International Journal of Technology, Leadership and Sciences (IJTLS)
ISSN: 3107-9083 www.ijtls.com Paper ID: TLS-26/V2/I2-015
DOI: https://doi.org/10.5281/zenodo.19124946

MODELING AND PERFORMANCE ANALYSIS OF A PMSG-BASED WIND ENERGY CONVERSION SYSTEM

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ABSTRACT: The global community is currently focused on the utilization of sustainable, clean, and natural energy sources to meet the energy needs of the future and provide a high-quality, pollution-free energy source to a growing number of environmentally conscious individuals. Power is generated by these energy sources through an infinite number of natural processes. A multitude of natural phenomena, including the sun, wind, and waves, serve as source of energy. Wind energy is now acknowledged as a significant and essential renewable energy source as a result of advancements in power electronics. In addition to these benefits, it is crucial to acknowledge that this energy exchange system is environmentally sustainable, less detrimental than alternative options, and accessible. The four primary components of a wind energy conversion system are the generator, wind rotor, connecting device, and control system. A diverse array of converter schemes is employed to connect the generating station to the grid station. PMSG is frequently employed in WECSs due to its numerous advantages, such as dependability and efficacy. A case study evaluates a Wind Energy Conversion System (WECS) that employs a Permanent Magnet Synchronous Generator (PMSG). In the event of a malfunction, a wind energy conversion system that employs a permanent magnet synchronous generator will exhibit instability and speed-related issues. A diverse array of control techniques must be implemented in order to optimize the system's dynamic performance and stability. Simulations can be conducted by anyone who has access to MATLAB/SIMULINK.

Keywords: *Wind Energy Conversion System, Permanent Magnet Synchronous Generator.*

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1. INTRODUCTION

Renewable energy sources are ones that can be used again and again, such as wind, solar, hydrological, oceanic, and wave energy. The best option is a direct-driven wind turbine equipped with a Permanent Magnet Synchronous Generator (PMSG). Rather than using a coil as its excitation field, a permanent magnet synchronous generator uses a permanent magnet. The majority of the electricity used by different industries is produced by symmetric engines. Electrical power can be produced from mechanical power produced by reciprocating, gas, steam, wind, and hydro turbines. The term "synchronous generators" refers to the requirement that the wheel's speed continuously match the power source's frequency. Permanent magnets create the magnetic field that powers the rotor in a permanent magnet generator. A magnetic field is created in the rotor winding by electromagnetics in a variety of turbine designs. A direct current-delivering slip ring system or brushless exciter powers the rotor field winding. Permanent magnet generators are ideal for high-power applications because of their remarkable efficiency, low maintenance requirements, and lack of a DC source in the excitation circuit. In many aspects of operation, variable-speed wind turbines outperform fixed-speed turbines. Benefits include reducing motor strain, increasing process efficiency, and optimizing power from varying wind speeds. The performance of a PMSG-based WECS (Permanent Magnet Synchronous Generator-based Wind Energy Conversion System) could be jeopardized if there is an instability caused by a malfunction. If control is inadequate, it will take a long time for the system to stabilize. However, a steady state can be quickly achieved with the right management practices.

2. WIND ENERGY CONVERSION SYSTEM

As fossil resources become increasingly difficult to locate and concerns regarding carbon dioxide emissions escalate, there is a significant interest in renewable energy sources, particularly wind power. Variable speed constant frequency (VSCF) wind energy conversion systems (WECS) have gained popularity since the late 1990s as a result of their proven capacity to optimize wind energy consumption. The two primary methods for converting wind energy into electrical power are the doubly-fed induction generator (DFIG) and the direct-drive permanent magnet synchronous generator (PMSG). The direct-drive Permanent Magnet Synchronous Generator (PMSG) is gaining popularity due to its exceptional dependability and efficiency. The illustration depicts a typical direct-drive wind energy

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conversion system (WECS) that includes a permanent magnet synchronous generator (PMSG).

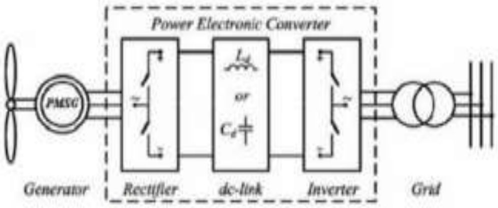

Fig 1 . Wind energy conversion system[1]

The mechanical energy of the wind rotor is converted into bidirectional alternating current (AC) electricity by the PMSG. After that, the data is transmitted to the power grid by a power electronic converter. The primary components of a wind energy conversion system (WECS) that employs a permanent magnet synchronous generator (PMSG) are illustrated in Figure 1. The wind energy conversion system is composed of several critical components, including the wind turbine, generator, converter, inverter, and grid.

Types of Wind turbine

At present, there are numerous varieties of wind turbine systems (WTS) available. They can be classified into two primary categories. The initial group adheres to the Danish principle of maintaining an uninterrupted and consistent work tempo. The generator is directly connected to both the grid and the propulsion system. Conversely, the generator is not directly connected to the electrical grid and operates at variable velocities. Electrical power converters are situated between the generator and the grid, enabling the rotor to rotate at varying velocities.

Fixed Speed Wind Turbine:

In constant speed arrangements, the powertrains function at a slower pace. The rotor shaft's utmost velocity is restricted by the generator's grid connection. The pitch control time constant and the mechanical characteristics of the constituent elements have an impact on the system's design and operation. The weather and the tower's shadow illustrate the rapid fluctuations in electricity generation. The mechanism of the grid-connected wind turbine is subjected to duress as a result of the aforementioned modifications, which in turn reduces the quality of the output and the lifespan of the turbine. Additionally, the optimal tip speed ratio necessitates the preservation of a consistent wind speed. Consequently, the wind machine is not always operating at its optimal level and is unable to capture the full energy of the wind. Differing velocity

Variable Speed Wind Turbine:

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Initially, wind energy conversion systems necessitated generators that were directly connected to the electrical infrastructure to ensure a consistent rotational velocity. Synchronous generators—or, in certain instances, asynchronous generators that maintained a relatively consistent speed—were employed to accomplish this. Power semiconductor technology has significantly affected wind energy conversion systems with variable speed. This method guarantees that the generator's variable frequency and the grid's constant frequency are in harmony. Wind turbine generators must be capable of varying their speed while simultaneously sustaining a consistent frequency from the grid.

Synchronous generators with field windings or permanent magnets and induction generators with enclosed or wound rotors necessitate a robust connection to a computer power converter. Variable-speed wind turbines offer numerous benefits when contrasted with wind turbines that operate at constant velocities. The rotating components of a variable-speed wind turbine can function similarly to a flywheel due to their substantial moment of inertia. This mitigates drivetrain tension and power fluctuations. Systems that operate at variable rates can optimize the extraction of energy from a partially loaded state. The rotor's velocity can also be altered through the use of adjustable speed designs. This enables the wind rotor system to operate at or near its optimal tip-to-speed ratio.

Generators Used in WECS

Wind energy conversion systems employ either Permanent Magnet Synchronous Generators (PMSG) or Doubly Fed Induction Generators (DFIG). The static and dynamic components of the DFIG are composed of windings. The windings in both sections can efficiently transfer a substantial quantity of electricity from the shaft to the grid. According to DFIG, converters are capable of managing only 25% to 30% of the total power generated by the rotor and transmitted to the grid. by the stator, the remaining electricity is transmitted directly to the grid. Conversely, the converter is responsible for the regulation of all electricity produced by the PMSG.In devices intended for DFIG WECS (Double Fed Induction Generator Wind Energy Conversion Systems), the expression "100%" refers to a three-stage clutch. Doubly Fed Induction Generator (DFIG) technology is the preferred choice of the majority of wind turbine manufacturers for their Wind Energy Conversion Systems (WECS) due to its affordability, portability, and spatial efficacy. Nevertheless, the brushes, slide rings, and gears of the DFIG are unreliable, which may render them unsuitable for certain applications. PMSG is highly efficient and necessitates minimal maintenance due to its absence of a

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transmission. Significant torque is delivered at low velocities by the PMSG drives, which operate independently and generate minimal noise.

Converters Used in WECS

There are numerous power converters for wind turbines that utilize direct-drive permanent magnet synchronous generators (PMSGs). The integration of a grid-side inverter with a generator-side rectifier is facilitated by the use of a dc-link component. Voltage source converters (VSCs) employ a capacitor, while current source converters (CSCs) employ an inductor. Additionally, each design necessitates a distinct inverter for the grid side and a distinct converter for the generator side. Generator-side rectifiers are classified into two categories: regulated and unregulated. A grid-side inverter is also known as a CSI or VSI. A comparison of the numerous layouts is then conducted.

Topologies	Advantages	Disadvantages
Thyristor supply side inverter	Continuous control of firing angle.	Harmonic distortion created
PMSG with diode rectifier converter	Robust in construction	Lost control flexibility
Back to Back two level VSC	Good performancecharact eristics	Voltage sharing issue
PMSG WECS using CSC	No switching harmonics	Poor stability of the system.
Back-to-back PWM converter	Separate control can be provided	Short life time
Multilevel VSC	Less Switching losses and Higher voltage and power capability	Voltage imbalance

Table 1: Comparison of converter topologies

3. SYSTEM MODEL

The direct drive system of the wind turbine eliminates the necessity for a transmission, as the mechanical output of the wind turbine is transmitted directly to the generator's rotor by a PMSG-based WECS. Alternating current (AC) electricity is transferred to the grid through the use of power electronic converters. The primary components of the system are the Permanent Magnet Synchronous Generator (PMSG), the propulsion system, and the wind turbine.

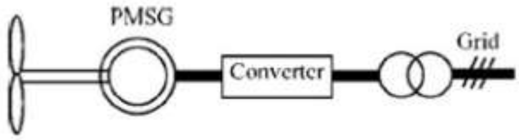

Fig 2. Grid-connected PMSG for direct-drive wind turbine [2]

The primary function of a wind turbine is to convert the linear velocity of the wind into rotational energy. Wind energy is transformed into electrical electricity by an electrical generator. A wind turbine generates electricity by utilizing wind energy.

$$P = 0.5\, C_p \rho A V^3 \quad (1)$$

The mass of air is denoted by ρ, while the area of the blade is represented by M2 A in square meters. Meters per second are the units of measurement for wind speed. The power coefficient, or CP, is the proportion of kinetic energy that the wind rotor converts to mechanical energy. The pitch speed ratio (λ) is employed by pitch-controlled turbines to modify the blades' pitch.

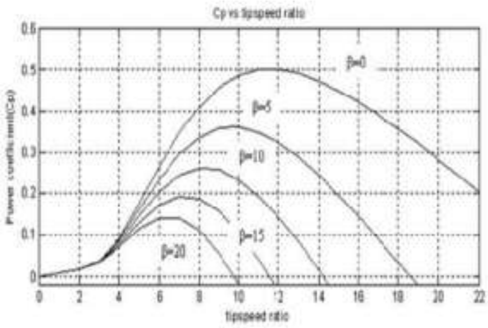

Fig 3: Power Coefficient of the Wind Turbine Model[3]

The power coefficient denotes the distinction between ideal and actual power. Particularly,

$$C_p = P_{actual} / P_{theoretical} \quad (2)$$

Pitch Control :

In order to optimize the wind turbine's energy output and prevent overpowering during strong surges, the blades' pitch angle is adjusted. If the generator speed surpasses the rated rotor speed, the pitch control system automatically adjusts the pitch angle to ensure that the turbine output remains at the appropriate level. The azimuth configuration of the wind turbine is adjustable.

4. SIMULATIONS

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The simulations were executed using MATLAB/SIMULINK. The image quality clearly demonstrates the wind energy conversion system's grid connection.

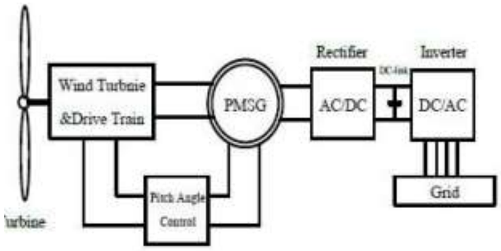

Fig.4: PMSG Based on WECS

The system's overall configuration is depicted in the figure. Power can be supplied to the grid and other applications through wind energy conversion systems. The output of the wind turbine within the wind energy conversion system is directly influenced by the permanent magnet rotor of the generator. A pulse width modulation voltage source inverter (PWM VSI) and a diameter rectifier are supplementary components that are used to connect the generator's output to the grid. The system's performance is evaluated under standard operating conditions. Figure 3.4 illustrates the challenge of evaluating the efficacy of the primary system that has been compromised. In the event of an issue, the grid-side power and voltage specifications, wind power plant, and capacity are insufficient.

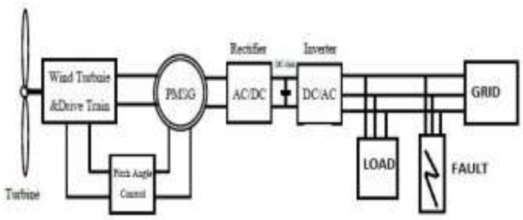

Fig 5: PMSG Based on WECS Under fault

Utilizing the equipment previously mentioned, a three-phase malfunction endures for 0.2 to 0.3 seconds. The graphic illustrates that the assessment is contingent upon the system's functionality during periods of inactivity.

5. RESULTS

The PMSG wind turbine's performance is easily accessible through a grid connection. Initially, the investigation is conducted within a conventional operational environment. Subsequently, the failure's efficacy is evaluated following its integration into the primary system.

Wind energy conversion system

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Wind energy exchange systems assess a variety of components, such as wind voltage, wind reactive power, and wind active power. Figure 6 illustrates the active power of the wind energy conversion system when it is functioning effectively. A speed-adjusting system is incorporated into a wind turbine, which results in fluctuations in power. Pitch angle regulation mitigates changes in force, regardless of the cause. Only when the wind turbine attains its utmost velocity does electricity generation commence.

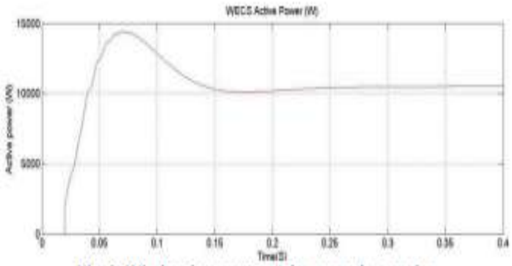

Fig 6: Wind active power under normal operation

The disruption of wind-generated power is illustrated in Figure 7. The power output of the wind device is reduced by a three-phase failure, which lasts for 0.2 to 0.3 seconds.

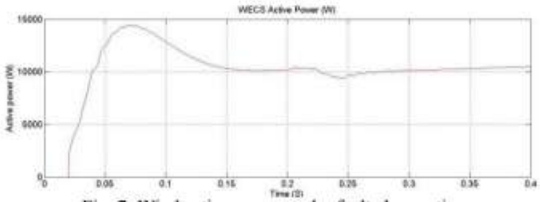

Fig. 7: Wind active power under faulted operation

Wind Reactive power : The standard operational response power of the wind turbine is depicted in Figure 8. The absence of electricity is a result of the need to reduce the pace during the commencement process.

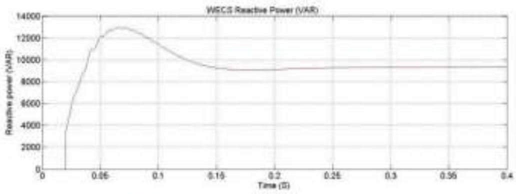

Figure 8: Wind reactive power under normal operation

The response when the wind is not operating effectively is illustrated in Figure 9. A three-phase fault typically lasts between 0.2 and 0.3 seconds. The system is presently unable to meet load demands as a result of fluctuations in reactive power.

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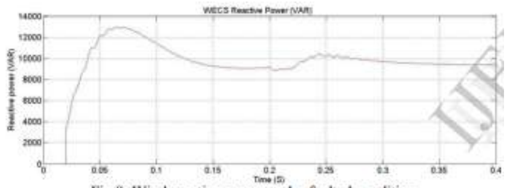

Fig.9: Wind reactive power under faulted condition

Wind Voltage profile : The output level of the wind system is illustrated in Figure 10. Wind turbines generate approximately 22 kilovolts of electricity.

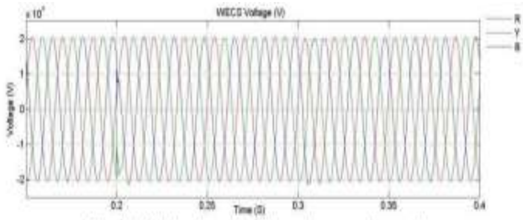

Fig.10: Wind voltage profile under normal operation

The voltage decreases to 10 kV within 0.2 to 0.3 seconds, which is equivalent to the duration of a three-phase fault. It is imperative to reduce this voltage loss in order to maintain the stability of the system.

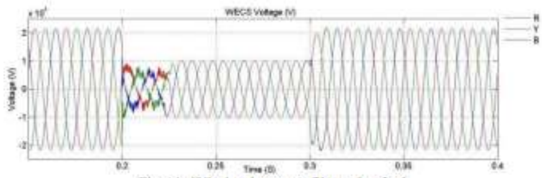

Fig.11: Wind voltage profile under fault

Wave forms at grid Grid Active power :

The grid's electricity consumption is depicted in Figure 12. Under standard conditions, the grid's operational electricity is approximately 7 MW.

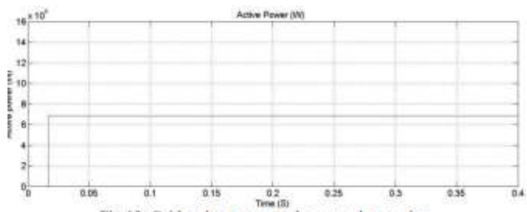

Fig.12: Grid active power under normal operation

The grid system's inadequate response time results in a disturbance caused by a three-phase failure that lasts for 0.2 to 0.3 seconds. The grid's active power is significantly reduced by the significant discrepancies in the power that is used.

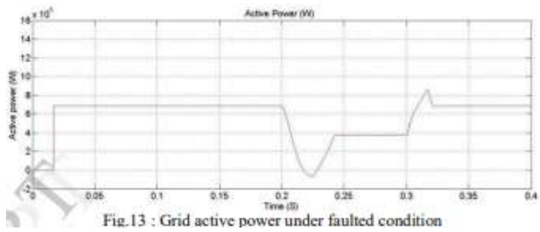

Fig.13 : Grid active power under faulted condition

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Grid Reactive power :

The grid's potential behavior is illustrated in Diagram 14. It is anticipated that the grid will generate 4 MVAR of reactive power under optimal circumstances.

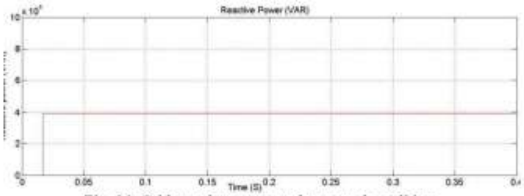

Fig. 14: Grid reactive power under normal condition

The system must make significant adjustments within 0.2 to 0.3 seconds as a result of the rapid fluctuations in the grid's power that occur following a three-phase failure.

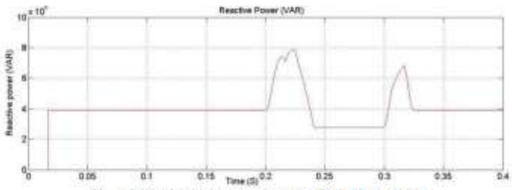

Fig. 15: Grid reactive power under faulted condition

The voltage curve of the grid is depicted in Diagram 16. At optimum operating conditions, the grid voltage is 39 kV.

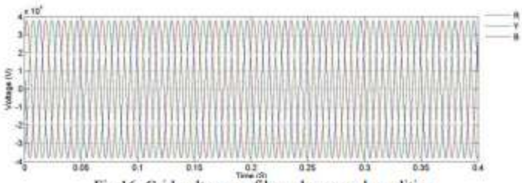
Fig.16: Grid voltage profile under normal condition

A three-phase failure with a duration of 0.2 to 0.3 seconds is depicted in Figure 17. The voltage waveform is disrupted, resulting in a decrease to 18 kV. It is imperative to preserve system stability in order to address this power decline.

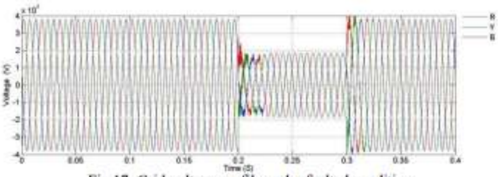
Fig.17: Grid voltage profile under faulted condition

When the reactive power, voltage, and current are within a specified range, a PMSG-based wind energy conversion system is operational. Every component of the system is replaced in the event of a three-phase failure. The machine's voltage and power will fluctuate. As a result, the system will demonstrate reduced stability. In order to operate efficiently, the wind turbine requires precise control methods to account for the potential rapid voltage fluctuations. The application of these control mechanisms promptly restores the system to its original configuration. The problem-solving process will be extended if they are not implemented.

6. CONCLUSION

A permanent magnet synchronous generator (PMSG) is the most suitable option for a wind turbine generator, as it does not require external power and operates at a moderate operating speed. Direct motors may be implemented in wind energy conversion systems (WeCS). This eliminates the need for you to consider the gearbox's mechanical intricacies and costs. The burden is secured by the stator winding insulation. The rotor is propelled by a system of magnetic poles that are exclusively magnetic. The Permanent Magnet Synchronous Generator (PMSG) operates with exceptional reliability and efficiency, without the need for external support or circuit losses. A power line adaptor is used to connect the Permanent Magnet Synchronous Generator (PMSG) to the electrical grid. In order to provide the grid with active electricity, this converter must operate at a specific voltage and frequency. Corresponding fluctuations in the frequency and amplitude of the terminal output voltage are the consequence of the PMSG's speed variation. The primary concern regarding the integration of wind turbines into the grid is the requirement to disengage them when the voltage falls below a predetermined threshold. A voltage decrease is the term used to describe this phenomenon. When the root mean square (RMS) voltage level decreases, a transient voltage reduction occurs. The duration may range from ten milliseconds to one minute. Temporal and depth/magnitude parameters are frequently the sole determinants of calculation methodologies. The voltage reduction may persist for a period of 50% to 1 minute and fluctuate between 10% and 90% of the standard voltage. The voltage drop in a three-phase system is the result of variations between each phase and between each phase and ground. During periods of high wind energy utilization, when grid personnel are unable to disengage the blades, an inverter, particularly an Isolated Gate Bipolar Transistor (IGBT), is employed to connect the Permanent Magnet Synchronous Generator (PMSG) to the grid. When the voltage decreases, the inverter is unable to modulate the current. It substantially augments the energy of the direct current (DC) capacitor. In order to prevent voltage instability and promptly restore voltage reductions to normal levels, the system must employ specific control strategies.

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