VOLTAGE CONTROL OF WIND SYSTEM USING ADAPTIVE FUZZY SLIDING METHOD WITH IOT MONITORING

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Abstract: The idea of employing an Adaptive Fuzzy Sliding (AFS)-operated matrix converter in a grid-connected Wind Energy Conversion System (WECS) for controlling voltage and frequency, with additional support for grid monitoring provided by an Internet of Things (IoT) server. The matrix converter is a power electronic device that facilitates direct voltage and frequency conversion, allowing a variable-speed turbine generator to be connected to the power grid. Matrix converter reliability and efficiency are ensured by the AFS control method's use of adaptive control, fuzzy logic, and sliding mode control. The fundamental function of the control system is to stabilize and guarantee the quality of the electricity being sent from the wind turbine generator to the grid. This system's capabilities are expanded by monitoring the grid status through an IoT server, in addition to controlling voltage and frequency. The system's responsiveness to grid fluctuations, grid faults, and abnormal situations is dynamic due to the constant monitoring of grid status. The AFS control approach, in integration with data from the IoT server, enables adaptive control modifications that facilitate the WES's smooth incorporation into the grid, which in turn helps to preserve grid stability and improves system dependability.

Keywords: Wind system, fuzzy logic, sliding mode, internet of things, grid system, adaptive control.

I. INTRODUCTION

One of the most promising recent developments in alternative energy is the utilization of wind energy conversion devices to replace traditional fossil fuels. It's a great way to help save energy while also benefiting the environment. In terms of systematically lower cost and obtaining the maximum amount of power available, the doubly fed induction generator (DFIG) is the speed wind turbine in use today. The presence of external disturbances all contributed to the difficulty of its management. Power quality and stability on the grid depend on accurate regulation of voltage and frequency, two of the most difficult characteristics to regulate.

Controls over-voltage and frequency maintain the wind energy system in step with the grid, ensuring safe and dependable power transmission. The wind turbine generator and the grid as responding to different climatic circumstances, and sophisticated control systems are necessary. Despite smart cities' sometimes severe environments, several sectors have seen significant innovation and customer satisfaction gains. In order to have an AC voltage output with a changeable frequency, a matrix converter must employ a power device configuration known as a differential bilateral switch. Capacitors used in the DC interface are not required for this system. Flexible AC Transmission Structures (FACTS) and other forms of renewable energy transmission employ matrix converters among their many components.

Many of the current approaches to controlling nonlinear systems need an extensive representation of the plant. Many new techniques for controlling less well-known nonlinear systems have emerged in recent decades. Sliding mode control (SMC), a popular technique for controlling uncertain nonlinear systems, is grounded on the theory of variable structure systems. When the anticipated bound of uncertainty is too large, traditional SMC methods may experience chattering in the controller's input signal as it attempts to maintain the closed-loop stability of unsure systems. It has been well-recognized that the fuzzy logic control (FLC) approach is a viable option for dealing with nonlinearities, uncertain dynamics, and exterior disturbances. To ensure closed-loop stability, traditional FLC approaches lack systematic ways for incorporating human knowledge into the rule basis of a fuzzy inference system.

Different combinations of the SMC and FLC approaches have been suggested to make use of their relative strengths. The so-called adaptive fuzzy sliding mode control (AFSMC) is one example of a hybrid control method. In particular, AFSMC works well with systems that have a high tolerance for uncertainty. Fuzzy control rules may be established systematically using this method. The IoT is a recently invented form of communication that finds widespread use in environmental situations. To get the desired results from the system, new services and applications must be implemented, which requires communication between the device and other data or items through wired and wireless connections and creative methods. One of the key goals of IoT is to make it easier for anybody in the proper part of the globe to utilize any kind of control at any time, from any location.

II. RELATED WORKS

The voltage and frequency control of existing grid-connected WESs are discussed in this section and the proposed methodology improves the drawbacks of the existing techniques. Power systems were rising in the incorporation of wind power production facilities, notably offshore wind energy production facilities. As a result, grid rules for wind power incorporation have emerged as an important part of keeping the electricity on. Wind power integration grid codes across the globe are compared [1-2]. To enable the reliable functioning of a power system with a large penetration of wind power production, it gives insight into the development of grid code specifications for integrating offshore wind power.

In order to increase the reliability of hybrid AC/multi-terminal high voltage direct current (DC) (MT-HVDC) power networks, a coordinated voltage and frequency management technique is provided [3]. Using a multi-dimensional droop technique, the coordinated control strategy is realized and used where there is no communication connection between voltage source converters (VSC). In order to enhance stability and dampen post-fault oscillations, the controller's settings are adaptive to the fault state. It is suggested to use an oscillation index to quantify the degree to which the AC voltage, frequency, and DC voltage are oscillating. When a lot of wind energy is added to the grid, the frequency of the fluctuations increases.

Therefore, wind farms increasingly contribute to frequency control on the grid. A novel nonlinear MPC (NMPC) technique for the frequency response of wind farms is provided [4] to overcome this problem. The NMPC accomplishes its goals of dynamically optimum frequency response and wind generator reliability by factoring in the nonlinear dynamics of each particular wind generator. Utilizing a proportional-integral (PI) controller, the DC voltage of the boost converter is regulated [5]. Through the use of a rectifier, the AC voltage produced by a wind turbine generator can be transformed into a DC voltage that can then be used to power the load and grid.

For multi-interconnected systems with RESs, an Adaptive Neuro-Fuzzy Inference System (ANFIS) trained by an antlion optimizer (ALO) is created [6]. DC-DC converters tie renewable energy systems like solar PV and wind turbine generators to a DC-DC converter-satisfied electrical and hydraulic network branches to form a system. A novel approach to energy management that makes use of fuzzy logic has been developed [7]. The suggested PV-Wind hybrid system has a reliable simulator model presented.

To keep the obtained power at its rated value while simultaneously increasing its quality and reducing the stresses placed on the generator and the transmission under full load, a fuzzy-logic-based adaptive controller is presented [8]. The DFIG wind system's components are first modeled in detail [9]. The method of pitch control is discussed in the second section. The FLC's starting settings are set after reviewing the relevant literature. Then, the optimum FLC is derived by fine-tuning those parameters. The hybrid control of a DFIG, utilizing AF logic and SMC (AFSMC), to establish a robust control of reactive and active power is presented [10]. The chattering problem, a significant drawback of variable-structure systems, is addressed by introducing this sort of control. The variable structure is used to provide a fast convergence rate and resistance to changes in parameters and outside disturbances.

Although SMC is popular in nonlinear systems because of its stability and robustness, it has a significant drawback in the form of chattering occurrences [11]. The adaptive fuzzy control, which modifies the switching gain, to solve this issue and enhance the control is decided. The P&O (perturb & observe) approach and the SMC will be used to verify this controller, which is termed an adaptive fuzzy (AF) SMC [12]. The setup includes a solar panel, a DC-DC boost converter, and a DC-powered centrifugal pump. Single-phase PV grid-connected inverters are the focus [13], which presents an AFS control approach. To boost performance and stability, the suggested method integrates FLC with SMC. Fuzzy logic is used in the control algorithm to make on-the-quick adjustments to the controller gains and parameter estimates.

The most recent advancements in IoT are seen as the foundation upon which power electronics converters may be built. There may not be enough time for simple signal generators with rigorous requirements on communication latency due to the slow response time of IoT devices. A Matrix Converter may be utilized with an IoT smart system by introducing a Neutral Point Clamped converter to reduce harmonic currents at the input and output [14]. The matrix converter receives the three-stage output voltage and channels this energy into medium-voltage, high-power applications. Considering the special scenario of under-actuated and uncertain affine MIMO systems, a novel adaptation of the traditional AFSMC strategy is introduced [15]. For instance, it is no longer required that the diagonal elements of the plant's input gain matrix all be non-zero. The influence of a single actuator on a set of canonical state equations may, in a roundabout way, affect the remaining equations. It uses the Lyapunov theory to demonstrate the asymptotic constancy of the suggested AFSM control mechanism.

In order to increase the quality of the input current and minimize the distortion of the input voltage, a matrix converter system requires an input filter. A novel direct space vector modulation (DSVM) technique for achieving the necessary angular displacement between the matrix converter's input voltage and the input current is provided [16]. Based on the maximum compensated angle, a novel switching technique is presented. The dissemination of a low-control equipment plan with a rapid execution capacity-based IoT structure for grid-tie matrix converters in residential settings is suggested [17].

Employing an AFS approach, the converter also keeps tabs on the grid's health with the help of an IoT server. A sinusoidal input and output results were achieved once the framework was linked to the AFS approach. The most current developments and applications of IoT in energy production, focusing on wind power, are explored [18]. Several IoT applications relevant to wind systems were investigated, including their integration with WES and their use in wind turbine monitoring and forecasting.

III. PROPOSED SYSTEM

A strategy for monitoring grid-connected wind energy plants that incorporates both voltage regulation through the AFS technique and the IoT is proposed. By combining them, the system is able to precisely manage voltage while also monitoring the grid in real-time. Adaptive control modifications and improved system performance may be made in real-time with the help of data gathered via IoT-based monitoring and the designed converter system is displayed in Figure 1.

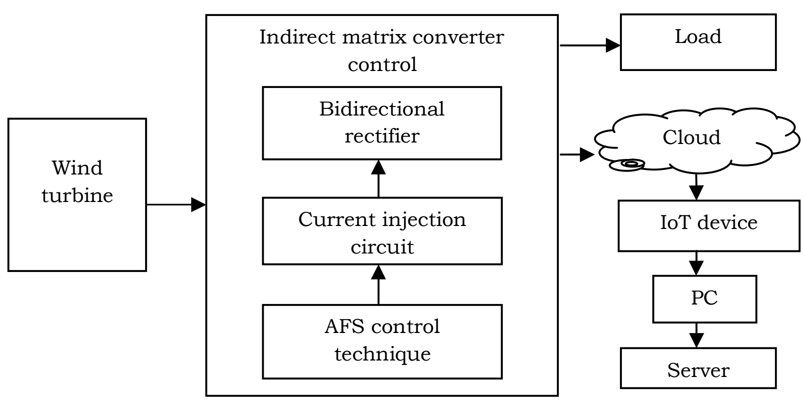

Fig. 1 Converter design and IoT system

The wind turbine generator, indirect matrix converter, AFS control block, IoT-based monitoring block, IoT server, and voltage control output are all shown connected to one another in this block diagram. The suggested technology integrates indirect matrix converter control, accurate voltage management using the AFS method, and real-time grid monitoring via IoT-based technologies. The functionality, effectiveness, and dependability of the WES that are tied to the power grid are improved.

The indirect matrix converter (IMC) now provides an AC supply from the wind energy that may be linked to a bidirectional rectifier. Distributed computing is then used to determine and save the specific parameters according to the amount of work. The IoT service has been connected to a PC and server through closed-loop control, allowing us to see the values of the service's parameters via the web or a mobile device. Designs for the coordination of information progress are made possible by the IoT. Expanding the AFS voltage exchange fraction of the IMC using the PWM technique reduces total harmonic distortion (THD) and boosts output.

The present third harmonic injection is made up of a reaction from the bridge legs, an inductor, and three bidirectional switches. The harmonic current is infused into its associated input stage by switching on only one of all three two-way switches under normal operating circumstances. The VSC’s output frequency, amplitude, and phase are all adjustable to meet the needs of the load. When the system is turned off, the power stored in the load's spilling inductance is kept using a clamp circuit. The third-symphony current is maintained by the bidirectional switch connected to the input circuits that have the lowest dominant voltage.

A. AFS control method

SMC is effective, but it has certain drawbacks. High oscillations near the sliding surface generate a chattering effect, which is a major drawback. In addition, it is suggested to employ significant amounts of switching gain to accomplish a rapid convergence and higher stability. However, the frequency of oscillations increases as gain increases. AFSMC, a method that combines AF Logic with SMC, is provided. Due to its resistance to the effects of the uncertainties inherent in the models used to represent the generator and the wind turbine, AFS mode control is able to achieve the goals set out in the introduction. It reduces the mechanical strain on the wind turbine's complete transmission by eliminating chattering and increasing dependability and energy efficiency. The block diagram of the AFS controller is shown in Figure 2.

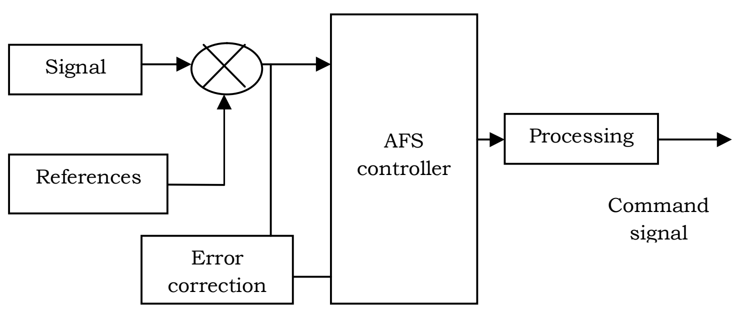

Fig. 2Block diagram of AFS controller

First, a parallel-shaped design for the information factors, or parameters, occurs; these parameters represent a fuzzy set of data. In order to complete the output fuzzification process, fuzzy administrators such as AND and OR are applied to the fuzzily represented data. Membership capacity is defined and calculated to follow the input data. As an individual progress through their education, so do the variables that govern their enrollment process. The framework's information yield relationship is used to create fuzzy principles. After rules have been established, various yields are accumulated, and finally, the resultant capacity is defuzzified to get an optimal yield. The collected data is then processed using the following propagation technique in the neural network. By shifting the focus of the neural system, one may reduce the mistake and get a more efficient result.

To maximize energy production from the wind turbine generator, the AFS control algorithm continually adjusts for factors, including changing wind speed and load fluctuations. Control settings are continuously adjusted to keep the system operating at its MPP, where it converts energy most efficiently. To make intelligent control modifications in response to changing operational circumstances, the AFS approach makes use of fuzzy logic, which offers a decision-making mechanism that utilizes linguistic principles. By offering a strong control action in the face of disruptions or uncertainties, the SMC feature guarantees rapid and precise control.The fuzzy rules denotes very small (VS), small (S), medium (M), large (L) and very large (VL). The AFS rules are displayed in Table 1.

TABLE 1 Rules of AFS

	VL	L	M	S	VS
VL	NS	ZO	NB	NB	NB
L	NS	ZO	NB	PB	PB
M	NS	NS	ZO	PB	PB
S	NS	PS	PS	ZO	NB
VS	NS	PS	PS	NS	ZO

B. IoT Device

Analytics for the IoT refers to the process of extracting useful information from the massive amounts of data created by interconnected IoT devices. Analytics for the IoT has the most promising future in the field of industrial IoT. Analytics from the IoT may help businesses figure out how to save money on repairs, keep their machinery running smoothly, and boost productivity overall. The operation of wind farm turbines can be analyzed in real time due to the sophisticated monitoring tactics and technologies that have been created. Wind turbine failure identification and diagnosis models will be part of a cloud-based IoT analytics platform.

The data is sent to an IoT server for further processing and analysis. The IoT server processes data in real-time and makes use of sophisticated algorithms to analyze the state of the grid, spot any irregularities or deviations from the ideal, and spot problems that might have an impact on voltage regulation and the overall efficiency of the system. The IoT server analyzes data and then sends signals to the AFS controller to change the settings as needed. As a result, the grid's functioning may be kept stable and dependable via the use of adaptive control measures in response to changes and disturbances.

III. RESULTS AND DISCUSSIONS

Simulation and experimental investigations were used to test the suggested approach of voltage regulation in grid-connected WES utilizing the AFS method with IoT monitoring. From the obtained outcomes, the integrated method is superior in controlling voltage precisely and improving system efficiency. Figure

3 shows the simulation of the matrix converter wind system. The AC voltage of the wind turbine is 100 V and the matrix converter is utilized for voltage control. It also improves the performance of the AFS control. The load voltage of the system is 170V. The voltage and current of the wind turbine and load are shown in Figure 4 and Figure 5, respectively.

In a grid-connected wind energy system, the suggested technology effectively accomplished accurate voltage regulation. The maximum power point (MPP) of the system was maintained by the AFS control algorithm, which optimized the extraction of power from the turbine's generator in response to fluctuating environmental circumstances. This allowed for consistent voltage regulation, ensuring smooth grid connection. The IoT server monitored the grid's status in real-time, indicating any changes that were beyond normal. By implementing proactive control modifications in response to the results of the analysis, the system maintained grid stability and reliability over dynamic changes.

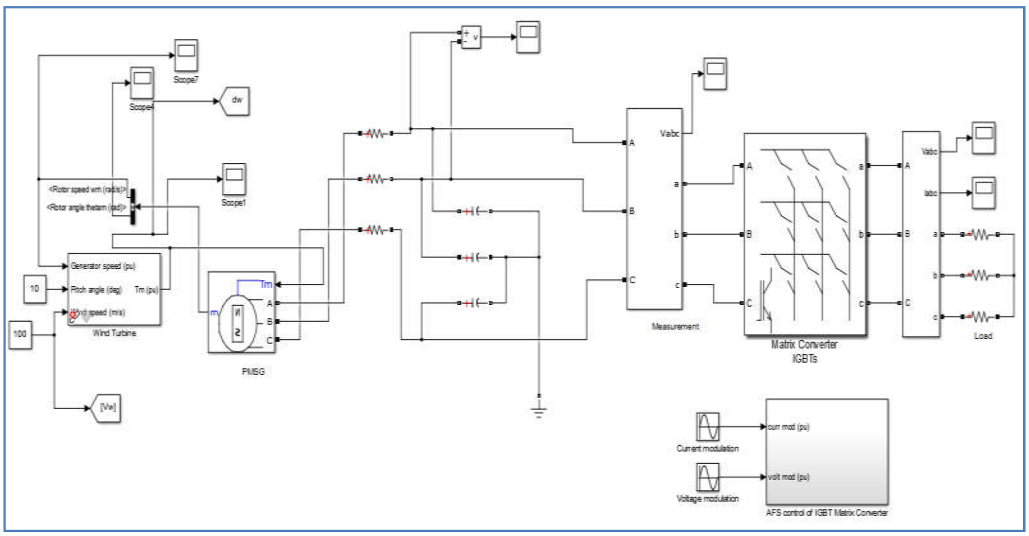

Fig. 3 Matrix converter-based wind system simulation

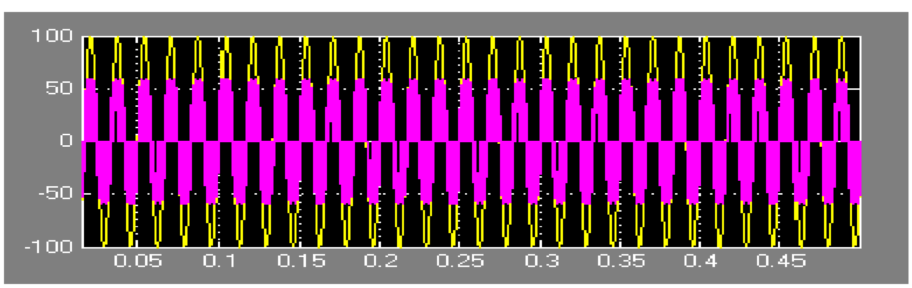

Fig. 4 Voltage and current of wind turbine

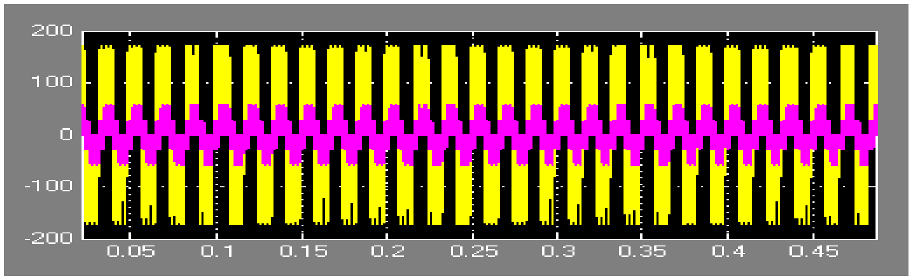

Fig. 5 Load voltage and current

IV. CONCLUSIONS

In order to precisely regulate voltage, improve system performance, and ensure smooth integration with the grid, the suggested approach of voltage control in grid-connected WES employs the AFS method in matrix converter with IoT monitoring. Through the use of IoT technology, real-time grid monitoring has become possible, and the AFS control algorithm has allowed for robust and adaptive control modifications in response to changing conditions in the environment. The suggested method has been shown to be successful via both simulation and experimental testing. MPP maintenance and stable regulation of voltage were both achieved due to the AFS control algorithm's optimization for energy extraction from the wind turbine generator. Real-time analysis of essential grid characteristics was made possible by the IoT-based monitoring system, allowing for prompt reactions to grid fluctuations and the early identification of problems. The suggested approach may be improved by additional study and innovation in the future. By incorporating a wider variety of grid characteristics into the IoT-based monitoring system, a deeper understanding of the grid's state will be provided and make better-informed control choices.

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Conflicts of Interest: The authors declare that they have no conflicts of interest to report regarding the present study.

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