Wind Energy Conversion System By Using Double Fed Induction Generator And Combined Active Power Filter Capabilities

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Abstract

This project deals with the operation of wind energy conversion system by using doubly fed induction generator (DFIG) with combined active power filter capabilities using grid-side converter (GSC) and rotor-side converter (RSC). The main contribution of this work lies in the control of GSC for supplying harmonics in addition to its slip power transfer and RSC is used for achieving maximum power extraction to supply required reactive power (Q) to DFIG, This wind energy conversion system (WECS) works as a static compensator (STATCOM) for supplying harmonics even when the wind turbine is in shutdown condition control algorithms of both GSC and RSC are presented in detail, The proposed DFIG-based WECS is simulated using MAT LAB/Simulink. A prototype of the proposed DFIG based WECS is developed using a digital signal processor (DSP). Simulated results are validated with test results of the developed DFIG for different practical conditions such as variable wind speed and unbalanced/single phase loads.

KEYWORDS: Doubly fed induction generator (DFIG), Grid-side converter (GSC), Wind energy conversion system (WECS), Static compensator, rotor-side converter.

INTRODUCTION

As the population increases and the demand for energy has rapidly grown many more unprecedented power plants have also been installed, and because of this the energy management system is also continuously developed. increased significantly. On the other hand, traditional energy sources like coal, oil, and natural gas such as propane are scarce and running out. This requires a transition to renewable energies. Which will be the future sources of energy? Wind energy is relatively more popular than other renewable sources trending with ecofriendly, sustainability and cost effectiveness due to technological advancements. Wind power now costs about the same as that of conventional power plants. Traditionally the earliest use of wind energy was fixed-speed wind turbines systems that utilize capacitor banks in squirrel cage induction generators. Fixed-speed wind turbines were preferred as more straightforward and affordable.

But testing wind turbines, the analysis of their characteristics indicates that these rotors must run at different speeds in the wind-speed range to extract the optimal power. Turbines to work with modern power electronic converters. at variable speeds, which greatly increases wind energy generation. Among various doubly fed induction generators (DFIGs) are commonly used as variable-speed wind turbines with regards to their cost-effective, enhanced energy yield pertinacious converter rating and productive generator utilization. Moreover, systems based on DFIG provide enhanced damping performance for weak grids. DFIG-Based Wind Energy Conversion System (WECS) has significant advantages due to the decoupled vector control scheme for independent control of active and reactive power control algorithm. This control is usually employed in a synchronously rotating chart aligned to the voltage or flux axis. In this study, the rotor-side converter (RSC) control with its traditional implementation in voltage-oriented reference frame the connection and operation of wind farms is subject to grid code requirements, and extensive studied. Comparatively, the response of DFIG based WECS to grid disturbances is analyzed to fixed-speed WECS. With increasing wind penetration in the power grid, variable-speed WECS should carry out additional functions such as power smoothing and harmonic mitigation with power generation. Buffering small power fluctuations with super magnets device, while ancillary services including reactive power compensation and Dynamic reactive power support & static compensation/displacement for SVC & for transient stability enhancement are provided through static compensators (STATCOM). A flywheel energy storage system (FESS)-based distribution STATCOM (DSTATCOM) is initiated in wind farm to suppress harmonic and frequency disturbances. However, more of these converters have been used for this purpose Furthermore, a supercapacitor prevents harmonics from being propagated to the DC link connecting the different energy storage system integrated in a Unified Power Quality Conditioner Unified Power Quality Controller (UPQC) is used to boost power quality and reliability. Researchers have used separate. for equipment in harmonic compensation and reactive power control. Subsequent work involved adopting traditional DFIG converter control strategies to resolve power quality issues and reactive power compensation. Harmonic compensation and RSC was used to control reactive power, causing the appearance of with electromagnetic noise and mechanical imbalances due to the impact of harmonics on the rotor winding leading to losses etc. Moreover, these approaches expanded the RSC rating. To overcome these limitations, the researchers proposed harmonic compensation and reactive power control to the grid-side converter (GSC) to avoid harmonics transmission via machine windings. Todeschini and Emanuel compared three control algorithms finding that combined harmonic compensation capability, which requires modulation of both RSC and GSC and reactive power control. However, in their study was used direct current control of the GSC, which was poorly adept at keeping Total Harmonic Distortion (THD) below 5% -- a requirement by IEEE-519 standards. Also, their simulation results were confirmed by experiments. Another indirect current control method is less complex and exhibits more effective than direct current control in harmonics elimination.

LITERATURE SURVEY

Typically, a Doubly Fed Induction Generator (DFIG) is designed using back-to-back PWM voltage- For the rotor circuit, they are called source converters. Supply-side PWM vector control scheme Converter independently controls active power and reactive power consumption from supply. while maintaining sinusoidal currents in the supplies. The rotor-connected vector control converter supports operation over a wide speed range, tucked inside control loops that optimize speed detection for home-made wind energy harvesting. A In [2], some capable active filtering is introduced with DFIGs employing the DFIG along with its system. Rotor Side Converter (RSC) for controlling the stator active and reactive power and concurrently canceling The report provides a review of prior research on solar energy and EV charging stations. The authors stress how crucial it is to have a dependable and sustainable charging infrastructure for the increasing number of EVs. They go over the advantages of using solar energy for EV charging stations as well as the difficulties in developing them, such as the fluctuation in solar energy production and shifting weather patterns. The suggested mathematical model accounts for the EVs' wireless charging, battery storage, and solar energy production. The writers also consider how the system's performance is impacted by environmental factors like temperature and humidity. The simulation findings demonstrate that the suggested system may offer EVs efficient and dependable charging services while reducing environmental impact.

The highest and most challenging harmonic currents of the utility grid. The proposed filter is a novel high selectivity harmonic is olator with self-tuning capability (STF) is presented. The harmonic isolator's efficacy is validated through simulation results Core and validate the theoretical filtering performance of a DFIG under harmonic filtering current components in the grid. DSTATCOM (Distribution Static Compensator) is in [3], which aims to perform reactive power and unbalanced loads compensation in a distribution system.

The method is evaluated on two different ways to obtain reference currents for the DSTATCOM: Q Instaneous Power Theory, Synchronous Reference Frame Theory and Adaline-Based Algorithm (an adaptive approach for extracting references). current signals. The methods are simulated in MATLAB by SIMULINK and PSB toolboxes, with simulation and experimental results showing the efficacy of these control methods in improving DSTATCOM performance. In [4], two current controls. The ripple in supply current due to the addressing is studied, comparing different pulse shaping execution of an Active Power Filter (APF). The closed-loop control model applied to a three-phase APF is realized with a TMS320C31 DSP and investigates direct and indirect current. control techniques. It uses a Current Controlled Voltage Source Inverter (CC-VSI) as an APF, with the nonlinear load resembling the three-phase diode bridge rectifier with R-L load. Experimental results show that indirect current control technique is successfully applied to realize removes the switching ripples as compared to direct control. In [5], a Wind Grid Connected Wound Rotor Induction Energy Conversion System (WECS) fixed speed and variable- in 0–3000 rpm range for high- speed systems based on a cage rotor induction machine. The comparison is made for major hardware components needed, operations area, and energy produced with a specific wind function based on real-world wind turbine characteristics. Fixed speed systems are simpler, however and more reliable, they dramatically restrict energy generation. In contrast, variable-speed wound rotor induction machine-based systems leads to better energy capture owing to their super-synchronous operating characteristics with the ability to produce rated torque. This configuration enabling (power generation) from both the rotor and the stator. Also, rotor-side control. lowers the power devices volt rating, shrinks the size of the DC bus capacitor bank, and requires uses a smaller line-side inductor. The results reported are indicative of the significant the benefits of the doubly fed system regarding energy efficiency and operational flexibility.

EXISTING SYSTEM

Traditional wind energy conversion systems (WECS) utilizing doubly fed induction generators (DFIG) have been widely used due to their efficiency in handling varying wind speeds. In these conventional

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systems, the rotor-side converter (RSC) manages the active and reactive power, while the grid-side converter (GSC) primarily regulates the DC-link voltage and facilitates slip power transfer. However, these systems have several limitations, particularly in terms of power quality, as they are prone to harmonic distortions, voltage fluctuations, and reactive power imbalances, especially when integrated with nonlinear loads. Additionally, conventional DFIG-based WECS do not provide harmonic compensation or reactive power support when the wind turbine is non-operational, limiting their grid support capabilities. To address harmonic issues, external passive or active filters are often required, increasing system complexity and cost. Another major drawback is their limited fault ride- through (FRT) capability, making them vulnerable to grid disturbances and voltage sags. Furthermore, these systems often fail to achieve optimal energy extraction due to inefficient Maximum Power Point Tracking (MPPT), resulting in reduced efficiency under variable wind conditions.

PROPOSED SYSTEM

The proposed system enhances the traditional DFIG-based wind energy conversion system (WECS) by integrating combined active power filter (APF) capabilities, significantly improving power quality and grid interaction. Unlike conventional systems, the grid-side converter (GSC) in the proposed model is designed to function as an active power filter, providing harmonic compensation alongside its conventional roles of DC-link voltage regulation and slip power transfer, thereby eliminating the need for external filters and reducing system complexity. The rotor- side converter (RSC) is optimized for efficient Maximum Power Point Tracking (MPPT) and reactive power (Q) management, ensuring stable grid voltage and maximizing energy extraction under varying wind conditions. Additionally, the system enables the WECS to operate as a Static Synchronous Compensator (STATCOM), supplying reactive power and harmonic compensation even when the wind turbine is in shutdown mode, thereby enhancing grid stability. The proposed model also improves the Fault Ride- Through (FRT) capability by employing advanced control algorithms, enabling it to withstand voltage sags and grid disturbances more effectively. To validate the effectiveness of this system, extensive simulations are performed in MATLAB/Simulink, and a prototype is developed using a Digital Signal Processor (DSP), demonstrating the feasibility of the approach under various practical conditions such as variable wind speeds and unbalanced loads. By integrating APF capabilities and advanced control strategies, the proposed system significantly improves the reliability, efficiency, and power quality of wind energy conversion systems.

Block diagram for proposed system:

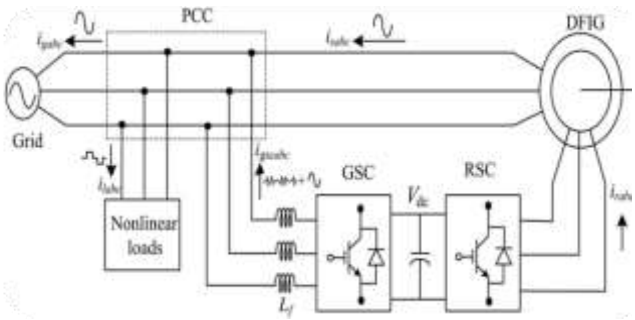

Fig1:Design of DFIG – based WECS

Control of RSC:

The main purpose of RSC is to extract maximum power with independent control of active and reactive powers. Here, the RSC is controlled in voltage-oriented reference frame. Therefore, the active and reactive powers are controlled by controlling direct and quadrature axis rotor currents (idr and iqr), respectively. Direct axis reference rotor current is selected such that maximum power is extracted for a particular wind speed. This can be achieved by running the DFIG at a rotor speed for a particular wind speed.

Control of GSC:

The novelty of this work lies in the control of this GSC for mitigating the harmonics produced by the nonlinear loads. The control block diagram of GSC is shown in Fig. 4. Here, indirect current control is applied on the grid currents for making them sinusoidal and balanced. Therefore, this GSC supplies the harmonics for making grid currents sinusoidal and balanced. These grid currents are calculated by subtracting the load currents from the summation of stator currents and GSC currents. Active power component of GSC current is obtained by processing the dc- link voltage error (vdce) between reference and estimated dc- link voltage ($V*dc$ and Vdc) through PI controller.

CONTROL STRATEGY

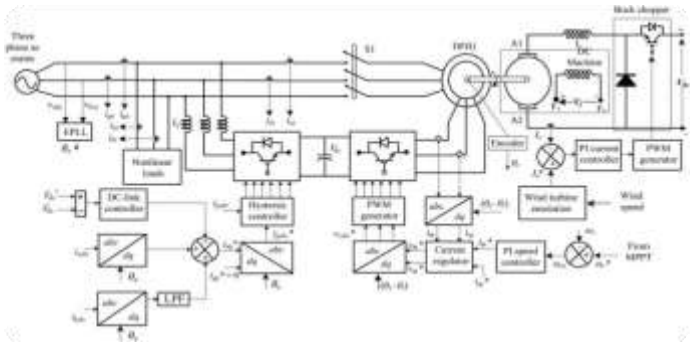

Fig2: Design of DFIG – based WECS

Control algorithms for both GSC and RSC are presented in this section. Complete control schematics are given in Fig. 3.1. The control algorithm for emulating wind turbine characteristics using dc machine and Type A chopper is also shown in above fig.

Control of RSC

The primary objective of the Rotor Side Converter (RSC) is to extract maximum power while independently controlling active and reactive power. This is achieved by operating the RSC in a voltage-oriented reference frame, where active and reactive power are controlled through the direct and quadrature axis rotor currents **(i_{dr})** and **(i_{qr})**, respectively.

The direct axis reference rotor current is determined to ensure maximum power extraction for a given wind speed by adjusting the rotor speed accordingly. A speed controller in the outer loop regulates this reference rotor current using a proportional-integral (PI) control strategy, where the speed error **(w_{er})** is computed as the difference between the reference speed **(ω^*)** and the sensed speed **(ω_r)**.

The PI controller is tuned using the Ziegler- Nichols method, where the proportional gain is set based on the oscillatory response, and the integral gain is calculated accordingly. The quadrature axis reference rotor current is generally set to maintain zero stator reactive power but can also be adjusted to inject the required reactive power. Inner current control loops ensure that the actual rotor currents closely follow their reference values. These currents are derived from sensed rotor currents (i_{ra}, i_{rb}, i_{rc}) using transformation equations based on the slip angle ($\theta_{slip} = \theta_c - \theta_r$), where θ_c is obtained from the Phase Locked Loop (PLL) and **θ_r** from an encoder. The direct and quadrature rotor voltages are then computed based on current errors using PI controllers, with decoupling terms included to compensate for coupling effects. The reference voltages are transformed into three- phase reference rotor voltages and compared with a triangular carrier wave of fixed switching frequency to generate Pulse Width Modulation (PWM) signals for the RSC, ensuring optimalpower extraction and control.

Control of GSC

The novelty of this work lies in the control of the Grid Side Converter (GSC) to mitigate harmonics produced by nonlinear loads. The control strategy utilizes an indirect current control applied to the grid currents to ensure they remain sinusoidal and balanced. The GSC actively supplies harmonic currents to achieve this objective. The grid currents are determined by subtracting the load currents from the sum of stator and GSC currents. The active power component of the GSC current is regulated through a Proportional-Integral (PI) controller, which adjusts based on the reference and estimated DC-link voltage errors. The proportional and integral gains (kpde and kide) of the DC-link voltage play a crucial role in this regulation.

The active power component of the stator current (ids) is derived from the sensed stator currents (isa, isb, and isc) using an abc-to-dq transformation. Fundamental active load current (Ita) is extracted using the Synchronous Reference Frame (SRF) theory, where instantaneous load currents are transformed into the synchronously rotating dq frame. In this frame, fundamental frequency currents are converted into DC components, while harmonics appear as AC components with a 50 Hz frequency shift. The DC values of the load currents in the dq frame are extracted using a low-pass filter (LPF). The direct axis component of the reference grid current (iga) is determined by combining the direct axis current of the stator (ids), the load current (ild), and the loss component of the GSC current. The quadrature axis component of the reference grid current (igq) is set to zero to avoid drawing reactive power from the grid.

To generate the required switching pulses for the GSC, a hysteresis current controller is employed. This controller ensures that the actual current closely follows the reference current within a defined hysteresis band. At every sampling instant, the actual current (igabc) is compared to the reference current (igabc*), and the difference (Δigabc) determines the switching state. If the actual current exceeds the upper hysteresis band, the lower switch is turned on, whereas if it falls below the lower hysteresis band, the upper switch is activated. This method ensures precise current tracking, enabling the GSC to effectively mitigate harmonics and maintain sinusoidal grid currents.

SIMULATION AND ITS RESULTS:

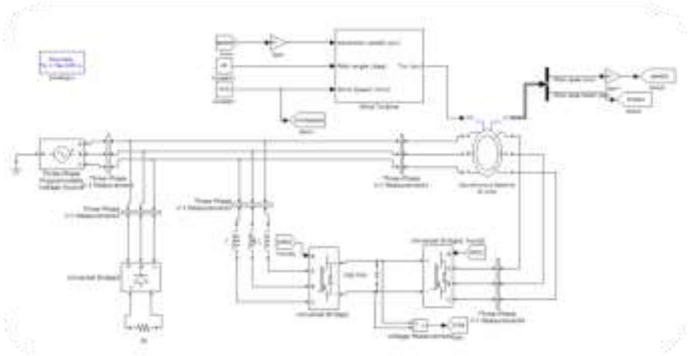

Fig3: Simulink Block Diagram

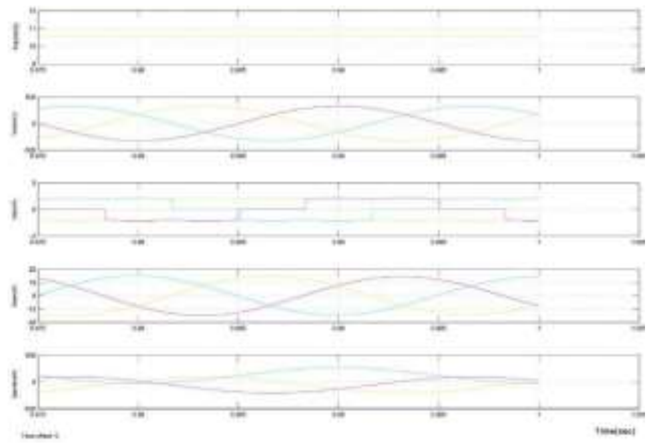

Fig4(a): Simulated performance of the proposed DFIG-based WECS at fixed wind speed

Fig4(a): shows that the wind speed is fixed (10.6m/s) and it is constant at any time. The time(s) is taken on x-axis and wind speed (m/s) is on y-axis, The 3- instantaneous load voltages at point of common of coupling. It is seen that the load end voltages are maintained constant and balanced irrespective of the non-linear loads. Time(s) is taken on x-axis and Vabc (v) is on y axis, Fig4(a): represents the 3-sinusoidal current at non-linear load and it's ranging from 1.6 to 1.6A. The time is taken on x-axis and Ilabc on y axis.

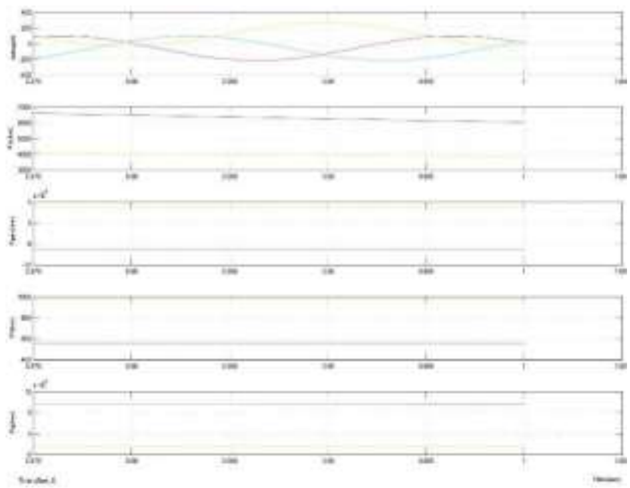

Fig4(b): Simulated performance of the proposed DFIG-based WECS at fixed wind speed

Fig4(b): shows the grid current ranging from 400 to -400 A. The grid current varies w.r.to time. It is seen like a pure sine wave. The time (sec) is taken on x-axis & Ig(A) on y-axis. Fig4(b): shows the power at non-linear load (P1). The time(s) is taken on x-axis and P1 (kW) on y-axis. The power P1 (kw) is constant throughout the time. Its value is 1.1kw. Fig4(b): shows the power at grid (Pg). It is also constant throughout the time, it’s value is 2.1 kw.The Pg(kw) is taken on y- axis.

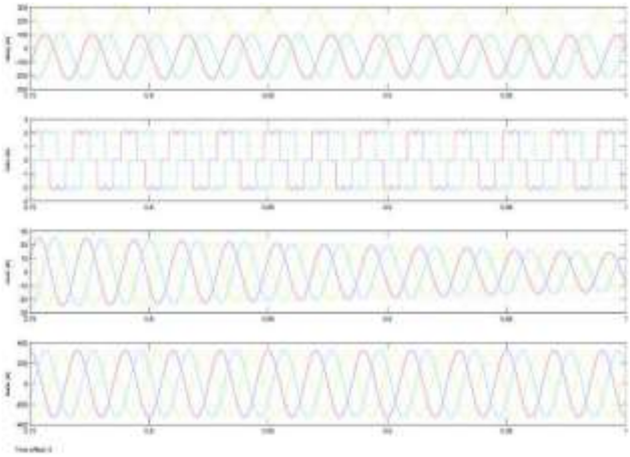

Fig5: Simulated performance of the proposed DFIG-based WECS working as a STATCOM at zero wind speed.

CONCLUSION

The proposed Wind Energy Conversion System (WECS) utilizing a Doubly Fed Induction Generator (DFIG) with integrated Active Power Filter (APF) capabilities effectively enhances power quality and ensures stable energy transfer to the grid. By combining the functionalities of the Grid-Side Converter (GSC) and Rotor-Side Converter (RSC), the system provides harmonic compensation and maintains reactive power support, even when the wind turbine is not operational.The control strategies for both GSC and RSC were rigorously tested and validated using MATLAB/Simulink simulations, followed by prototype implementation on a Digital Signal Processor (DSP). Experimental results, obtained under varying wind speeds and unbalanced/single-phase load conditions, confirmed the system's robustness.This research highlights the potential of DFIG-based WECS as an efficient renewable energy solution that not only generates power but also addresses critical power quality challenges.

FUTURE SCOPE

- Extending this approach to a hybrid system that integrates solar, wind, and battery storage can significantly enhance system reliability and efficiency.
- The controller can be adapted and implemented using a fuzzy logic controller (FLC), which offers improved steady-state performance and faster response times.
- Further research on enhancing the efficiency and cost effectiveness of power electronic components, such as converters and inverters, will contribute to the system's commercial viability.
- Implementing advanced active power filter techniques can further enhance harmonic suppression and improve dynamic stability, especially under extreme load conditions.

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