC-link voltage, hence as soon as the wind velocity reaches cut-in or is reduced to re-cut-in the turbine starts generating power. The turbine rotor speed increases in velocity from 5.6 RPM at cut-in velocity to 15.3 RPM for the velocities above rated and below cut-out. The rotor speed is increased to 550-1500 RPM using a 3 - stage gearbox within the turbine nacelle[4].

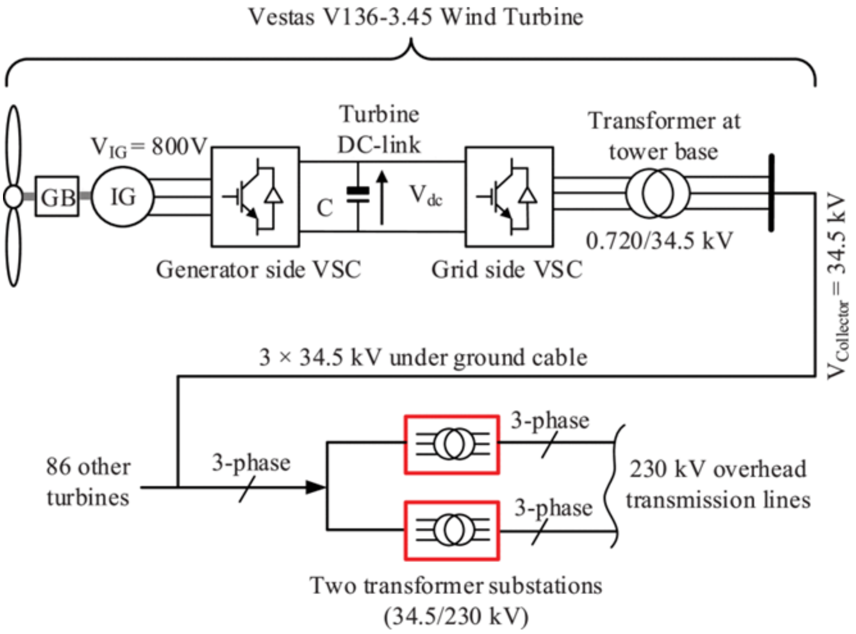

Figure 1 – Wind Turbine Conversion system and Electrical Connections [14]

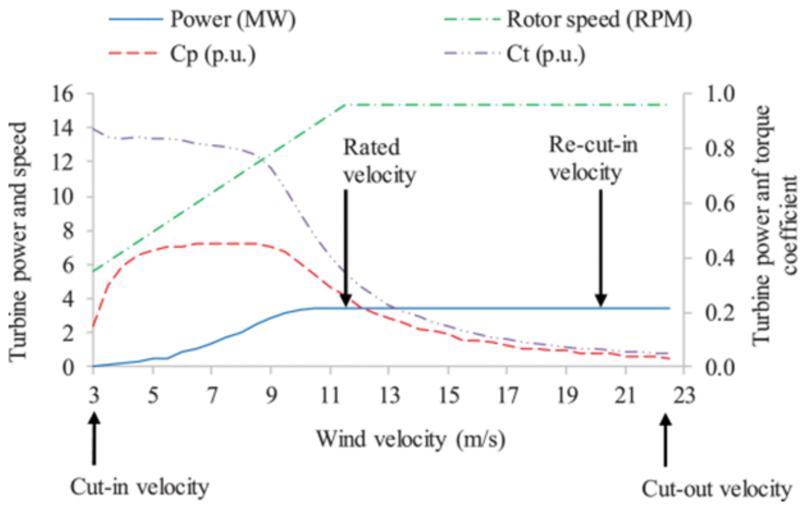

Figure 2 – Wind Turbine – Characteristics [14]

2.2. Components of wind turbines

Figure 3 presents the component parts of a wind turbine[15].

The rotors, or the blades, converts the wind into energy. The blades job is to, in essence, “catch” the wind. This causes the blades to start to rotate and create rotational shaft energy[4]. It essentially converts kinetic energy into mechanical energy. This mechanical energy is then converted into electrical energy by other various parts in the wind turbine[10], [15].

The wind-turbine shaft is connected to the center of the rotor. The shaft spins when the rotor spins. The rotor transfers it`s rotational mechanical energy into the shaft which is connected to an electric generator on the other end[15], [16].

The electric generator uses the properties of electromagnetic induction to produce an electrical voltage. At the heart of the operation of all AC machines is the concept of the rotating field produced by a set of static coils. There is also a set of windings in the rotor. Any rotation of the rotor shaft will cause an electromagnetic induction. A voltage will be induced in the rotor conductor. The current will then be generated in the coil which will drive the power through the distribution lines[8], [15].

There are many miscellaneous parts to wind turbines that might not affect the bigger wind turbines but have a significant effect on the smaller less expensive versions: anemometer, wind vane (it shows the direction of the wind[15], [17], [18].

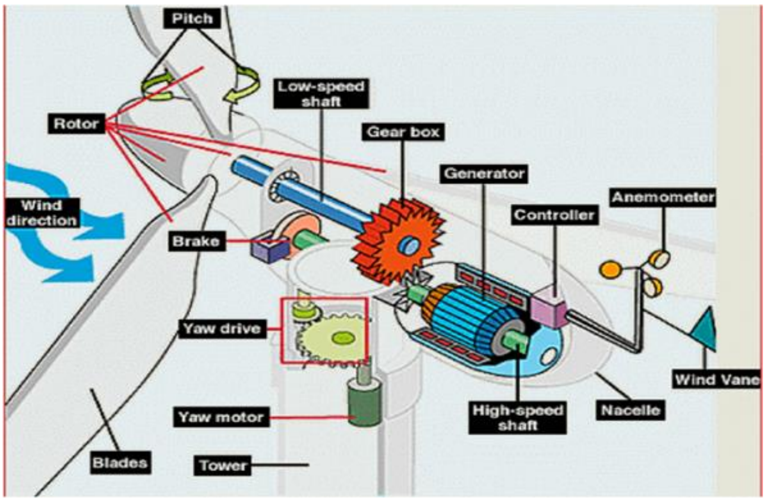

Figure 3 – Components of an HAWT – Horizontal – axis Wind turbine [15]

3. Photovoltaic panels

3.1. Photovoltaic Panels - Introduction

Photovoltaics (PV) has revolutionized electricity production and consumption. Solar energy systems harness the power of the sun, offering a sustainable alternative to conventional fossil fuels[1], [19]. This comprehensive guide covers all aspects of solar power, from its functioning to its various types. Photovoltaic technology employs semiconductors to generate electricity through the photovoltaic effect. When photons of light, whether natural or artificial, enter a photovoltaic cell with adequate energy, they can energize electrons, prompting them to transition to a higher energy state[20], [21], [22].

Within a semiconductor, previously immobile electrons become activated and start to behave as if they were in a conductive material. These liberated electrons can subsequently be harnessed, generating an electric current that can be utilized for generating electricity[1], [23], [24], [25]. The amount of electricity produced is directly linked to the level of light absorption by the cell; the more light absorbed, the greater the electricity generation. Through this photovoltaic process, solar energy can be effectively converted into electricity, presenting a sustainable substitute for traditional energy production methods[13], [26], [27].

In recent years, there has been a notable surge in the global adoption of renewable energy sources, including wind and photovoltaics (PV)[24]. These alternatives are increasingly regarded as practical options for diminishing reliance on fossil fuels and curbing greenhouse gas emissions[28]. The deployment of PV systems, spanning from small-scale to large-scale installations, has seen substantial growth, mainly attributable to the affordability of setting up and maintaining PV systems. Nevertheless, photovoltaic power generation is susceptible to weather conditions, resulting in fluctuations in power output during adverse weather. Distributed PV generation offers significant advantages, including adaptability to local conditions, environmental friendliness, and high efficiency[29]. In China, there's a noticeable surge in the expansion of distributed PV systems. However, a challenge arises when increasing the share of PV alongside conventional energy sources due to the power system's limited ability to regulate at low frequencies. This introduces greater uncertainty and risks in grid operations[30], [31], [32], [33].

As the costs of solar photovoltaic (PV) and energy storage technologies continue to decline, the integration of these systems under the "PV plus storage" concept has become economically viable[30]. Global warming, largely driven by carbon dioxide emissions from fossil fuel combustion for energy generation, stands as a critical concern for humanity. Renewable energy sources offer a significant opportunity to reduce carbon dioxide emissions, serving as an environmentally friendly alternative for energy production[30], [31], [33].

3.2. The principles of how photovoltaic panels work.

The fundamental principle behind the operation of photovoltaic panels is based on the use of special materials known as semiconductors. Solar cells, which make up photovoltaic panels, are typically made from crystalline silicon or other semiconductor materials. These materials possess unique properties that enable them to absorb photons of light and release electrons from their atomic structure[31], [33].

Solar cells function by absorbing sunlight, which liberates electrons from semiconductor material atoms, creating electron-hole pairs due to electromagnetism. These cells have a layered structure, with essential layers being phosphorus-doped and boron-doped silicon. Electrons move between these layers when exposed to sunlight, creating an electric current[1], [24]. This conversion into electricity is clean and eco-friendly, emitting no pollutants or noise. However, solar panel efficiency can be affected by factors like panel orientation, sunlight quality, and temperature. Solar panels are a crucial technology that transforms sunlight into electricity, offering a renewable energy source to reduce reliance on traditional power and combat climate change. Monocrystalline solar panels are a highly pure form of photovoltaic cells, recognized by their uniformly black appearance with rounded edges facing inwards[21], [34], [35].

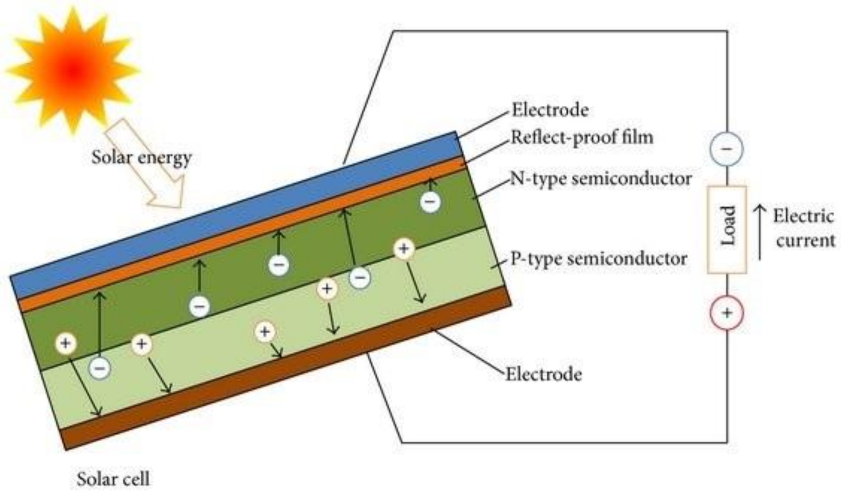

Figure 4 – Schematic operating principle of a PV solar cell[36]

The high purity of the silicon allows more space for electron movement, with an efficiency of around 20%[37].

Polycrystalline solar panels – Easily distinguishable, these cells have no cut corners, are blue in colour and are made by melting silicon in its natural state, a much faster and less expensive process than monocrystalline cells[37], [38].

Thin-film solar panels – Thin-film solar cells are made by depositing one or more films of photovoltaic material on a substrate such as glass, plastic or metal. The photovoltaic material can be silicon, cadmium, or copper. Because less material is needed for manufacturing, thin-film solar cells are the simplest and least expensive type of solar cell. However, their efficiency is about 15% lower[37], [38], [39].

An important component of a photovoltaic system is the photovoltaic cell. Photovoltaic cells, which are semiconductor devices, directly convert solar light into electricity through the photovoltaic effect. These constitute the fundamental building blocks of photovoltaic panels and are responsible for capturing and transforming solar energy into direct current (DC). Multiple photovoltaic cells are linked both in series and in parallel to create a photovoltaic module, which serves as the primary element of a solar panel.

In addition to photovoltaic cells, a photovoltaic system incorporates various essential components, including:

Inverters: These devices change the direct current (DC) generated by photovoltaic cells into alternating current (AC), which is used in most electrical applications[38], [39], [40].

Storage batteries (if applicable): Certain photovoltaic systems include batteries for storing electricity generated during daylight hours, which can then be used during periods without sunlight, such as evenings or overcast days[37], [39], [41].

Installation systems: These encompass the structures and is used for positioning and orienting photovoltaic panels optimally to capture maximum solar energy.

Monitoring and Control Systems: These enable the monitoring of the photovoltaic system's performance and the adjustment of parameters to enhance efficiency and safety[37], [39], [41].

Protection and Safety Devices: These consist of components such as overvoltage protection devices and short-circuit protection devices, ensuring the safety of both the system and its users[39], [42].

While all these components are critical for the correct and efficient operation of a photovoltaic system, the photovoltaic cell remains it`s core, as it is responsible for the conversion of solar energy into electricity[37].

The conversion efficiency of a photovoltaic system denotes the percentage of received light energy (solar energy) that is transformed into electricity. Conversion efficiency can vary depending on the type of solar cell and technology employed. In general, commercial solar cells on the market have exhibited an efficiency, though this efficiency is not yet available for large-scale installations[38], [39].

Innovations in photovoltaic systems continue to progress with the aim of enhancing efficiency, reducing costs, and making solar energy more accessible and diverse. Here are some recent innovations[37], [39]:

Wide Spectrum Photovoltaic Cells: Researchers are actively developing photovoltaic cells capable of capturing a broader range of solar light, including invisible infrared and ultraviolet light. This advancement can significantly enhance conversion efficiency[37].

Transparent Solar Panels: Ongoing research focuses on creating transparent solar panels that can be seamlessly integrated into windows and buildings, optimizing space utilization and solar energy capture[37], [39].

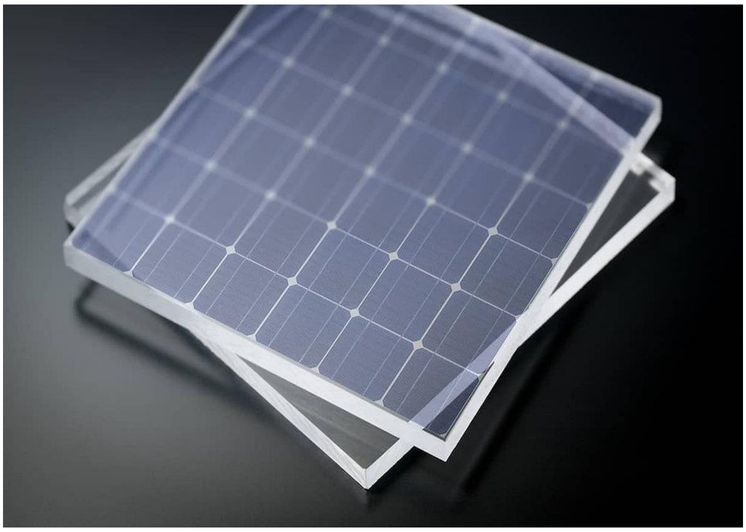

Figure 5 – Transparent solar panels[43]

Advanced Energy Storage Technology: Concurrently with solar energy systems, energy storage technology, encompassing more efficient batteries and thermal storage systems, is rapidly advancing[38].

Flexible and Lightweight Solar Panels: The development of flexible, lightweight solar panels suitable for use in mobile applications and integration into textiles, such as clothing and solar tents, is gaining traction[37], [38].

Hybrid Photovoltaic Systems: Integration of photovoltaic systems with other renewable energy sources, such as wind and hydropower, is being explored to create more efficient and diversified hybrid systems[37], [38].

Light Focusing and Cooling Technology: Efficient cooling technology and solar light focusing methods are being employed to enhance photovoltaic panel performance, especially in high-temperature and low-brightness conditions[38], [39].

Blockchain and Smart Grid: The utilization of blockchain and Smart Grid technology for the efficient management and distribution of locally generated solar energy is being explored as a promising avenue for the future[37].

4. Conclusions

This paper, of the "state of the art" type, is designed to provide essential information to those who are beginners in the field of renewable energy sources. The purpose of this document is to serve as a valuable resource for young researchers, offering them fundamental principles related to photovoltaic panels and wind turbines. Renewable energy, represented by photovoltaic panels (PV) and wind turbines, plays a pivotal role in addressing climate change and reducing our reliance on fossil fuels. These technologies offer substantial environmental benefits by virtually eliminating CO2 emissions during electricity generation, unlike conventional power plants that produce harmful pollutants. PV panels utilize the photovoltaic effect to convert sunlight into electricity, providing a clean and sustainable energy source for homes and businesses. Wind turbines harness wind power, an abundant renewable resource, to produce electricity and contribute to lower CO2 emissions. Advancements in both technologies continue to improve efficiency and make them increasingly attractive options for a greener and more sustainable future. Investing in renewable energy sources like PV and wind turbines brings numerous advantages. Aside from reducing CO2 emissions, they create jobs, foster innovation, enhance energy independence, and diversify the electricity supply. Moreover, these investments promote long-term energy price stability as solar and wind resources are abundant and free. This can result in lower costs for consumers and reduced energy market volatility. PV panels and wind turbines are pivotal solutions for curbing CO2 emissions and addressing climate change. Supporting their development on a scale is crucial for a sustainable and prosperous future.

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