Comparative Study and Dynamic Performance Analysis of DFIG based Wind Energy Conversion System

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***Abstract*:**

This paper presents a novel control strategy for wind energy conversion system for improving the dynamic stability of the system. In off-grid applications, the load voltage and frequency should be managed in steady-state and transient circumstances. For rural areas with unpredictable wind and load circumstances, electricity quality and control are crucial tasks. In order to improve power quality, dynamic stability and power management in direct drive standalone wind energy systems, this research provides a coordinated proportional resonant (PR) controller. Under different operating situations, such as variable wind with step increases and decreases in wind velocity, balanced and unbalanced load conditions, the dynamic performance of a doubly-fed induction generator (DFIG) is evaluated. In order to meet the load requirement, the suggested PR control technique with battery energy controller also provides efficient power balancing between the wind and battery sources. A fair performance comparison is made between the proposed control strategy and conventional vector control strategy by using the MATLAB/SIMULINK platform under varying wind and load circumstances. The proposed control approach shown better dynamic stability, improving the power quality of the system and better synchronization.

Keywords:*doubly-fed induction generator (DFIG), dynamic stability, proportional resonant (PR) controller, wind energy conversion system*

1. Introduction

One of the primary priorities of regulators and governments throughout the world has been to lessen the economy's reliance on energy derived from fossil fuels. In recent years, fossil fuel supplies have become scarce and have a large negative influence on the environment by increasing the atmospheric concentration of CO2 and causing global warming. Wind energy is one of the most promising renewable energy technologies. It has the greatest potential to lower the traditional generation of energy because it has already been in use for a long time compared to other alternative energy sources [1]. In many regions of the world, the share of wind-based generation in the overall energy production mix has been steadily increasing. The most dependable and advanced renewable energy source in recent decades is wind power. The growth of wind power systems has been largely influenced by rising public awareness of renewable energy, government assistance, and significant advancements in the power electronics sector, which forms the basis of wind power systems [2]. As a result, wind power's proportion of the world's installed power capacity is rising. The most widely used wind turbine in the market, particularly for multimegawatt capacity, is the WECS employing variable-speed variable-pitch wind turbine with DFIG. The DFIG-based WECS is attractive because it has a cheap cost due to the partial size rated power converters required to accomplish complete control of the machine and an efficient power conversion capability at changing wind speed with decreased mechanical stress [3]. Due to its advantageous technical and financial properties, this wind turbine has swiftly entered the commercial market in the current wind power sector. Numerous wind farms currently use DFIG (dual fed induction generator) variable speed wind turbines. With slip rings to provide rotor winding current regulation, the DFIG is a wound rotor machine. Due to the fluctuating nature and unpredictability of the wind speeds, a WECS coupled with a DFIG is the most preferred alternative to harvest wind energy when compared to other wind turbine types, such as fixed speed wind turbines and restricted variable speed wind turbines. Improved efficiency, a smaller converter rating, lower costs, easier power factor correction implementation, variable speed operation, and four quadrant control of active and reactive power management capabilities are all benefits of a DFIG-based WECS. Variable speed operation results in a 20–30% increase in total energy output in the case of DFIG-based WECS, which improves capacity utilization and lowers the cost per kWh of energy. Therefore, the goal of this thesis is to improve knowledge of DFIG-based WECS and DFIG control in order to lessen grid power fluctuations brought on by the variable and unpredictable nature of wind [4-5].

Many control strategies have been reported in the literature for improving power management and quality in standalone wind energy systems. The authors have reported on a vector PI control strategy in dq reference frame to improve power quality for DFIG under variable wind and load conditions. The authors [6] have developed a vector control method to enhance power quality and power management in a wind energy system with an independent battery bank.But these control strategies work only with linear loads that are perfectly balanced; they have no effect on loads that are not perfectly balanced. To determine the phase angle of the load voltage in both balanced and unbalanced grid conditions, all of the aforementioned control methods use the Synchronous Reference Frame (SRF) PLL. However, SRF PLL is only reliable when operating in a balanced load condition. Torque oscillations at two different frequencies are induced in the generator by the negative sequence voltage component when the load voltage is unbalanced, putting a great deal of strain on the mechanical drive train. For the controller to function properly in an unbalanced situation, it has to be in lockstep with the load voltage at all times and have access to precise data. As a consequence, the authors [7] suggested a dual vector control approach for a freestanding wind energy system to offset the undesirable sequence effect produced by unbalanced loads. The dual vector control system may be set up in two different reference frames, one positive and one negative, to allow for the extraction of positive and negative sequence components from a load voltage vector that is otherwise unbalanced. However, since it needs complex transformations, breaking download amounts into sequence components might slow down controller performance [8].

The authors [9] presented fuzzy and predictive control algorithms to improve the dynamic performance of standalone DFIG under fluctuating wind and load conditions. However, when the load is uneven, these control measures are useless. The fuzzy and predictive controller must be constructed in two synchronous reference frames to discriminate between positive and negative sequence components under unbalanced load scenarios. Furthermore, the controller's complexity and computational burden rise. To overcome these challenges and improve system performance, the authors [10] devised proportional resonant control for DFIG (Doublely Fed Induction Generator) wind energy systems under balanced, unbalanced, and distorted conditions. However, in the aforementioned research, the authors focused on power quality issues while ignoring reliability and power management issues. As a result, this study studies a coordinated proportional resonant (PR) and battery energy controller for freestanding battery integrated DFIG to enhance power quality and power management under changing wind and load conditions. The efficiency of the proposed control strategy is shown by using the usual vector control technique and the Matlab/Simpower system to evaluate the data.

The key contributions of this paper is summarized as follows:

1. The dynamic stability of the DFIG based WESC is crucial when it is connected to utility grid. The unpredictable changes in the wind causes fluctuations in the electricity generation by the DFID. A DFIG with battery power supply is proposed in this paper to improve the power enhancement, dynamic stability of the system.

2. The DC-link voltage in the grid side converter (GSC) is key element in stabilizing the voltage between the utility grid and WECS. But this DC-link voltage undergoes overshoot and overshoot when the system experiences the sudden perturbations. In order to stabilize the DC-link voltage under load and DFIG integration, PR controller is proposed in this paper.
3. A fair performance comparison is made between the proposed PR controller and conventional PI controller to examine the superiority of the proposed controller.
4. The proposed system with the proposed controller is modelled using MATLAB/ Simulink environment. The superiority of the proposed controller is tested under steady state and dyamic condition of load and wind variations.

The organization of the paper is as follows. Section 2 describe the DFIG based WECS architecture. Section 3 depicts the proposed control strategy. The MATLAB modelling and simulation results are presented in Section 4. A fair performance comparison is made between conventional vector PI controller and proposed PR controller under various conditions. A detailed simulation results are presented. The conclusion of the paper is summarized in Section 5.

2. Architecture of DFIG based Wind Energy System

The principal components in wind electricity conversion devices are illustrated in figure1. The gadget consists of a rotor with turbine blades, an electric generator, a strength electronic converter, a transformer for connecting to the grid [23].

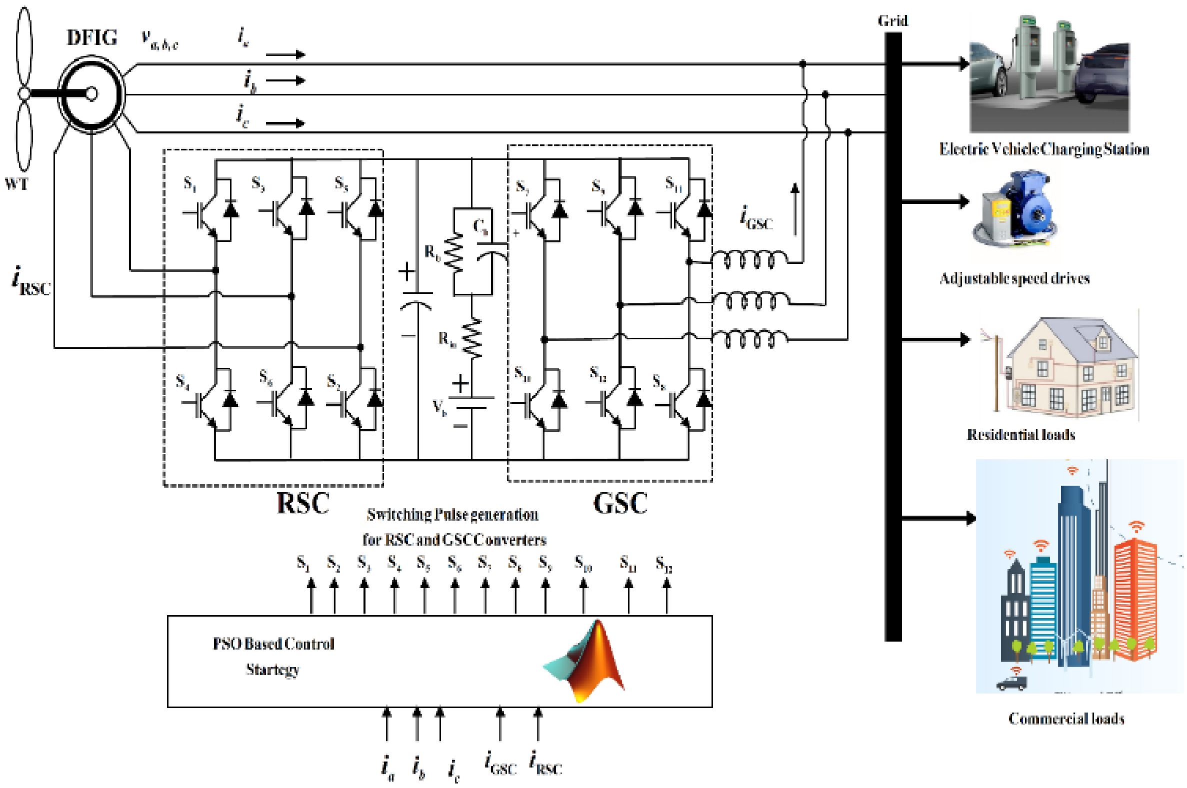

Figure 1. DFTG based wind energy system

3. Control Strategy for DFIG based WECS

Control strategies play an important role in DFIG based WECS. The wind energy generation is completely depends on the speed of the wind. Hence, control structure of the WECS is complicated due to unpredictable changes of wind. The reference active power is the grid power, which is regulated to be a set value and determined by the average power previously computed. The error is then processed using a proportionalintegral (PI) controller to create the -axis component of the reference grid current, and this is compared with the actual grid power at any given moment. The controllable variable for the GSC's reactive power outer-loop control might be the stator reactive power. Depending on the power-sharing plan with the GSC, there are many ways to determine the reactive power set point when it is controlled. If the total reactive power ($Q_{total}=Q_{stator}+Q_{GSC}$) satisfies the network's need while being within operational bounds, the desired reactive power sharing scheme (between the DFIG stator and the GSC) may be selected. The reference active and reactive powers components are used to calculate the d and q components of the reference grid currents to be sent to the GSC's PWM controller.The block diagram of control structure is shown in Figure 2. In the next subsections, both the conventional control method as well as the suggested control technique will be described.

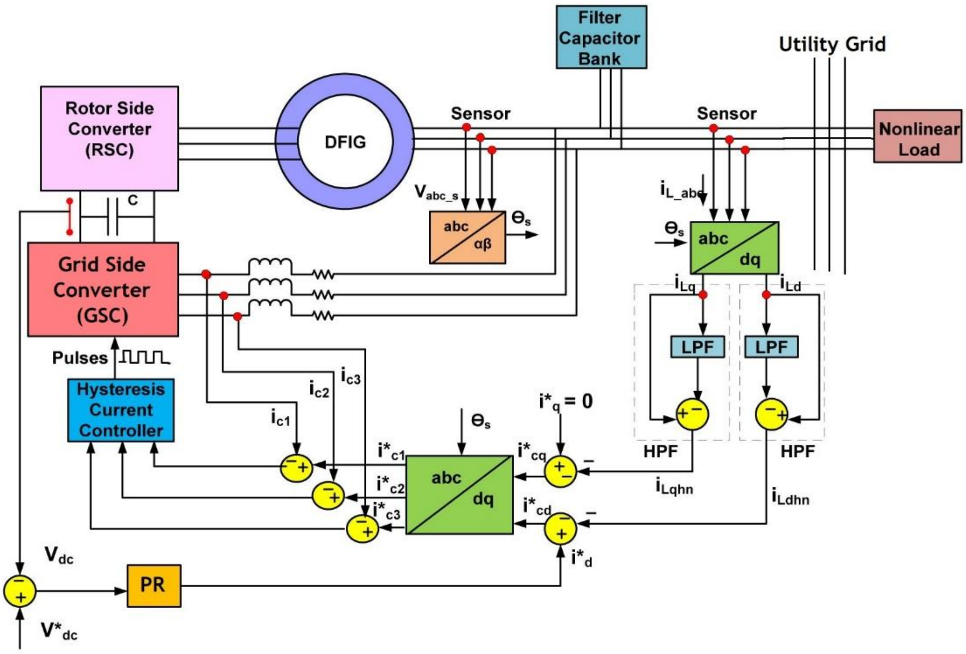

Figure 2. Block diagram of proposed PR controller

3.1. Conventional vector-PI controller

The traditional decoupled vector PI controller is used for controlling the standalone PMSG through inverter control. The components of the load voltage in the synchronous dq reference frame is written as follows:

$$U_{ld} = Ri_{fd} + L_f \frac{di_{fd}}{dt} + \omega L_f i_{fd} + U_{fd} \tag{1}$$

$$U_{lq} = Ri_{fq} + L_f \frac{di_{fq}}{dt} + \omega L_f i_{fq} + U_{fq} \tag{2}$$

Where, L_f and R are the grid interfaced inductor and resistance respectively. The angular speed ω, U_{fd}, U_{fq}, U_{ld} and U_{lq} are the GSC output voltage, q and d axis voltages of GSC, U_{ld} and U_{lq} are the load d and q axis load voltages, respectively.

3.1 Proposed PR Control Strategy

Proportional resonant controller is offered to analyze the dynamic performance of the system under external disturbances. The PR controller boosts the fundamental frequency and closely matches the sinusoidal reference, minimizing steady-state error and improving dynamic performance [35]. The recommended control strategy uses a single fixed reference frame to correct for positive and negative sequence components under unbalanced conditions. The computational cost is reduced compared to PI controller. The converting stationary reference frame to the synchronous (dq) reference frame is as follows:

$$K_{\alpha\beta} = \frac{1}{2}\begin{bmatrix} K_{dq}^{+} + K_{dq}^{-} & JK_{dq}^{+} - JK_{dq}^{-} \\ JK_{dq}^{+} + JK_{dq}^{-} & K_{dq}^{+} + K_{dq}^{-} \end{bmatrix} \tag{3}$$

Where $K_{dq}^{+} = K_{\alpha\beta}(S + J\omega), K_{dq}^{+} = K_{\alpha\beta}(S - J\omega)$

The equivalent positive sequence of the controller is written as follows:

$$K_{\alpha\beta}^{+} = \frac{1}{2}\begin{bmatrix} \frac{2h_{ri}s}{s^2+\omega_r^2} & \frac{2h_{ri}s}{s^2+\omega_r^2} \\ -\frac{2h_{ri}s}{s^2+\omega_r^2} & \frac{2h_{ri}s}{s^2+\omega_r^2} \end{bmatrix} \tag{4}$$

The equivalent negative sequence of the controller is written as follows:

$$K_{\alpha\beta}^{-} = \frac{1}{2}\begin{bmatrix} \frac{2h_{ri}s}{s^2+\omega_r^2} & -\frac{2h_{ri}s}{s^2+\omega_r^2} \\ \frac{2h_{ri}s}{s^2+\omega_r^2} & \frac{2h_{ri}s}{s^2+\omega_r^2} \end{bmatrix} \tag{5}$$

The diagonal terms in (4) and (5) are identical. The positive and negative sequence frames' opposing off-diagonal words reveal a direction reversal.Combining the above two equations gives the single stationary reference frame controller for balancing positive and negative sequence components (6) and (7) as follows:

$$K_{\alpha\beta}(s) = K_{\alpha\beta}^{+}(s) + K_{\alpha\beta}^{-} \tag{6}$$

$$K_{\alpha\beta}(s) = \frac{1}{2}\begin{bmatrix} \frac{2k_{ri}s}{s^2+\omega_r^2} & 0 \\ 0 & \frac{2h_{ri}s}{s^2+\omega_r^2} \end{bmatrix} \tag{7}$$

The cross coupling between the alpha and beta signals on the stationary reference axis is cancelled, as seen by the zero off diagonal components in the transfer function matrix above. Additionally, there is no longer any need for voltage feed forward adjustment.When the load is unbalanced, the load voltage has sinusoidal positive and negative sequence components in a single constant reference frame. The PR controller must be set to regulate positive and negative sequence currents in a stationary frame. The PR controller parameters are tuned as per following equations.

$$K_{\alpha\beta} = k_p + \frac{2k_{ri}}{s^2+\omega_r^2} \tag{8}$$

$$V_{\alpha\beta}^{*} = \left(k_p + \frac{2k_{ri}\omega}{s^2+\omega_r^2}\right)\left(i_{\alpha\beta}^{*} - i_{\alpha\beta}\right) \tag{9}$$

4. Simulation results and discussion

Simulations of the whole model i.e the turbine and the DFIG using an indirect control strategy and a power loop inside the framework of MATLAB/Simulink/SimPowerSystems.The simulations are performed that were reached by the implementation of the proposed PRcontrol and conventional PI vector control. The details of parameters used in MATLAB modelling is tabulated in Appendix-A.

4.1 Performance of WECS with DFIG under varying wind speed windspeed

Performance of WECS with DFIG with an increase in wind speed is shown in Fig. 3. It is observed that in Fig. 3 (b), when the wind is applied at 0.3s, the torque is developed and rotor of DFIG is gradually increases as shown in Figure 3 (c) and (d), respectively. The wind is generated the power and feds the utility grid through the GSC. The DC-link voltage is not having much overshoot and undershoot during the sudden turn on of the DFIG system. It is observed that the proposed PR controller is having better dynamic performance.

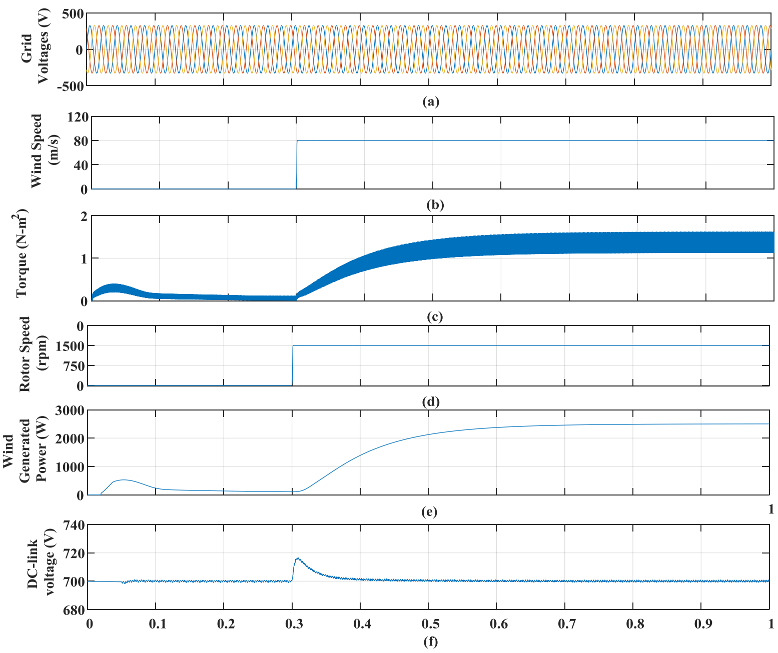

Figure. 3. Performance of the WECS DFIG system

4.2 Performance of WECS with DFIG integration with utility Grid

The grid synchronization of DFIG based WECS is shown in Figure 4. It is noticed in Figure 4 that initially, the total load demand is supplied by grid alone. When the WECS started generation at t=0.3s, the load shared by the DFIG system and grid. A smooth integration has been taken place with the help of proposed PR controller. Figure 4 (b) shows that the grid currents are remain sinusoidal at the time of DFIG system integration, a smooth power transfer is has happed. I addition, the nonlinear load currents injects the harmonic currents into the main grid which are mitigated by the proposed controller. It is conclude from these results that the proposed controller is superior in DFIG based WECS integration, improving the power quality by improving the grid currents wave as per IEEE 519-2022 standards.

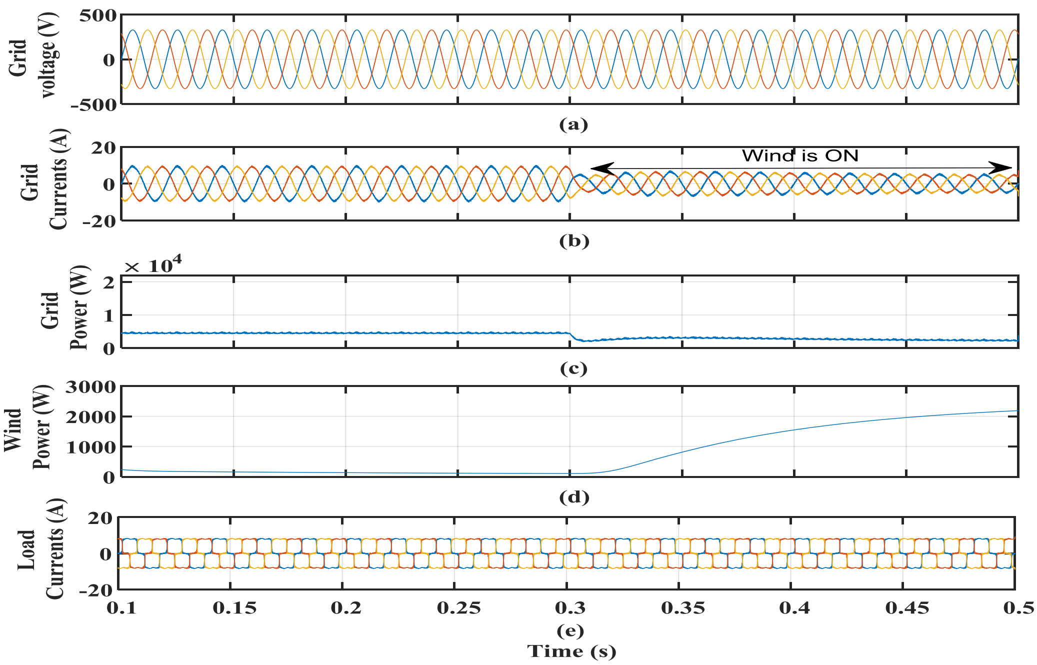

Figure 4. Performance of grid synchronization of DFIG based WECS

4.3 Performance of Comparison of proposed PR and Conventional vector PI controller

A fair comparison study between conventional vector PI controller and proposed PR controller as shown in Figure 3. The proposed PR controller has better performance when the wind turbine starts. The DFIG generator started the power generation, during this time, the DC-link voltage experiences a tremendous overshoot experience. The proposed PR controller settles the DC-link voltage at its rated values within 0.02s where the conventional vector PI controller has overshoot of 50V and settles after 0.12s. This shows that the proposed PR controller is robust, effect in WECS with DFIG system.

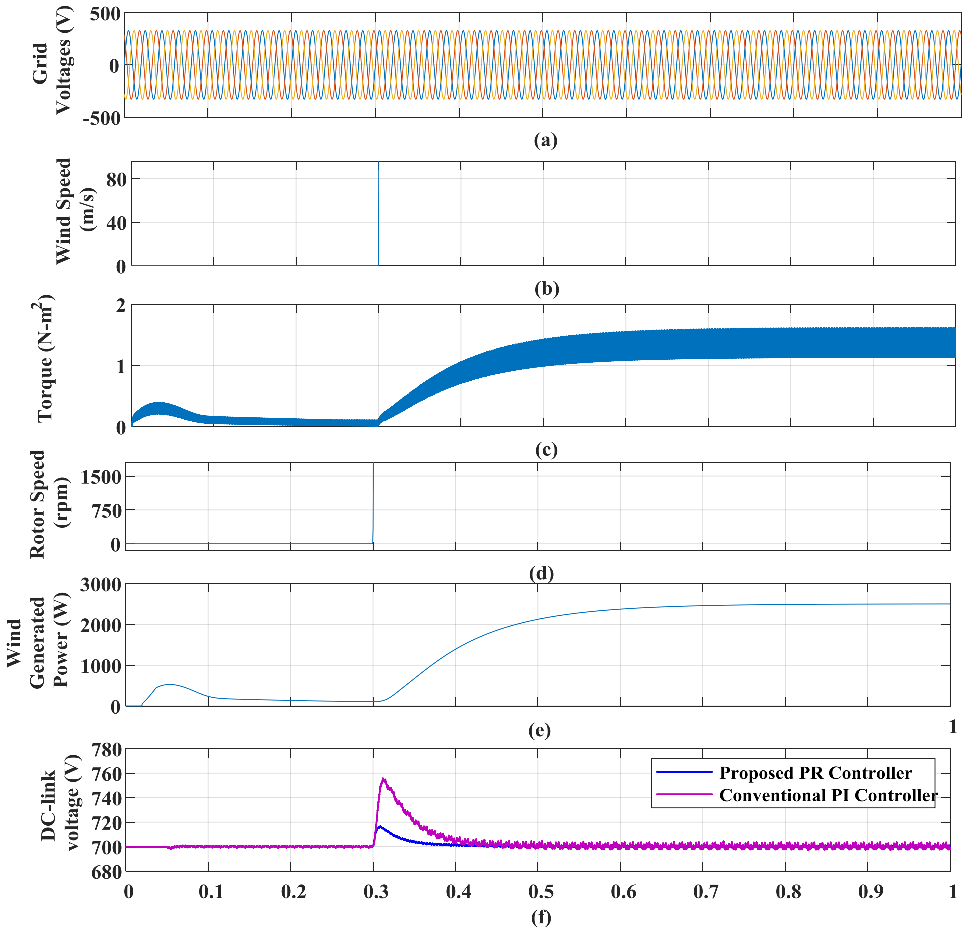

Figure 3. Performance Comparison of Conventional PI and Proposed PR Controller

Conclusion

This study uses DFIG under MATLAB/Simulink to model and simulate a wind turbine. A method for controlling the active and reactive power for a wind power conversion system outfitted with a DFIG and linked to the grid has been presented. First, a wind turbine analytical model and its power coefficient features were examined. Additionally, a mathematical model of a wind farm with improved RSC and GSC control utilizing PI and PR controllers was constructed. The PR controller was well tuned, and the effects were quite noticeable in terms of rotor speed stability. Our simulation findings confirm that the PI control method performs with sensitivity, substantial oscillations, and sluggish convergence. The suggested PR controller, in contrast, offers a superior dynamic response, reduced sensitivity, quick convergence, less oscillation, and robustness.

References

[1] amji, and N. Ramesh Babu. "Recent developments of control strategies for wind energy conversion ;tem." *Renewable and Sustainable Energy Reviews* 66 (2016): 268-285.

[2] Omar, Haitham Abu-Rub, and FredeBlaabjerg. "Renewable energy resources: Current status, future ɔspects and their enabling technology." *Renewable and sustainable energy reviews* 39 (2014): 748-4.

[3] Iuhammad, Imran Siddiqui, ShafiqurRehman, Shamim Khan, and Luai M. Alhems. "Assessment of nd energy potential using wind energy conversion system." *Journal of cleaner production* 216 (2019): 6-360.

[4] man Abdulla, Adel Merabet, and RachidBeguenane. "Real-time control of active and reactive power · doubly fed induction generator (DFIG)-based wind energy conversion system." *Energies* 8, no. 9)15): 10389-10408.

[5] , BukolaBabatunde, and Christopher MainaMuriithi. "Impact of integrating large-scale DFIG-based nd energy conversion system on the voltage stability of weak national grids: A case study of the gerian power grid." *Energy Reports* 7 (2021): 654-666.

[6] ·nni, Habib, and NicuBizon. "Advanced direct vector control method for optimizing the operation of a uble-powered induction generator-based dual-rotor wind turbine system." *Mathematics* 9, no. 19)21): 2403.

[7] iz, G. E., Guerrero, J. M. R., Paternina, M. R. A., de la Cruz, J., Zamora-Mendez, A., & Pedraza, P.)22). Enhancing Grid Integration and Design of Low Speed PMSGs by Exploiting SRF-PLL-based nsorless Control and Holistic Modeling. *IEEE Transactions on Energy Conversion*.

[8] ıivaji, and Ritula Thakur. "Recent trends of control strategies for doubly fed induction generator based nd turbine systems: A comparative review." *Archives of Computational Methods in Engineering* 28, . 1 (2021): 15-29.

[9] ı Ahmed, and Abdel LatifElshafei. "Model predictive control stabilization of a power system including vind power plant." *Journal of Energy Systems* 6, no. 2 (2022): 188-209.

[10] M. A., Hasanien, H. M., Azazi, H. Z., El-Kholy, E. E., & Mahmoud, S. A. (2018). An adaptive fuzzy ;ic control strategy for performance enhancement of a grid-connected PMSG-based wind ·bine. *IEEE Transactions on Industrial Informatics*, *15*(6), 3163-3173.

Appendix-A

Parameter	**Rating**
DFIGparameters	
Powerrating,P	6.5kW
Gridfrequency	50Hz
Gridvoltage	328 V
Statorresistance,R_s	1.17mΩ
Rotorresistance,R_r	1.98mΩ
Statorinductance,Ls	3.15mH
Rotorinductance,Lr	3.13mH
Magnetizinginductance,L_M=M	2.5mH

Polepairs,p	2
Ratedspeed,N	1500rpm
Gridparameters	
Gridfilterresistance(Rf)	0.025mΩ
Gridfilterinductance(Lf)	0.3mH
Turbineparameters	
Ratedwindspeed	81m/sec
Ratedturbinepower	1.5MW
WindturbineinertiaconstantH(s)	4.32
Shaft spring constant (pu ofNominalmechanicaltorque/rad)	1.11
Shaft mutual damping (pu ofnominalmechanicaltorque/pudw)	1.5
Shaftbasespeed(rad/s)	177.2
Turbineinitialspeed(puofbasespeed)	1
Initial output torque (pu ofnominalmechanicaltorque)	0.91