Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024

AN INNOVATIVE MECHANISM OF STATCOM CAPACITOR & DFIG CONVERTER FOR ZERO VOLTAGE FAULT RIDE WITH BALANCING METHOD

[1]Arra Revathi Sree, [2]M. Pakkiranna

[1]M.Tech Scholar, Department of EEE, Holy Mary Institute of Technology & Science(A), Keesara - Bogaram - Ghatkesar Rd, Kondapur, Telangana 501301

[2]Assistant Professor, Department of EEE, Holy Mary Institute of Technology & Science, Keesara - Bogaram - Ghatkesar Rd, Kondapur, Telangana 501301

E-Mail: [1]arrarevathisree1920@gmail.com , [2]mastanbasha220786@gmail.com

ABSTRACT

The increasing integration of renewable energy sources, particularly wind power, has highlighted the need for robust solutions to ensure grid stability during voltage disturbances. This paper presents an innovative mechanism that combines Static Synchronous Compensator (STATCOM) capacitors with Doubly-Fed Induction Generator (DFIG) converters to enhance fault ride-through capabilities during zero voltage events. The proposed approach focuses on developing a balancing method that effectively manages the reactive power flow and supports voltage recovery in the event of grid faults. The mechanism operates by leveraging the STATCOM's rapid response to voltage dips, providing immediate reactive power support while the DFIG converter employs advanced control strategies to maintain rotor speed and power output. Simulation results demonstrate the effectiveness of the proposed mechanism in mitigating voltage sags and enhancing the fault ride-through capability of DFIG systems. The balancing method ensures optimal utilization of both the STATCOM and DFIG resources, resulting in improved voltage stability and reduced impact on the overall power system. This innovative approach not only enhances the performance of wind energy systems during disturbances but also promotes greater acceptance of renewable energy integration into existing grids, paving the way for a more sustainable and reliable energy future.

Keywords: *STATCOM (Static Synchronous Compensator), Fault Ride-Through (FRT), DFIG, Voltage Stability, Zero Voltage Fault, Wind Energy Systems, Balancing Method.*

INTRODUCTION:

The transition toward renewable energy sources has become a pivotal aspect of modern power systems, with wind energy playing a significant role in this shift. However, the integration of wind power into the electrical grid poses unique challenges, particularly in maintaining system stability during voltage disturbances such as faults. One of the critical concerns is ensuring that wind turbines can effectively ride through zero voltage faults, preventing disconnection from the grid and ensuring continuity of service. Static Synchronous Compensators (STATCOMs) are increasingly recognized for their ability to provide dynamic reactive power support, enhancing voltage stability during disturbances. When combined with Doubly-Fed Induction Generators (DFIGs), which are commonly used in wind energy systems, a synergistic effect can be achieved. The DFIG's inherent ability to control active and reactive power, coupled with the STATCOM's rapid response capabilities, can significantly improve the fault ride-through performance of wind turbines. This paper proposes an innovative mechanism that integrates STATCOM capacitors with DFIG converters, employing a balancing method to optimize their interaction during zero voltage faults. The proposed mechanism aims to provide immediate reactive power support while enabling the DFIG to maintain rotor speed and output power. By coordinating the control of both systems, this approach enhances the overall resilience of the wind energy system and contributes to the stability of the electrical grid. Through simulations and analyses, the study evaluates the effectiveness of the proposed mechanism in mitigating voltage sags and ensuring reliable operation during fault conditions. The results aim to demonstrate that this innovative approach not only enhances the fault ride-through capabilities of DFIG-based wind turbines but also fosters greater integration of renewable energy into existing power networks, thereby promoting a sustainable energy future. This research sets the context for the study, highlights the challenges associated with wind energy integration, and outlines the innovative mechanism being proposed.

Develop an Integrated Mechanism: Design an innovative mechanism that combines STATCOM capacitors with DFIG converters to enhance fault ride-through capabilities during zero voltage faults. Some objectives are proposed for this work

Implement a Balancing Method: Create a balancing method to optimize the interaction between the STATCOM and DFIG systems, ensuring efficient reactive power support and stable operation. Evaluate Fault Ride-Through Performance: Assess the effectiveness of the proposed mechanism in improving the fault ride-through performance of DFIG-based wind turbines during zero voltage events. Analyze Voltage Stability: Investigate the impact of the integrated system on voltage stability during disturbances, focusing on its ability to mitigate voltage sags and maintain grid reliability. Conduct Simulations and Testing: Perform simulations and experimental testing to validate the performance of the proposed mechanism under various fault conditions and operational scenarios. Enhance Renewable Energy Integration: Contribute to the development of robust strategies for the integration of renewable energy sources into the electrical grid, promoting a more resilient and sustainable energy system. Provide Recommendations for Future Work: Offer insights and recommendations based on the findings to guide future research and developments in the area of fault ride-through mechanisms for wind energy systems.

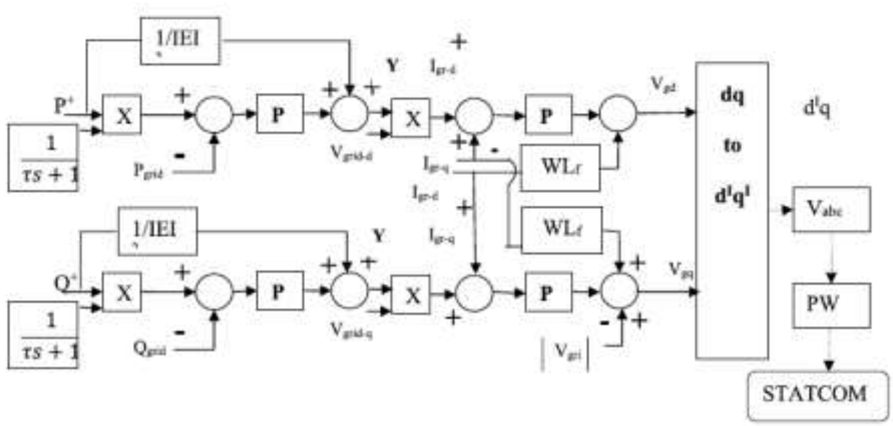


Figure1: Architecture of three levels STATCOM

LITERATURE SERVEY

The use of transverse flux generators has been investigated for application in wind turbines because in literature, very high force densities are claimed for this machine type. However, this high force density disappears when the machine has a large air gap, which generally is the case in large direct-drive generators. An advantage of transverse flux generators is the simple stator winding geometry, which offers possibilities to apply high voltage insulation. Disadvantages are the very low power factor and the complex construction, which may result in mechanical problems and audible noise. In the TFPM machine with toothed rotor proposed in , some rotor construction problems have been solved. the literature that primarily deals with limiting the surge current in the RSC windings, reactive power support, and dynamic response. However, the DFIG needs to operate without trailing synchronism under-voltage dip to meet the modern grid norms, known as Low Voltage Ride Through (LVRT). This Literature discusses the DFIG operation under unbalanced grid faults with modifications in the GSC control scheme. Similarly, scaled-current control, feed-forward and feed-backward scheme, feed-forward transient current control, Virtual Damping Flux, active disturbance rejection controller, and Coordinated fault ride-through (FRT) are few contemporary methods to overcome the FRT. In these methods, internal current control or external power or speed control loops in the RSC are modified to compensate for the current or voltage and other DFIG parameters. In the application of dynamic voltage restorer as an external device and a new control strategy to enhance the DFIG operation during symmetrical and asymmetrical faults. How the DFIG must meet the modern grid rules is discussed in detail by Huang and Li. A fundamental step to overcome the above effects is with the help of crowbar protection S. Liu et al, and Moursi and Zeineldin that is placed on the rotor side of the DFIG. The crowbar disconnects the RSC during fault and makes the DFIG operate as an induction motor. This method has disadvantages like over speeding the machine, drawing enormous grid reactive power, and discontinuing the power supply. When a power supply disturbance like voltage sag occurs, the crowbar operates and diverts the RSC. This operation protects the rotor circuit from inrush current but cannot solve issues for improving performance during a fault. Hence, this is an auxiliary method instead of a solution for LVRT. Connecting and disconnecting the system with a crowbar makes the dc-link voltage across the capacitor fluctuate with larger magnitudes. A study on the HVRT issue by Xie et al. discusses the DFIG rotor current dynamics under sudden voltage swells. The power system’s low or high-voltage faults will occur due to short circuits, lightning, or disturbances in the grid load. Such abnormal behavior will damage the DFIG rotor windings and the back-to-back converters. Also, open circuit fault leads to a drastic effect on DFIG and its converter. Understanding the behavior of the DFIG under abnormal conditions is explained using differential equations and solved with a robust method. The classification of power system faults sequences is pre-fault, during fault or fault on, and post-fault. The system ride-through capability depends on withstanding at low voltage sag known as LVRT, and voltage swell is called HVRT. The significant challenges for LVRT issues are rotor winding fault current during or instant fault occurrence, over-voltage in DC link capacitor, large electromagnetic oscillations, and rotor speed increasing beyond control during fault. The better strategy for limiting them is enhanced control of reactive power and efficient rotor and stator flux management by using RSC. Many types of research on LVRT issues for DFIG and mostly succeeded in effective control in curtailing surge fault inrush current and capacitor voltage maintenance across the RSC and GSC controllers. Kanchanaharuthai et al. studied an additional DFIG winding for the power flow control to overcome the grid fault and build pre-fault voltage quickly when the fault was cleared.

METHODOLOGY:

DFIG and STATCOM Modeling: Develop mathematical models for both the Doubly-Fed Induction Generator (DFIG) and the Static Synchronous Compensator (STATCOM) to capture their dynamic behavior during grid disturbances. The DFIG model includes the rotor-side converter (RSC) and grid-side converter (GSC), while the STATCOM model includes its capacitor and control system.

Software Environment: Utilize simulation software, such as MATLAB/Simulink or PSCAD, to simulate the integrated DFIG-STATCOM system under various grid fault conditions, particularly zero voltage faults.

Balancing Method Design:

Reactive Power Management: Develop a balancing method to coordinate the reactive power support between the STATCOM and the DFIG system during voltage sags. This involves setting up control algorithms that allocate reactive power generation between the STATCOM and the DFIG's grid-side converter (GSC) to stabilize voltage.

Control Strategy for STATCOM: Implement a fast-response control strategy for the STATCOM to quickly inject reactive power during the onset of zero voltage faults, thus ensuring immediate voltage support.

Control Strategy for DFIG: Design an adaptive control scheme for the rotor-side and grid-side converters of the DFIG to maintain the stability of rotor speed and prevent excessive current during grid faults. This may include using Field-Oriented Control (FOC) or vector control techniques.

Fault Ride-Through Scenario Definition:

Fault Scenarios: Define several fault ride-through scenarios, including balanced and unbalanced grid faults and varying levels of voltage dips, with a focus on zero voltage fault conditions. These scenarios will allow for comprehensive testing of the system's response under real-world conditions.

Simulation Timeframe: Set appropriate simulation durations to capture the dynamic response of both STATCOM and DFIG systems during and after the fault event.

Performance Metrics:

Voltage Stability: Monitor and evaluate the system's ability to maintain voltage levels at the point of common coupling (PCC) during faults.

Reactive Power Support: Measure the reactive power supplied by both the STATCOM and DFIG system to ensure proper coordination and adequate fault ride-through capability.

Current and Rotor Speed Management: Assess the DFIG rotor current and speed to ensure that the rotor does not exceed safe operational limits during zero voltage faults.

System Efficiency and Fault Recovery: Analyze how efficiently the system recovers from faults and how quickly the wind turbine resumes normal operation after the fault is cleared. The wind systems that exist over the earth's surface are a result of variations in air pressure.

These are in turn due to the variations in solar heating. Warm air rises and cooler air rushes in to take its place. Wind is merely the movement of air from one place to another. There are global wind patterns related to large scale solar heating of different regions of the earth's surface and seasonal variations in solar incidence. There are also localized wind patterns due the effects of temperature differences between land and seas, or mountains and valleys. Wind speed generally increases with height above ground. This is because the roughness of ground features such as vegetation and houses cause the wind to be slowed.

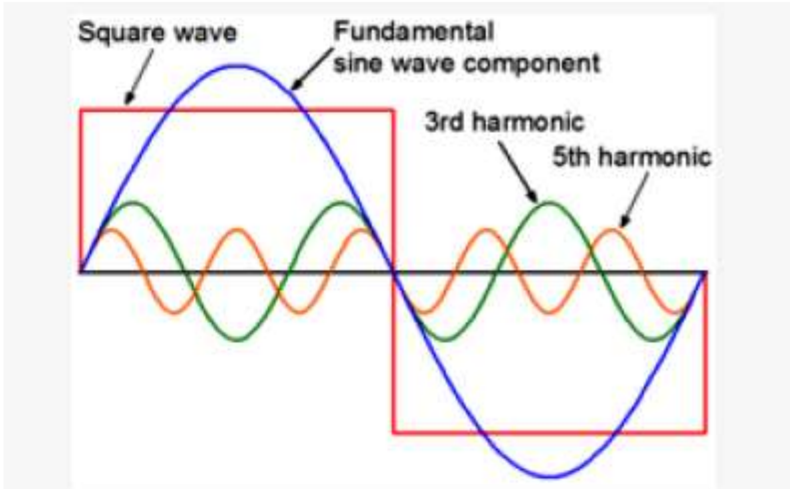
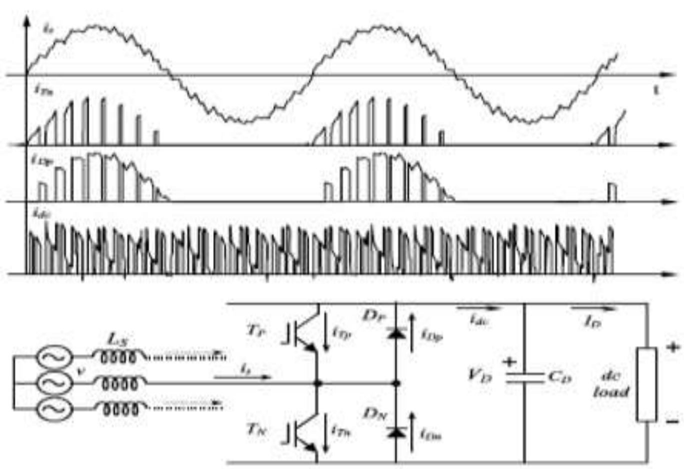


Figure2: Square waveform with wave component

RESULT ANALYSIS:

The result analysis discussed in section 5 deals with earlier methods using the proposed control scheme and common dc-link shared STATCOM topology in MATLAB/Simulink environment. In this Section, 80% voltage dip is compared with and separately under two sub-sections with different analyses. The fault is assumed to occur at the point of common coupling (PCC) with fault resistance of 0.001 ohms. Further, the DFIG system performance with the proposed method at 30%, 60%, and 80% symmetrical voltage dip is discussed. Zero-voltage fault ride through is investigated with the proposed control scheme under symmetrical and asymmetrical single line-to ground fault for super-synchronous speed and sub-synchronous rotor speed.



Industrial Engineering Journal
ISSN: 0970-2555
Volume : 53, Issue 9, September : 2024

Figure3: Modern waveforms via DC Link

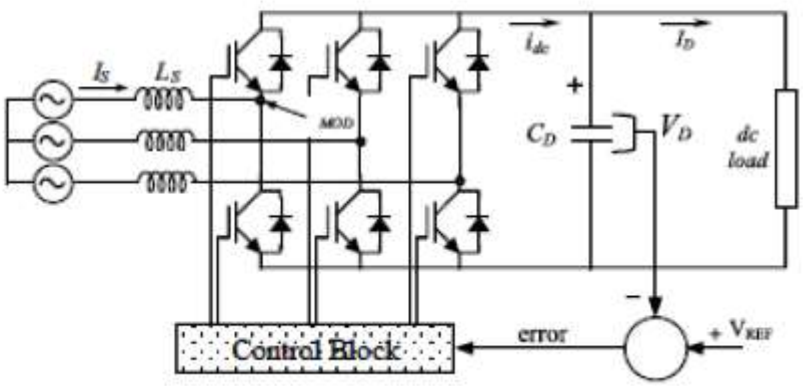


Figure4: Capacitor operation at zero power Factor

CONCLUSION:

This study presents an innovative mechanism that effectively integrates STATCOM capacitors with DFIG converters to enhance the fault ride-through capabilities during zero voltage events. The proposed balancing method optimizes the interaction between these two systems, ensuring that the STATCOM provides immediate reactive power support while the DFIG maintains its operational stability. The results demonstrate significant improvements in voltage stability and fault ride-through performance, confirming the efficacy of the integrated approach. This advancement not only enhances the resilience of DFIG-based wind energy systems but also supports the overall stability of the electrical grid. This research contributes to the broader goal of promoting renewable energy integration by providing robust solutions for voltage disturbances. A generalized DFIG wind energy conversion system-based test-bed system connected to the grid is considered in the paper. The work tested in the starting cases with two different research papers works with proposed method under an 80% dip. Later, the proposed methodology compared under 30%, 60%, and 80% dip, and the DFIG behavior is examined. Further, under three different cases, LG, LLG and LLG faults without and STATCOM are compared to show STATCOM controller’s effectiveness. An improved field-oriented control scheme for the DFIG with real and reactive power lookup-based control in the outer control loops.

REFERENCES:

[1] V. P. Suppioni, A. P. Grilo, and J. C. Teixeira, ``Coordinated control for the series grid side converter-based DFIG at subsynchronous operation," Electr. Power Syst. Res., vol. 173, pp. 18-28, Aug. 2019.

[2] G. F. Gontijo, T. C. Tricarico, L. F. da Silva, D. Krejci, B. W. Franca, M. Aredes, and J. M. Guerrero, ``Modeling, control, and experimental veri_cation of a DFIG with a series-grid-side converter with voltage sag, unbalance, and distortion compensation capabilities," *IEEE Trans. Ind. Appl.*, vol. 56, no. 1, pp. 584_600, Jan. 2020.

[3] M. R. Islam, J. Hasan, M. R. R. Shipon, M. A. H. Sadi, A. Abuhussein, and T. K. Roy, ``Neuro fuzzy logic controlled parallel resonance type fault current limiter to improve the fault ride through capability of DFIG based wind farm," IEEE Access, vol. 8, pp. 115314-115334, 2020.

[4] J. Sun, J. Yi, and Z. Pu, ``Fixed-time adaptive fuzzy control for uncertain nonstrict-feedback systems with time-varying constraints and input saturations," *IEEE Trans. Fuzzy Syst.*, early access, Jan. 18, 2021, doi: 10.1109/TFUZZ.2021.3052610.

[5] S. Kovacevic, D. Jovcic, P. Rault, and O. Despouys, “Three-way subsynchronous torsional interactions between LCC HVDC, MMC HVDC and a thermal generator,” J. Mod. Power Syst. Clean Energy, vol. 11, no. 4, pp. 1331–1340, Jul. 2023.

[6] F. Simonetti, A. D’Innocenzo, and C. Cecati, “Neural network model predictive control for CHB converters with FPGA implementation,” IEEE Trans. Ind. Informat., vol. 19, no. 9, pp. 9691–9702, Sep. 2023.

[7] Chatterjee, S. Samanta, and N. R. Chaudhuri, “Sights to dissipating energy-based source/Sk characterization of TCSC and STATCOM for low-frequency oscillations,” IEEE Trans. Power Del., vol. 38, no. 2, pp. 1426–1439, Apr. 2023.

[8] Y. Chen and J. He, “Fault detection and ride through of CHB converterbased star-connected STATCOM through exploring the inherent information of multiloop controllers,” IEEE Trans. Power Electron., vol. 38, no. 2, pp. 1366–1371, Feb. 2023.