AN INNOVATIVE CONTROL STRATEGY FOR WIND TURBINE OPERATED DFIG INTERGATED FUZZY LOGIC CONTROLLER

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ABSTRACT

The integration of wind energy into the utility grid necessitates sophisticated control strategies to ensure stable and efficient operation. This paper introduces a novel control scheme tailored for a wind turbine-driven Doubly Fed Induction Generator (DFIG) interfaced to the utility grid, leveraging a Fuzzy Logic Controller (FLC). The primary goal of this proposed control scheme is to optimize the performance of the DFIG system by regulating both the rotor-side and grid-side converters using fuzzy logic techniques. The FLC is adept at adaptively adjusting control parameters based on real-time operating conditions, thereby enabling robust and efficient operation under varying wind speeds and grid conditions. The results demonstrate that the FLC-based control scheme outperforms conventional control methods, showcasing improved grid synchronization, reduced power fluctuations, and enhanced fault ride-through capability. Moreover, the adaptability of fuzzy logic control enables the seamless integration of the DFIG system into the utility grid, ensuring reliable and stable operation even under challenging operating conditions.In conclusion, the proposed control scheme represents a promising solution for enhancing the performance of wind turbine-driven DFIG systems. Its implementation could significantly contribute to the efficient utilization of wind energy and facilitate its seamless integration into modern power grids.

Keywords: Fuzzy Logic Controller (FLC), Doubly Fed Induction Generator (DFIG)

1. INTRODUCTION

Increasing electricity demand driven by industrial growth and population expansion has amplified concerns related to pollution, global warming, and dwindling fossil fuel reservoirs. Wind energy, being a renewable resource, holds immense promise globally. While various generators convert wind turbine mechanical energy into electrical power, squirrel cage induction generators, though commonly used, aren't ideal for variable speed operation and suffer from lower efficiency. Conversely, Doubly Fed Induction Generators (DFIGs) are well-suited for variable speed wind turbines due to their benefits such as reduced converter rating, variable speed operation for optimal wind power extraction, and minimized losses. DFIG-based wind turbines operate in both standalone and grid-connected modes, ensuring constant terminal voltage and frequency at the load end. Battery energy storage (BES) assists in power balance and indirectly aids in maximum power point tracking (MPPT) operation of wind turbines. BES is crucial in standalone wind energy conversion systems for extracting maximum power with greater efficiency. In grid-connected DFIG-based Wind Energy Conversion Systems

(WECS), power smoothing/regulation and computation of grid reference power are pivotal. While methods for power smoothing/regulation exist in literature, they often lack practical implementation and topology. The use of BES for power leveling in the grid, while beneficial, leads to higher dc-link voltage and lower rotor voltage. Moreover, there's a lack of MATLAB setup investigations to validate such systems.

This study focuses on DFIG-based WECS interfaced to the grid with BES, emphasizing control aspects like exporting regulated power to the grid based on averaged wind power and state of charge (SOC). Reactive power requirement of DFIG is managed by controlling the rotor-side converter (RSC) while ensuring maximum power extraction from the wind. An off-MPPT control logic is incorporated into the RSC control algorithm to maintain BES operation within limits and export constant power to the grid. Energy management schemes for both exporting and importing power to/from the grid are presented, along with a PLL to suppress dc offset and ensure satisfactory control of grid-side and rotor-side converters. In summary, this research contributes to advancing control strategies for DFIG-based wind turbines, leveraging fuzzy logic techniques to enhance system performance, reliability, and grid integration capabilities in renewable energy generation contexts

2. RELATED WORK

INTRODUCTION

Wind power is a type of renewable energy that uses the power of the wind to generate electricity. Wind turbines are used to convert the kinetic energy of the wind into mechanical power, which is then used to generate electricity. Wind power is a clean and sustainable source of energy that does not produce any greenhouse gases. wind power is generated almost completely with wind turbines, generally grouped into wind farms and connected to the electrical grid.

Wind power has become increasingly popular in recent years, as the cost of wind turbines has fallen and the efficiency of wind turbines has increased. In 2020, wind power accounted for 6.5% of global electricity generation. In 2022, wind supplied over 2000 TWh of electricity, which was over 7% of world electricity and about 2% of world energy. With about 100 GW added during 2021, mostly in China and the United States, global installed wind power capacity exceeded 800 GW.

2.2 HISTORY OF WIND POWER

Some 5000 years ago, firstly wind power was used to navigate ships in the Nile. The Europeans used it to pump water and grind grains in 1700s and 1800s. The first windmill which generated electricity was installed in 1890 in U.S. The first commercial wind turbine was built in Denmark in 1890. Wind power has been used for centuries to power mills and other machines. However, it was not until the late 19th century that wind turbines were first used to generate electricity. A grid connected wind turbine generator with a capacity of as 2 MW was commissioned in 1979 on Howard Knob Mountain nearby Boon. A 3-MW turbine was commissioned in 1988 on Berger Hill in Orkney, Scotland. The electric power developed from wind is used in lighting the buildings which are at remote places and not connected to the grid. Today wind power generators are available in small size suitable for standalone system and larger utility-generators that could be connected to the electricity grids. In 2003, the worldwide wind power capacity was about 39,294 MW and India wind power capacity was 1550 MW.

2.3 UTILIZATION OF WIND POWER

Wind turbines are commonly described in terms of rated power also known as rated output or rated capacity. Rated power is the instantaneous output of the turbine (measured in watts) at a certain wind speed (called the rated speed) at a standard temperature and altitude. The rated power of small wind turbines falls in the range of 1.000 to 100.000 watts. One thousand watts is one kilowatt (kW). Large wind turbines include all of those turbines over 100 kilowatts. Most of the larger turbines, however, are rated at one megawatt or higher. A megawatt is a million watts or 1,000 kilowatts. It is important to note that wind turbines do not produce their rated power all of the time, only when they're running at their rated wind speed, while rated power is commonly used when describing wind turbines, it is one of the least useful and most misleading of all parameters by which to judge a wind generator.

2.4 WIND ENERGY

Wind energy is the kinetic energy of air in motion, also called wind. Total wind energy flowing through an imaginary surface with area A during the time t is:

$E = 1/2\ mv^2 = 1/2(vt\rho)\ v^2 = 1/2t\rho v^3$

where p is the density of air; v is the wind speed; A vt is the volume of air passing through A (which is considered perpendicular to the direction of the wind); A vtp is therefore the mass m passing through "A". Note that $\frac{1}{2}\ pv^2$ is the kinetic energy of the moving air per unit volume. Power is energy per unit time, so the wind power incident on A (e.g. equal to the rotor area of a wind turbine) is:

$E = P/t = 1/2\ A\ \rho v^3$

3. IMPLMENTATION STUDY

Wind Turbine Design and DFIG Rating

In this topology, the rating of the wind turbine is considered as 11 kW at a rated wind speed of 9 m/s. The power extracted by the wind turbine is a function of air density (ρ), length of each blade (r), wind speed (Vw), and power efficiency of wind turbine (Cp) as

$$P_t = (1/2) \times \rho \pi r^2 V_w^3 C_p(\lambda, \beta_b).$$

Moreover, the Cp which depends on tip speed ratio (λ) and blade pitch angle (βb) is expressed as

$$C_p = \left\{ (C_2/\lambda_j) - C_3\beta_b - C_4\beta_b^y - C_5 \right\} C_1 e^{-C_6/\lambda_j}$$

Where, $\frac{1}{\lambda_j} = \frac{1}{\lambda + 0.08\beta_b} - \frac{0.035}{\beta_b^3 + 1}.$

In the chosen constant parameters are C1 = 0.73, C2 = 151, C3 = 0.58, C4 = 0.002, y = 2.14, C5 = 13.2, C6 = 18.4, and βb = 0◦. After plotting the characteristics of Cp for different values of λ, it is found that Cp max = 0.4412 and corresponding optimal tip speed ratio λ∗ = 5.67.

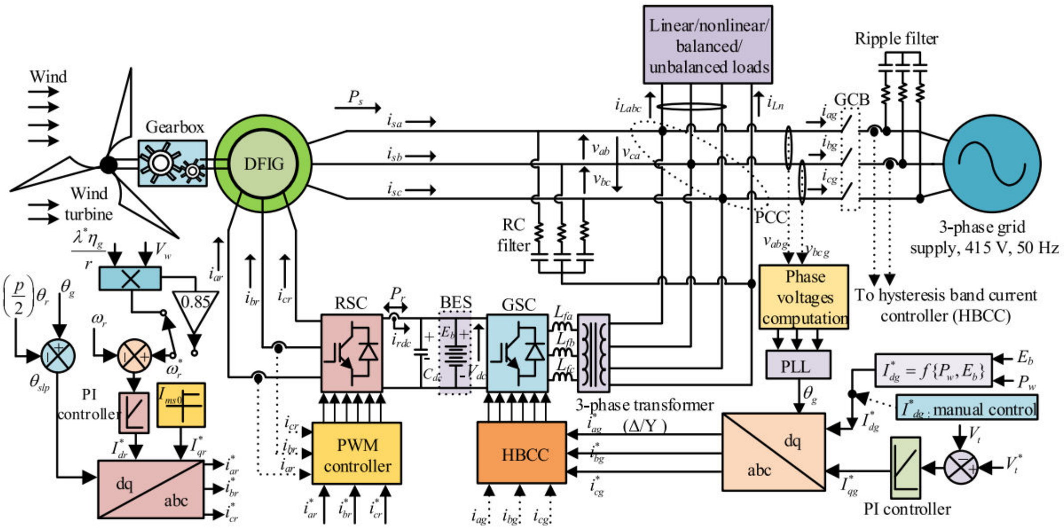

Fig.1 Utility grid-interfaced wind turbine driven DFIG

Moreover, the speed range of DFIG is considered between 110 and 198 rad/s. The corresponding slip range is between +30% and -26%. From this available information, the length of each blade, r calculated from (1), is 4.34 m. By considering the step-up gear mechanism, the computed gear ratio (ηg) is 16.84. As per the tip speed ratio MPPT method, the reference speed (ω∗ r) for extracting the maximum power from the wind is obtained from the following relation as:

$$\omega_r^* = \frac{\eta_g \times \lambda^* \times V_w}{r}.$$

Now, the rating of the DFIG is determined as follows:

$$\left. \begin{array}{l} P_t = P_{sr} + P_{rr} = P_{sr} + s_r P_{sr} = P_{sr}(1 + s_r) \\ P_{sr} = P_t / (1 + s_r) = 11000 / (1 + 0.26) = 8.73 \text{ kW} \end{array} \right\}$$

where Psr, Prr, and sr represent the rated stator power (DFIG rating), rotor power at rated condition, and rated slip, respectively.

The computed value of Psr from (4) is 8.73 kW. However, it is chosen as 8.75 kW. This indicates that an 8.75-kW rated DFIG is sufficient for an 11-kW wind turbine, which is one of the advantages of using DFIG for WECS.

A. Selection of DC-Link Voltage and BES Design

The dc-link voltage (V_{dc}) depends on the maximum ac-line voltage of both RSC and GSC. The maximum line voltage of RSC occurs at maximum slip of 0.3 and its voltage is Vcr = 415 × 0.3 = 124.5 ≈ 125 V. To make ac-line voltage of GSC same as RSC, the transformer of 125/415 V (delta/star), 10 kVA rating is chosen and the same is connected between PCC and GSC, as depicted in Fig. 1. Now, the dc-link voltage is computed from the following as:

$$V_{\mathrm{dc}} \geq \frac{\left(V_{cr}/\sqrt{3}\right) 2\sqrt{2}}{m}.$$

From the Vdc is obtained as 204.12 V. Here, the modulation index, m is chosen as unity. Since the BES is connected directly at dc link, the battery voltage (Eb)is same as Vdc. However, the Eb is selected as 240 V in view of voltage drop during BES discharge. Moreover, the BES is designed to meet power of 4 kW for 20 h in the presented grid-interfaced DFIG-based WECS. Then the kilowatt hour capacity of BES is obtained as 80 kWh. Moreover, the ampere–hour (Ah) capacity becomes 333 Ah (i.e., 80 kWh/240 V). However, the BES of 360 Ah is chosen by considering the deterioration of Ah capacity with time and losses in the system. Therefore, a 360-Ah, 240-V (20 numbers of 12 V of each lead-acid battery) battery bank is selected.

3.1 PROPOSED MODEL

The Fuzzy Logic Toolbox provides GUIs to let you perform classical fuzzy system development and pattern recognition. Using the toolbox, you can develop and analyse fuzzy inference systems, develop adaptive neuro fuzzy inference systems, and perform fuzzy clustering. In addition, the toolbox provides a fuzzy controller block that you can use in Simulink to model and simulate a fuzzy control system. From Simulink, you can generate C code for use in embedded applications that include fuzzy logic.

4. METHODOLOGIES & Algorithm

Modules Description:

A. RSC Control Algorithm

The RSC control is designed for following objectives.

1) It supplies the reactive power requirement of DFIG to maintain unity power factor at the stator terminals.
2) It controls the speed to acquire maximum power from available wind and, moreover, to deviate from wind MPPT.

The reference reactive component of rotor current (I∗ qr) is equal to the no load magnetizing current (Ims0) of the machine, which is computed as

$$I_{ms0} = I^*_{qr} = \left(\sqrt{\frac{2}{3}}\right) \frac{V_g}{X_m}.$$

The active reference current (I∗ dr) is obtained by comparing reference rotor speed (ω∗ r) with actual speed (ωr) and passing error through the proportional and integral (PI) controller. The mathematical form to estimate I∗ dr is as follows:

$$I^*_{dr(k)} = I^*_{dr(k-1)} + K_{p\omega}\left(\omega_{\mathrm{err}(k)} - \omega_{\mathrm{err}(k-1)}\right) + K_{i\omega}\omega_{\mathrm{err}(k)}$$

where Kpω and Kiω represent PI constants of speed controller, and ωerr(k) and ωerr(k−1) represent speed error at kth and (k-1) th instants, respectively.

By using slip angle (θslp), are transformed to actual abc quantities (I∗ ar, I∗ br, and I∗ cr) and they are compared with the sensed rotor currents (iar, ibr, and icr) to generate pulses for RSC, as depicted in Fig. 1. The angle of transformation (θslp) is computed from the angle generated from PLL (θg) and rotor angle from encoder (θr) as

$$\theta_{\mathrm{slp}} = \theta_g - \left(\frac{p}{2}\right) \theta_r$$

where p represents number of poles of the machine.

B. GSC Control Algorithm

The GSC functions to achieve the following objectives.

1) It provides the reactive power requirement of the load.
2) It regulates the export/import power along the utility grid.
3) It helps in power quality improvement in the grid side such as harmonics elimination, unbalanced load compensation, thereby maintaining total harmonic distortion (THD) of PCC voltages and currents within the IEEE 519 standard.

The control of GSC is shown in Fig. 1, in which the reference terminal voltage (V ∗ t) and actual voltage (Vt) are compared, and the error is passed through PI voltage controller to generate the reactive reference component (I∗ qg) of the grid current. The computation of I∗ qg is as follows:

$$I^*_{qg(k)} = I^*_{qg(k-1)} + K_{pv}\left(\delta V_{(k)} - \delta V_{(k-1)}\right) + K_{iv}\delta V_{(k)}$$

where voltage error at kth instant δV(k) = V ∗ t(k) − Vt(k), and Kpv and Kiv represent PI constants of PI voltage controller.

In this work, a new approach is introduced to generate the active reference current component of grid current (I∗ dg) apart from the manual selection of the same, as depicted in Fig. 1. First, the manual selection of I∗ dg is decided based on average active power generation by DFIG for certain time interval and samples of wind speeds, which changes time to time. Second, it is computed based on SOC of the battery. If the power generation is more than the reference grid power, remaining power goes to BES for charging and BES discharges in another scenario. Pricing of local generation and utility grid decide either to export or import power to/from the grid.

5. RESULTS AND DISCUSSION SCREENSHOTS:

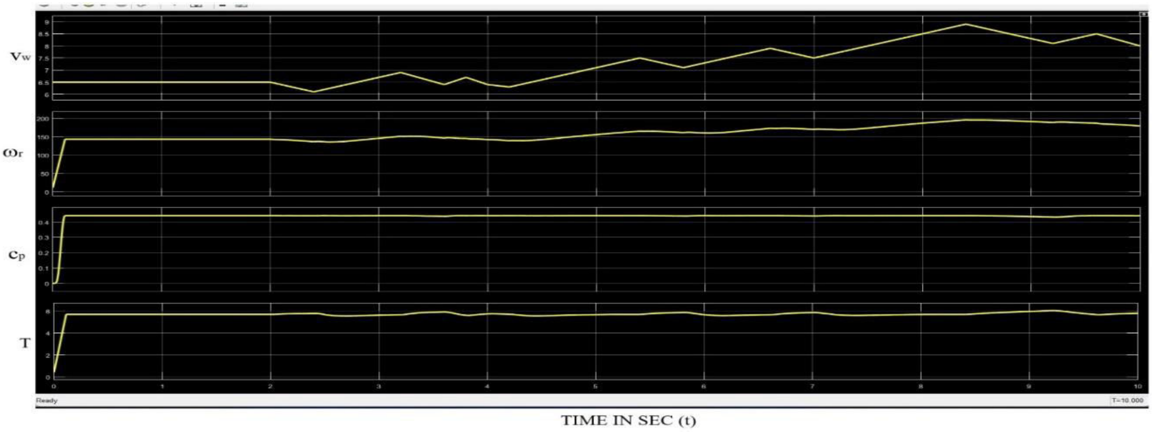

Figure 2 system performance at wind turbulence condition (Vw , ωr , Cp , T)

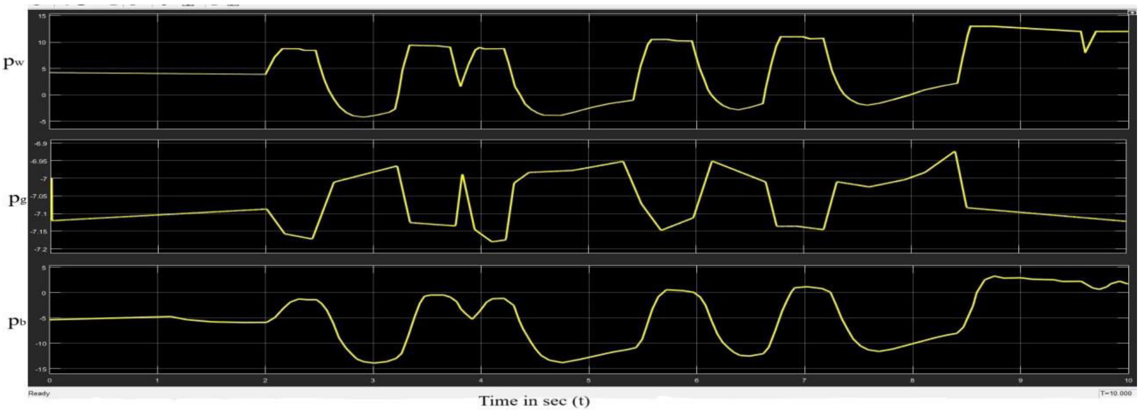

Figure.3 system performance at wind turbulence condition (Pw , Pg , Pb)

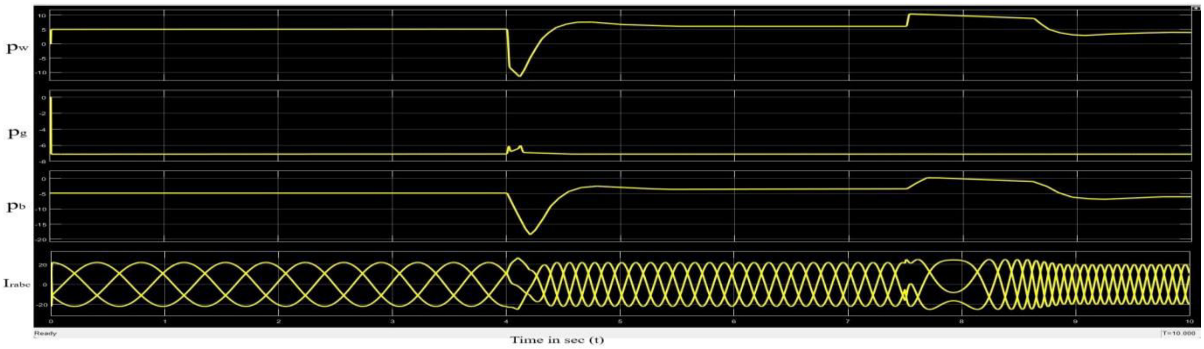

Figure 4 system performance at Non- linear load condition (Pw , Pg , Pb , Irabc)

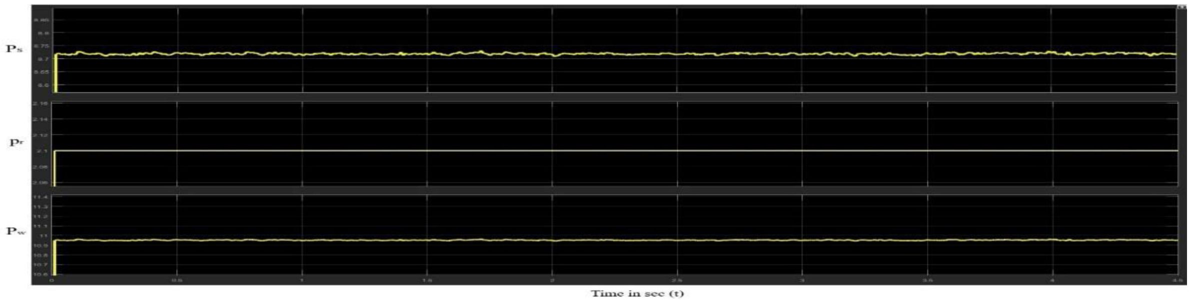

Figure .5 system performance at constant wind speed (Ps , Pr , Pw)

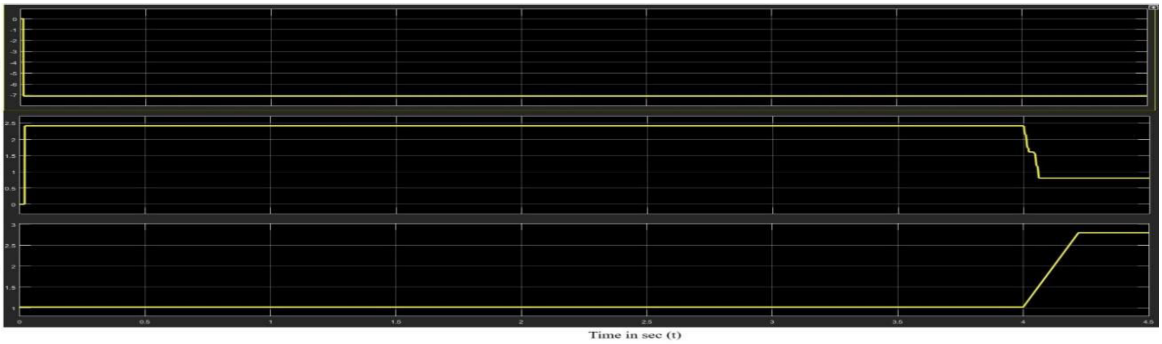

Figure 6 System performance at constant wind speed (Pg , Pi , Pw)

6. CONCLUSION

A Doubly Fed Induction Generator (DFIG) wind turbine using a fuzzy logic controller could summarize the effectiveness and benefits of employing fuzzy logic control in enhancing the performance and efficiency of DFIG wind turbines.

The overall performance and efficiency of the DFIG wind turbine system using fuzzy logic controller are observed at varying wind speed considering turbulence, at non-linear loads conditions, at constant wind speed conditions are observed in practically through MATLAB Simulation results. The optimization and integration of fuzzy logic control into wind turbine systems to meet evolving energy demands and environmental goals.

The fuzzy logic controller effectively regulates doubly fed induction generator (DFIG) and converter systems, leading to improved power quality, better transient response, and increased energy capture from varying wind conditions. With this discussion, the further works carry forwarded with ANN also.

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