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Review on Employing Doubly Fed Induction Generator to produce Wind energy

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***Abstract*— Recently, an emerging trend has been observed in the past few years, concern for the utilization of sources, specifically in the field of electricity development and production. Extensive research and testing have been conducted by scientists and researchers to investigate the efficient utilization of wind energy. The study of energy research holds great importance and intricacy as it significantly impacts our daily activities. As a result of thorough research, wind energy is now commonly employed for power generation. This article offers a comprehensive analysis of the Doubly Fed Induction Generator (DFIG) in the context of the Wind Energy Conversion System (WECS). Essentially, this research has shed light on the various obstacles associated with grid-connected wind turbines based on Doubly Fed Induction Generators. In this paper, an examination is carried out on nonlinear wind turbine models utilizing DFIG and an explanation is provided on the DFIG configuration.**

***Index Terms*— Double-fed induction generator (DFIG), variable speed at constant frequency, and model reference adaptive system (MRAS).**

I. INTRODUCTION

Wind power currently holds the distinction of being the renewable energy source with the most rapid rate of expansion. The global installed capacity of wind power, as stated by the Global Wind Energy Council (GWEC), is in accordance with the information provided has experienced a substantial surge, reaching an impressive 906 GW by the conclusion of 2022. In the early stages of 2022, a remarkable 77.6 GW of wind power load was successfully integrated into power networks worldwide. India, situated in South Asia, achieved its peak wind energy capacity of nearly 41 GW in 2022, demonstrating an increase compared to the previous year's value of approximately 40 GW. At present, Tamil Nadu stands as the sole state in India that boasts the largest production of wind energy. Denmark holds the distinction of being the only country that has achieved 100 percent wind power utilization. The employment of generators has emerged as the prevailing methodology in recent times for seizing a greater amount of wind energy. In order to exploit wind energy to its fullest potential, the concept of variable speed operation has been implemented. Doubly Fed Induction with Variable Speed Constant Frequency (VSCF) generators possess numerous benefits over alternative generator models

The utilization of Doubly Fed Induction with Variable Speed Constant Frequency (VSCF) generators presents numerous advantages in comparison to alternative generator types. Several of these large-scale turbines are designed to rotate in accordance with the force of the wind, thereby generating electricity. In the year 2022, the leading global markets for new installations were composed of China, the United States, Brazil, Germany, and

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Sweden. Collectively, these five nations accounted for a substantial proportion of the worldwide installations, totaling 71%, which was 3% lower than the previous year. The primary factor contributing to this decline can be attributed to China, which remains one of the largest markets on a global scale.

II. LITERATURE REVIEW

Leonhard and P. Vas have brilliantly showcased an all-encompassing exposition of the cutting-edge vector techniques employed for the discrete regulation of torque and excitation current within the synchronous frame, as brilliantly exemplified by the esteemed Yamamoto and Motoyushi. These researchers have showcased the methods to segregate the control of the powers of the machine. In this methodology, the shape of reference remains immobile with respect to the air-gap flux, whereas the rotor aspect is fixed to the power grid through employment of a cycloconverter. The elucidation of the converter's design and control methodologies is explicated by Ned Mohan, Pena. Clare and Asher have furnished a thorough blueprint of generator utilizing back-to-back sources in the rotor circuit. Moreover, they have subjected the system to experimental assessment. The independent regulation of power necessitates knowledge of the rotor's precise position is relative to the stator. High-resolution position encoders for the system tend to have a higher cost and a lower level of reliability. The process of mounting the encoder in the DFIG wind turbine system can be quite challenging. It is essential to ensure that the encoder is positioned in a manner that allows for easy access to the angle between rotor and stator axis. The machine's sensor-less vector control was also discussed by P. Vas, who delved into the topic of a position sensor-free method for the machine's rotor side field-oriented control. V.T. Ranganathan further developed this method. Pena estimated the same while utilizing a model reference adaptive system (MRAS). Numerous scholars have put forth various methodologies for calculating the rotor position, rotor currents, and the torque angle. The majority of modern Conversion Systems that are connected to the power grid utilize systems based on DFIG. The configuration offers several benefits, such as the capability to efficiently track the maximum power, the ability to operate at variable speeds while maintaining a constant frequency, and the option for independent control of different powers. However, due to the direct connection of the stator side to the grid and the utilization of a back-to-back converter on the rotor side, the DFIG system is highly vulnerable to disturbances in the grid. Furthermore, these turbines must be able to resume their regular operation once the fault has been resolved and cleared. It is essential to devise a control strategy that enables the generator to function effectively in both typical and challenging grid conditions. It is crucial to maintain the voltage and regulate the fluctuations in the current of the generator side converter (GSC), even in the presence of a fault. Once the fault is rectified, the GSC resumes normal operation. However, this process leads to variations in the voltage, which is undesirable as it may impact the management of rotor current. While direct capacitor current control and current injection have been suggested as improved control methodologies in the literature, they do not meet the required performance and stability criteria.

A. DFIG

As suggested by its nomenclature, it represents a type of induction generator that includes windings of numerous phases positioned on the rotor as well as stator bodies. Additionally, it is comprised of a slip ring assembly of multiple phases to facilitate power transfer to the rotor prior. It is imperative to grasp a concise understanding of power generation through wind energy. The DFIG consists of a wound rotor and a wound stator, both having three phases. The rotor is activated by a three-phase AC signal, resulting in the generation of an alternating current in the rotor windings. As the wind turbines undergo rotational movement, they apply a mechanical force on the rotor, resulting in its rotation. Consequently, as the rotor turns, the generated magnetic field, resulting from the alternating current, exhibits a rotational movement that is directly correlated to the frequency of the AC signal being applied to the rotor windings. The production of an incessantly revolving magnetic flux leads to the generation of oscillating electric current in the coils of the stator. As a consequence, the velocity at which the magnetic field of the stator rotates is contingent upon both the speed the operational characteristics of the rotor and the frequency of the alternating current that is given to the rotor windings. The fundamental prerequisite for wind energy is to generate an alternating current signal with a consistent frequency, regardless of the wind speed. Put simply, the persistence of the generated alternating current signal across the stator is expected to be constant, irrespective of any changes in rotor speed. The adjustment of the frequency of the applied current signal to the rotor is necessary to achieve this goal.

III. COMPONENTS

A. Wind Turbine

It is commonly composed of a tri-blade fan that undergoes rotation upon impact. It is of utmost importance that the axis of rotation is properly aligned with the prevailing wind direction.

B. Gear Box

An intricate system that employs a mechanical approach to transform energy from one apparatus to other.

C. Double Fed Induction Generator

An electrical device employed for the transformation of mechanical energy into electrical/wind energy, manifesting in the manifestation of a frequency that fluctuates.

D. Rotor side converter

The device under consideration is an AC-DC inverter, a crucial component utilized for the purpose of supplying regulated AC voltage to the rotor.

E. Grid side converter

The DC-AC converter circuit utilized with the aim of providing a controlled DC voltage to the inverter. Its role is to maintain a consistent DC voltage.

IV. Configuration

The generator has been set up to function as a Wound Rotor Induction Generator (WRIG), where the connections are interconnected to stator terminal via the AC/DC/AC converter, and the stator windings which are directly linked to the power grid. In order to guarantee voltage level compatibility, a transformer is used to establish a connection between the two side converters.
The structured state of the configuration is delineated as follows:-

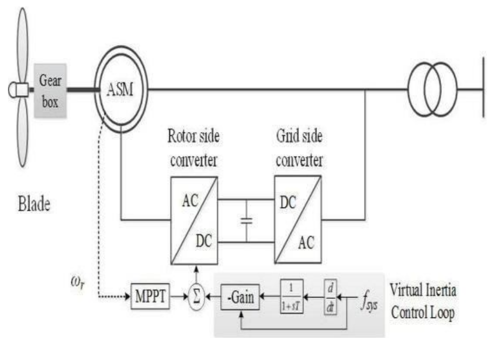

Fig 1: Configuration of DFIG

The DFIG system provides significant ability to adjust and control both active and reactive power which are essential for applications that necessitate a broad spectrum of speeds. The bidirectional power converter consists the system of a pair of typical voltage source converters that employee pulse width modulation, additionally featuring a capacitor for DC-link purposes, and a mutual DC bus. Back-to-back converters are commonly employed in DFIG-based systems for wind power applications in order to enhance power output. Recently, the advent of high-speed digital signal processors has greatly assisted in addressing the computational challenges associated with this. The denotation of the mechanical power of the wind turbine is expressed as;

$$P_{mech} = T_t \omega_t \qquad (1)$$

The Grid Synchronization Controller (GSC) is tasked with the responsibility of overseeing the regulation of reactive power within the grid as well as the management of the generator. In order to get the stability of the system, it is of utmost importance that the voltage remains consistent. The control methodology employed by the Rotor Side Converter (RSC) primarily focuses on the management of electromagnetic torque and the regulation of currents. A framework for the entire control mechanism is provided by a synchronous reference frame that is divided into d-q components. The primary aim of this framework is to uphold a consistent power factor of unity. The control of the DC-link voltage in the GSC control is so brilliantly represented by the utilization of the d-axis voltage vector. The q-axis current governs the control of the electromagnetic torque, while also regulating the power factor. It should be emphasized that in the event that the velocity regulator's dynamics exhibit excessive rapidity, it is of utmost significance, there is a possibility of experiencing large transients in the system. The DFIG apparently has some sort of special ability to work as both a generator and a motor in sub-synchronous (0<1) and super-synchronous (s>0) modals due to the converter's capability to transfer power in both directions. For the sake of simplicity, the power relation can be calculated by disregarding all losses.

$$Protor \simeq sPstator$$

$$Pstator \simeq Pgrid/\ 1-s$$

$$Pmech \simeq Protor\ /1-s = Pstator + Protor$$

The ensuing equations outline the standard voltage equations for an induction generator, as well as the equations for flux linkage. These equations are instrumental in constructing the mathematical model of a DFIG in a d-q frame that rotates at synchronous speed.

$$Vds = Rs\ ids + d\psi ds/\ dt - \omega s\psi qs$$

$$Vqs = Rs\ iqs + d\psi qs/\ dt - \omega s\psi ds$$

$$Vdr = Rs\ idr + d\psi dr\ /dt - (\ \omega s - \omega r\ )\psi qr$$

$$Vqr = Rs\ iqr + d\psi qr\ /dt - (\ \omega s - \omega r\ )\psi d\mathrm{r}.$$

V, I, R, and L represent the respective symbols denoting voltages, currents, resistances, flux-linkages, and winding inductances.

V. Applications

This type of generator is widely preferred for wind energy applications owing to its inherent benefits in regulating power output and facilitating seamless integration with the grid. The following are a few notable applications:-

A. Variable speed operation

DFIG allows variable sped operations, means it can adjust its rotor speed to optimize energy capture from varying wind speeds.

B. Grid integration

It can easily be synchronized with the grid, allowing for efficient power transfer and grid stability.

C. Reactive power control

DFIG can provide or absorb reactive power, aiding in voltage regulation and stability of the grid.

D. Partial load efficiency

It maintains high efficiency even at partial load, which is essential in areas with fluctuating wind speed.

E. Power smoothing

DFIG in combination with power electronics , can smooth out fluctuations in power output caused by gusty winds

VI. Challenges

The Doubly Fed Induction Generator (DFIG) is widely favoured for wind energy applications due to its inherent advantages in power output regulation and seamless integration with the grid. There are several notable applications of this generator. The power fluctuations caused by the grid, torque, and power variability, which are the main causes of the flicker problem, have a significant impact. Moreover, the cyclic aerodynamic torque change leads to increased loads and voltages. The nonlinearity of the system, the environment, and the constant modification of the operating point make the design of a controller more challenging. As a result, the utilization of control methods without sensors is frequently observed in the design. The estimation of the DFIG flux and rotor position is commonly utilized in order to reduce the cost, size, and maintenance requirements of the system. However, determining the rotor position can be a complex task due to the nonlinear dynamics of wind turbines and the stochastic nature of wind behaviour. Particularly challenging is the calculation of the angular difference using a wide range of vector angles. Additionally, the estimation of the rotor position and machine flow presents another significant challenge. Typically, open loop and observer methods are employed to estimate the rotor location. By means of parameter measurement and reference frame transformation, direct observation of the rotor position can be achieved. The differentiation of the rotor position allows for the determination of the rotor speed, although this may introduce some noise into the speed estimator, it is a necessary factor to consider. Moreover, the accuracy of open loop estimators cannot be guaranteed.

VII. CONCLUSION

The primary focus of this research pertains to the diverse challenges encountered by grid-connected nonlinear wind turbines. Furthermore, the study also addressed significant control issues associated with the DFIG device that is linked to the wind turbine. In summary, this review has thoroughly examined the utilization of Doubly Fed Induction Generators (DFIGs) for the purpose of wind energy production. Through a comprehensive analysis of various research papers and studies, it is apparent that DFIG technology exhibits considerable potential in effectively harnessing wind energy. The benefits of variable speed operation and improved control capabilities render DFIG a viable option for wind energy systems. Given the escalating demand for clean energy sources, the findings of this review underscore the critical role that DFIGs can fulfill in meeting these requirements. Researchers and industry professionals have the potential to drive the extensive implementation of DFIG technology in the renewable sector by tackling obstacles such as fault ride-through capability and adherence to grid code compliance. This review offers valuable perspectives on the potential of Doubly Fed Induction Generators (DFIGs) as a pivotal contributor in the journey towards a more eco-friendly and sustainable energy future. The persistence of research, innovation, and collaboration in this domain assumes utmost significance in actualizing the complete potential of wind generation based on DFIGs. The presented review highlights the potential of DFIGs in addressing the growing global demand for clean and sustainable energy. It emphasizes the need for continued dedication from researchers and industry professionals to refine and innovate in this field. Through their efforts, the widespread implementation of DFIG-based wind energy generation will undoubtedly be propelled. This study provides a compelling case for the pivotal role that DFIG technology plays in the transition towards a more environmentally conscious and sustainable energy future. With ongoing research, collaboration, and technological advancements, we are poised to unlock the full potential of DFIGs as a cornerstone in the renewable energy revolution. This thorough evaluation has illuminated notable advancements in the utilization of Doubly Fed Induction Generators (DFIGs) for harnessing energy. Through a detailed analysis of multiple studies and research efforts, it becomes apparent that DFIG technology represents a crucial solution in the pursuit of efficient wind power generation.

In conclusion, generating wind energy with the help of this type of generator is a practical and efficient technique to exploit wind resources to produce sustainable energy. We have examined the main traits and benefits of DFIG systems in the context of wind energy generating throughout this work.

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