Optimizing Power Control for Dual Excited Synchronous Generators in Wind Turbine Systems

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Abstract - This study presents a MATLAB Simulink-based approach for optimizing power control in wind turbine systems with dual excited synchronous generators (DESGs), implementing an Adaptive Neuro-Fuzzy Inference System (ANFIS) controller. DESGs offer advantages in efficiency and reliability, necessitating effective power control strategies. The proposed methodology integrates Simulink models of wind turbine dynamics, DESG behavior, and an ANFIS controller to optimize power output while ensuring stability and minimizing losses. Various factors such as wind speed variations and grid conditions are incorporated into the simulation environment. The ANFIS controller dynamically adjusts DESG control parameters based on real-time inputs, enhancing system adaptability and performance. Simulation graphs validate the efficiency of proposed approach in improving DESG performance and overall wind turbine system efficiency. This research contributes to advancing renewable energy technologies by leveraging MATLAB Simulink and ANFIS controllers for optimized power control in DESG-based wind turbine systems.

Key Words: Wind power generation, Grid, DESG, MSC, GSC, and ANFIS.

1. INTRODUCTION

As the global demand for renewable energy sources continues to rise, wind turbine systems stand at the forefront of sustainable power generation. Among various wind turbine configurations, dual excited synchronous generators (DESGs) have garnered significant attention due to their promising potential in enhancing efficiency and reliability. This introduction aims to elucidate the importance of optimizing power control for DESGs within wind turbine systems, [1-4] exploring the technological advancements and challenges in this domain., [5, 6]

The utilization of dual excited synchronous generators in wind turbine systems offers several advantages over conventional designs. These generators feature separate excitation sources for the rotor and stator windings, enabling enhanced control over power output and system performance. By decoupling the excitation sources, DESGs facilitate efficient power generation across a wide range of wind speeds, [7-9] thereby maximizing energy capture and minimizing operational losses.[10]

Traditionally, various control strategies have been employed to regulate the power output of DESGs in wind turbine systems. These strategies typically involve control algorithms designed to maintain desired parameters such as rotor speed, power factor, and voltage within acceptable ranges. Among the commonly utilized methods are field-oriented control, direct torque control, and vector control techniques.[11-14] While these methods have shown effectiveness in certain scenarios, they often suffer from drawbacks such as complexity, sensitivity to parameter variations, and suboptimal performance under varying operating conditions, and also WECS like the BDFIG, as well as a DESG, Stator-permanent magnet machines, which include like axial field flux-switching PM machines, doubly salient PM machine, and stator interior permanent magnet generators are implemented and PI controller is also employed, so by this reason the some disadvantages are appear in the system like Less reliability, Less stable. To overcome these problems An ANFIS controller is implemented in this project with conventional power control strategies for DESGs in wind turbine systems, this project proposes a novel approach based on advanced control algorithms and optimization techniques. [15,16] The proposed method aims to enhance the dynamic response, improve efficiency, and ensure robust performance of DESGs under diverse operating conditions.[17]

By leveraging multi-objective stochastic control (MSC) and genetic algorithm-based stochastic control (GSC), the proposed method offers several advantages over traditional control strategies. Firstly, it facilitates precise tracking of desired setpoint and swift response to disturbances, thereby enhancing the overall stability and reliability of the wind turbine system. [18-20] Additionally, MSC and GSC allow for the incorporation of constraints such as mechanical and electrical limits, ensuring safe operation and preventing equipment damage. Furthermore, the optimization capabilities of MSC and GSC enable the maximization of energy capture while minimizing wear and tear on components, leading to improved longevity and reduced maintenance costs. The optimization of power control for DESGs in wind turbine systems is a critical aspect of ensuring efficient and reliable operation. Previous methods have shown limitations in terms of dynamic response, efficiency, and robustness. To address these shortcomings, this project proposes a novel approach based on MSC and GSC, along with advanced control techniques. By offering enhanced dynamic performance, efficiency gains, and operational reliability, the proposed method holds the potential to advance the state-of-the-art in wind turbine power control optimization. [21, 22]

The paper is organized into separate sections to present a coherent structure. Section I serves as an introduction, Section II elaborates on the system description, Section III outlines the Proposed Adaptive Neuro-Fuzzy Inference System Control Topology, Section IV showcases Simulation Results, and lastly, Section V represents the conclusion.

2. SYSTEM DESCRIPTION

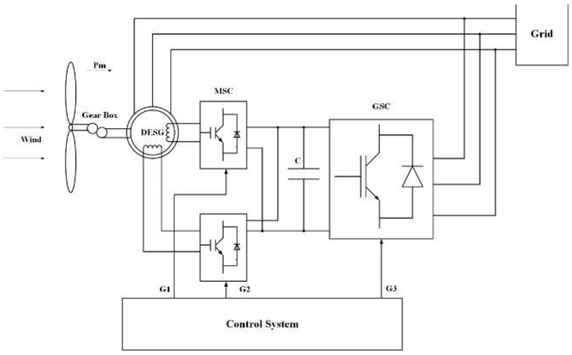


Fig.1 proposed block diagram

The system designed for optimizing power control for DESGs in wind turbine systems comprises several interconnected components aimed at maximizing efficiency and reliability. At its core lies the wind turbine, which harnesses wind energy and converts it into mechanical energy through its rotating blades. This mechanical energy is then transmitted through a gearbox, which serves to increase the rotational speed to levels suitable for power generation. The gearbox acts as a crucial intermediary, enabling the efficient transfer of energy from the wind turbine to the electrical generator.

Integrated within the wind turbine system is the dual excited synchronous generator (DESG), a key component responsible for converting mechanical energy into electrical energy. Unlike traditional synchronous generators, DESGs feature separate excitation sources for the rotor and stator windings, allowing for finer control over power output and system performance. This design enables DESGs to operate efficiently across a wide range of wind speeds, maximizing energy capture and minimizing operational losses.

In addition to the DESG, the system incorporates a machine-side converter (MSC) and a grid-side converter (GSC), both of which play vital roles in regulating a flow of electrical energy between the generator and the grid. The MSC acts as an interface between the DESG and the power electronics, converting the variable-frequency AC output of generator into a fixed-frequency AC suitable for grid connection. Conversely, the GSC serves to synchronize the generated power with the grid frequency and voltage, ensuring seamless integration into the existing electrical infrastructure.

Central to the control and optimization of the system are the implemented algorithms, specifically the multi-objective stochastic control (MSC) and genetic algorithm-based stochastic control (GSC). These algorithms, facilitated by an ANFIS controller, provide real-time optimization of power output and system performance. By continuously analyzing input data and predicting future system behavior, the ANFIS controller adjusts control parameters to maximize energy capture, minimize losses, and ensure stable operation under varying conditions.

Overall, the system description encompasses a comprehensive integration of wind turbine components, power electronics, and control algorithms aimed at optimizing power control for DESGs in wind turbine systems. Through the coordinated operation of the wind turbine, DESG, converters, and control algorithms, the system aims to maximize efficiency, reliability, and grid integration while minimizing operational costs and environmental impact.

CONTROL TECHNIQUE

Maximizing energy output despite wind speed variations is a prime advantage of DESGs in wind power systems. Achieving this requires selecting suitable excitation current control methods. DESG wind energy conversion systems utilize two single-phase MSC powered through the DC link, illustrated in Fig. 1, while a GSC maintains a steady DC link voltage.

A) MACHINE SIDE CONVERTERS CONTROL

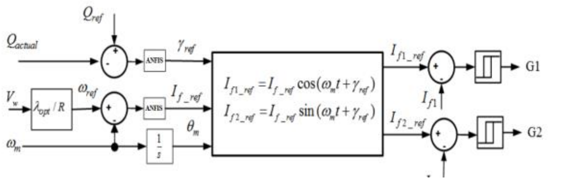


Fig. 2 controlling of MSC

The DESG mathematical model analysis demonstrates how the magnitude of the field-current space phasor and the phase angle (γ) of the field-voltage space phasor influence the relationship between electromechanical torque, field current parameters, and armature reactive power. In the suggested control scheme depicted in Figure 2, the phase angle of the field voltage space phasor governs armature reactive power, while the magnitude of the field-current space phasor is utilized for electromechanical torque control. Figure 1 illustrates the control strategy diagram, where the two single-phase converters regulating the field windings are represented by the gate signals G1 and G2.

B) GRID SIDE CONVERTER CONTROL

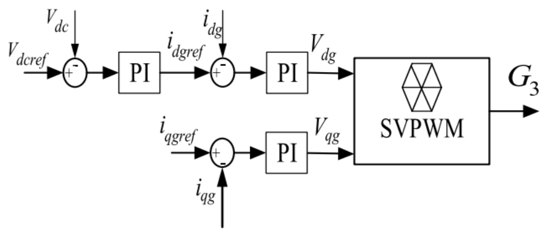


Fig. 3 controlling of GSC

Maintaining a steady DC-link voltage is the primary function of the GSC. For this purpose, a field-oriented control method was employed. A suggested configuration for this technique is shown in Fig. 3. The DC-link voltage was kept constant in these approach by using the d-axis module of grid current (idg). To verify zero rotor reactive power, however, the q-axis current (iqg) was set to zero. Consequently, just the armature side is used for reactive power exchange, which lowers the need for power converters. The system parameter value are evaluated in the following tables

Table-1 Parameter values of wind

Parameter	value
Rated mechanical power of wind turbine	1.1 kW
Cpmax	0.376478
λopt	5.03808
Rated wind speed	10.5m/s
Turbine blade radius	1.1 m

Table 2. Parameters values of DESG

Parameter	Value
Nominal power	1.1 kW
Nominal frequency	50 Hz
Nominal line voltage	380 v
Pairs poles	2
Resistance of armature winding (Rs)	4.65 Ω
Resistance of the first field winding (Rf1)	4.7 Ω
Resistance of the second field winding (Rf2)	9.4 Ω
Self- inductance of armature winding (Ls)	0.5330 mH
Mutual inductance	518 mH
Self-inductance of first field winding (Lf1)	0.5405 mH
Self-inductance of second field winding (Lf2)	1.599
Moment of inertia	0.0108 kg.m^2

Table 3 characteristics of SEDC Motor

Parameter	Value
Rated power	1.1 kW
Rated Voltage of Armature	440 V
Rated Voltage of Field	190 V
Rated Current of Armature windings	3.6 A
Rated current of Field windings	0.6 A
No of Poles	2

3. PROPOSED METHOD

An artificial neural network type called an ANFIS is used to model and control complicated systems. Fuzzy logic and neural networks are two potent techniques that are integrated to form the foundation of ANFIS. In contrast to neural networks, which can learn from data to make predictions and control decisions, fuzzy logic offers a mathematical foundation for handling imprecise and ambiguous information.

In this project we proposed ANFIS control and the below section provides the ANFIS structure and operation

ANFIS stands for Adaptive Neuro-Fuzzy Inference System, a hybrid intelligent system that merges neural networks and fuzzy logic to form a robust controller. It's frequently employed in scenarios where conventional control approaches face challenges, particularly in systems with nonlinear or uncertain dynamics.

The ANFIS controller consists of a fuzzy rule set and a neural network, with the neural network being trained to interpret the fuzzy rule base. Fuzzy sets and linguistic variables define this rule base, establishing the relationship between input and output variables. To train the neural network, a hybrid learning algorithm combines backpropagation and least squares techniques.

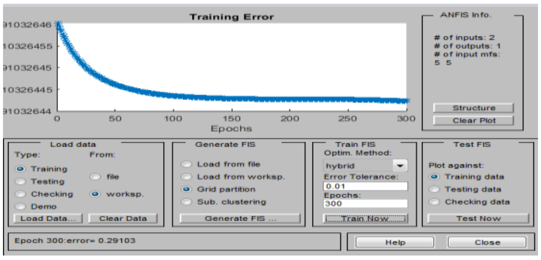


Fig. 4 ANFIS training error

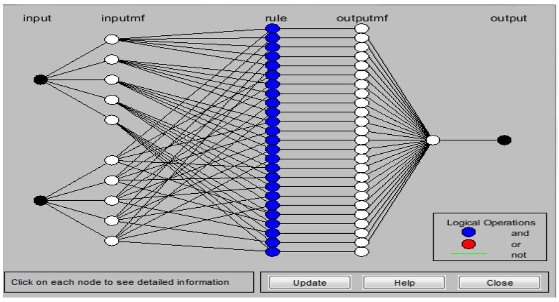
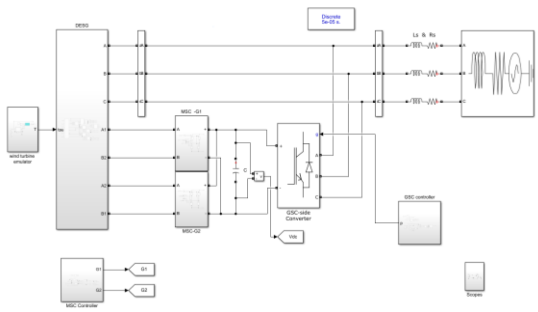


Fig. 5 ANFIS structure

4. SIMULATION RESULTS AND DISCUSSION



Using an ANFIS controller, the effectiveness of the proposed control technique was evaluated through MATLAB/SIMULINK simulations. The validation was conducted for both constant-speed and variable-speed operation cases.

CONSTANT SPEED OPERATION USING ANFIS

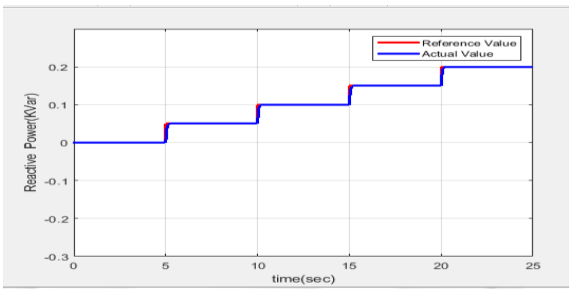


Fig (a) Reference and Armature Reactive Power Response

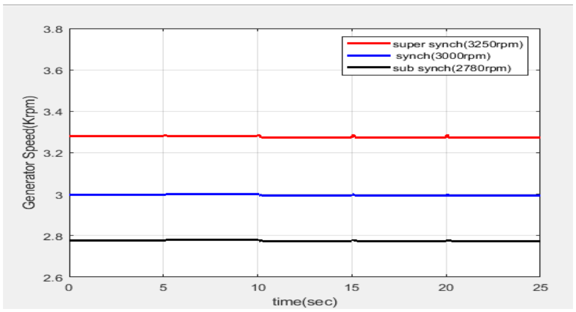


Fig (b) Rotational speed of the generator

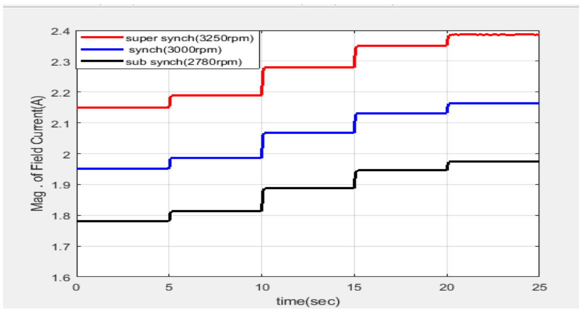


Fig (c) The current space vector's amplitude

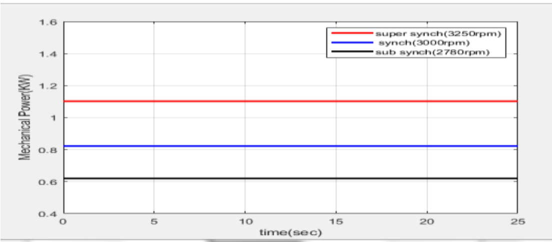


Fig (d) Response to mechanical power

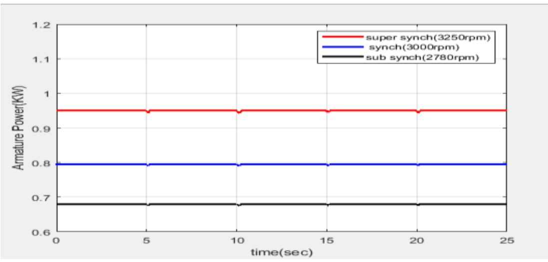


Fig (e) Armature power response

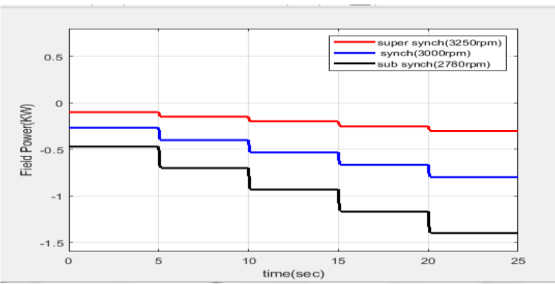


Fig (f) Field power response

FIGURE 6. Simulation outcomes depicting step changes in armature reactive power utilizing ANFIS: fig(a) Reference and Armature Reactive Power Response, Fig (b) Rotational speed of the generator, Fig (c) The current space vector's amplitude (d) response of Mechanical power, (e) Response of the armature power, (f) response of Field power.

Employing an ANFIS controller, the proposed method remained assessed for phase changes in armature reactive power at three wind speed values, as shown in Figure 6. The ANFIS controller effectively regulated reactive power changes to meet desired references (Fig. 6a), ensuring a generator's rotational speed remained constant and aligned with intended values (Fig. 6b). Control actions were depicted in Figures 6(c) and 6(d), with field voltage angle adjustments tracing armature reactive power variations while maintaining consistent rotational speed. Both captured mechanical and generated armature active powers exhibited constant values under various functioning speeds (Figs. 6e and 6f), facilitated by the ANFIS controller.

VARIABLE SPEED OPERATION USING ANFIS

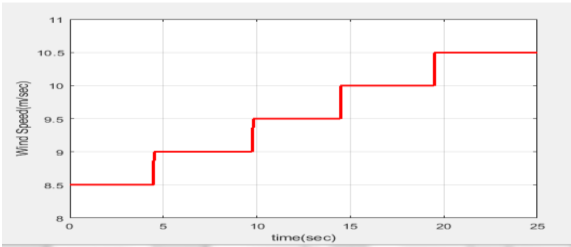


Fig (a) Wind velocities

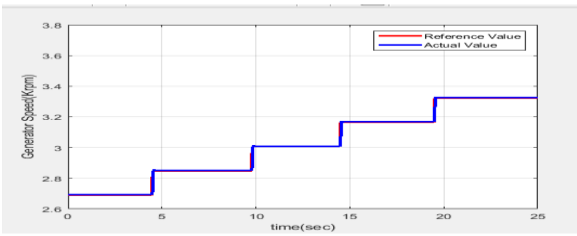


Fig (b) Rotational speed of the generator

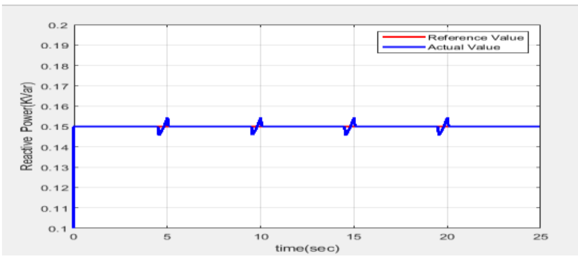


Fig (c) Angle of the field voltage space phasor (γ)

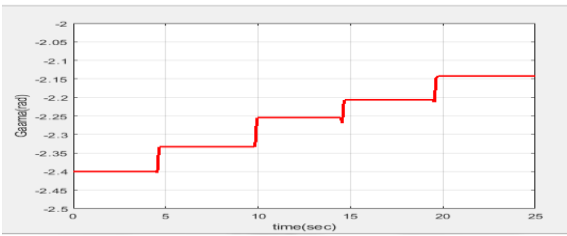


Fig (d) Magnitude of the field current space phasor

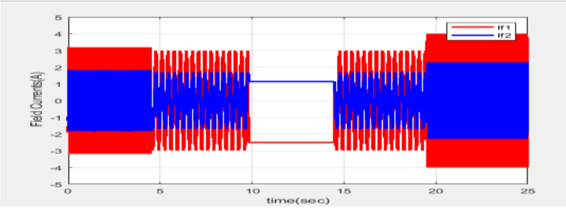


Fig (e) Response of the field current

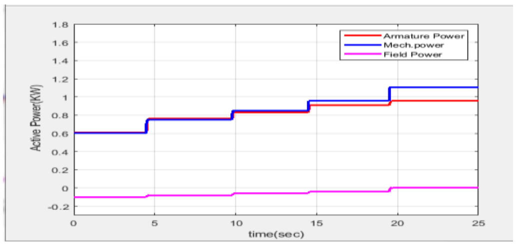


Fig (f) Response of active power

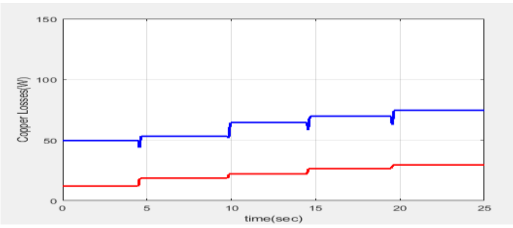


Fig (g) Copper losses in the armature and field.

FIGURE 7. Simulation results for step changes in wind speed using ANFIS: (a) Wind velocities (b) Rotational speed of the generator (c) Angle of the field voltage space phasor (γ) (d) Magnitude of the field current space phasor (e) Response of the field current (f) Response of active power (g) Copper losses in the armature and field.

The ANFIS controller regulated wind turbine operations, managing wind speed fluctuations while maintaining constant armature reactive power (Fig. 7). It adjusted active power for Maximum Power Point Tracking (MPPT), effectively tracking changes (Fig. 7(a) and (b). Armature reactive power remained consistent (Fig. 7(c), and control actions, incorporating ANFIS's adaptive capabilities, were depicted (Fig. 7(d) and (e). Field-current space phasor modifications compensated for armature reactive power (Fig. 7(f). Field currents exhibited variable amplitudes and a 90° phase shift due to non-identical field windings, reflecting the operating speed's slip frequency. Transitioning from sub-synchronous to super-synchronous speeds reversed the sequence of field currents. Active power variations were optimized by the ANFIS controller at each wind speed (Fig. 7(g)).

5. CONCLUSION

In conclusion, the utilization of an ANFIS for optimizing power control in wind turbine systems with dual excited synchronous generators (DESGs) represents a significant advancement in renewable energy technology. Through the integration of ANFIS within MATLAB Simulink software, this study has successfully demonstrated a robust approach to enhance the efficiency and reliability of DESG-based wind turbines. The ANFIS controller offers adaptability and responsiveness to varying environmental and grid conditions, resulting in improved power regulation and reduced losses. By leveraging ANFIS capabilities, DESGs can dynamically adjust their control parameters, ensuring optimal performance under diverse operating scenarios. The simulations conducted in this research showcase the effectiveness of the proposed methodology in achieving optimized power control for DESG-based wind turbine systems. This study contributes to advancement of renewable energy integration by providing a practical framework for enhancing the performance of wind turbines through ANFIS-based power control optimization.

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