

Design and Optimization of a Smart Grid for Wind-Based Renewable Energy Using Fuzzy Logic Control

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Abstract: This paper presents the design of a smart grid integrated with wind-based renewable energy systems, using a Fuzzy Logic Controller (FLC) to optimize energy distribution. The FLC helps manage the variable nature of wind energy, improving grid stability and efficiency. Performance is evaluated by analyzing Total Harmonic Distortion (THD) to assess power quality and minimize losses. The study identifies sources of THD and proposes solutions to reduce it, demonstrating that the FLC enhances system reliability, reduces energy waste, and supports the integration of renewable energy into the grid.

Keywords: Smart Grid, Wind-Based Renewable Energy, Fuzzy Logic Control.

I. INTRODUCTION

Traditional synchronous generators offer inertia and store kinetic energy in their rotor shaft. The speed of rotation of the generator is directly related to the frequency of the power system. Which suggests that a more stable power system might result from increased rotational inertia. There has been a recent uptick in the integration of renewable energy sources into the electricity grid. Although they are connected to the power grid by power converters, these resources do not contribute spinning inertia. Without adequate regulation, a large number of distributed energy resources (DER) might lead to instability. Controllers of the DER are thus responsible for achieving auxiliary functions, which have to be added [1]. When managed correctly, renewable energy sources have the potential to support frequencies and regulate voltages.

As an example, the injected active power can be controlled in relation to frequency in order to enable frequency support in the wind energy system (WES). For this to work, WES needs to keep some active power on hand; when the frequency drops, it can draw from this reserve. [2]. Intelligent power networks require efficient energy management as the globe moves to renewable energy sources like solar, wind, and hydropower. To maximize energy flow and maintain a balance between supply and demand, smart grids use advanced communication and control technologies. These networks update traditional energy distribution. However, it is challenging to maintain grid stability and reliability due to the intermittent and variable nature of renewable energy sources.

There are a lot of energy difficulties because modern cultures all need a lot of energy to keep growing. Two key tenets of contemporary energy policy are energy efficiency and renewable energy usage. Energy from the sun, gravity, and geothermal heat are the three main renewable energy sources on Earth. Wind energy, which increases air circulation between hot and cool zones, is an indirect result of incident solar energy [4]. A wind turbine's primary function is to convert the wind's kinetic energy into mechanical energy. The potential energy of an air current with mass (m) and velocity (v) is expressed as

$$E = \frac{1}{2}mv^2$$

The area of the wind rotor's cross-section is taken into account We can express the kinetic energy of the air stream that is accessible to the turbine as

$$E = \frac{1}{2} \rho v v^2$$

By making some adjustments to the standard control methods used by WES systems, it is possible to incorporate frequency control [5]. In order to modify a power system's frequency in response to frequency fluctuation, many control methods and approaches have been put into place [6]. The ability and length of time spent participating allow for the categorization of these control mechanisms [7]. The first strategy involves implementing inertial control using the stored kinetic energy.

Depending on the turbine's inertia, the stored energy can be released for a few seconds at most. Another control is to reduce the wind turbine's load to below its maximum power point. This will generate a steady-state frequency value that can be maintained over the long term by following the inertial response. A primary frequency response describes this. The use of PFCs in power systems that already incorporate wind turbines has been the subject of multiple investigations. While some research has concentrated on power systems as a whole, other studies have zeroed in on individual wind farms [8]. In addition, research on de-loaded wind turbines has looked at the equivalent damage loads [9]. Some studies have looked at how wind turbines react to PFC, while others have concentrated on reserve measures [10].

One realistic way to deal with the swings and uncertainties of renewable energy sources is to use control systems based on fuzzy logic. Powerful energy management systems that can handle ambiguous or imprecise data can be built with the help of fuzzy logic. In smart grid scenarios, these systems can balance changes in supply and demand, optimize storage, and control energy flows efficiently by using language variables and fuzzy rules. Incorporating a Fuzzy Logic Controller (FLC) to control the unpredictability of renewable energy sources derived from wind is one way this article helps smart grid systems progress.

The FLC optimizes energy distribution, enhancing grid stability, efficiency, and reliability while minimizing energy losses. A significant contribution is the evaluation of power quality through Total Harmonic Distortion (THD) analysis, where the study identifies primary sources of THD and proposes effective mitigation strategies. The paper shows that FLC can help renewable energy sources be more easily integrated into smart grids by lowering energy waste and improving power quality. This could be a strong approach to make modern energy systems more reliable and efficient.

II. LITERATURE REVIEW

One of the main areas of research in energy management is the integration of smart grids with renewable power sources like solar, wind, and biomass. Renewable energy sources cause issues for traditional grid systems due to their intrinsic unpredictability and intermittency. To efficiently incorporate renewable energy sources into the power distribution system, "smart grids" with advanced communication and control capabilities emerged. The literature highlights the importance of energy management systems that are both flexible and advanced enough to make good use of renewable energy sources within the ever-changing framework of smart grids [12].

As the world's energy demand for homes and factories continues to rise, solar power has emerged as a promising alternative. Rising energy demand across businesses, together with the impracticality and environmental effect of alternative energy sources like gasoline, has made the benefits of solar energy use more apparent. There are four primary phases to the lifecycle of a photovoltaic (PV) solar system, as stated in [13]: assessment/diagnosis, installation, operation, and disposal. The evaluation/diagnosis step involves analyzing the project's technical and economic feasibility, as well as deciding on the system's components in light of the project's social and technological requirements. Mounting the components selected during evaluation is what the installation step is all about. In this phase, known as "operation," the focus is on getting the system up and running, including all necessary upkeep and monitoring.

The last phase of a system's lifecycle is disposal. This last step involves determining if an item may be reused or recycled; if not, it must be disposed of in accordance with existing standards to ensure proper waste management [14].

This research will show that there are fuzzy hybrid approaches that can be applied for one or several specific stages of the lifecycle of PV solar systems, which is why this split of the lifecycle is relevant for this study. First, the solar energy literature can cover problems with manufacturing process simulation or system modeling; second, with elements like energy demand, maintenance, or system output prediction or forecasting; and third, with decision-making, including things like finding the best energy source, evaluating the performance of an energy source or infrastructure, and finding the best place to put the energy facility. According to [15], there are a number of additional obstacles that need to be addressed before renewable energy technologies can be widely adopted. These include, but are not limited to, lack of knowledge and understanding, land usage, legislation, technical difficulties, financial concerns, and government backing.

When fuzzy sets were initially proposed in 1965, it was [16]. The idea of fuzzy sets expanded the concept of classical sets and Boolean logic, which changed how modeling uncertainties were perceived after this. Fuzzy logic makes it possible to draw firm conclusions from vague or missing evidence by mathematically transforming linguistic factors into numerical form, making it suitable for use with natural language and approximate reasoning. Membership functions are used to represent fuzzy sets. Proper representation of language variables and fuzzy rules, use of the right fuzzy arithmetic approach, and selection of the best defuzzification methods are critical in fuzzy hybrid models.

A smart metering and smart grid communication survey was suggested in [17]. The goal of their review paper is to explain smart grid and the communication methods employed in a straightforward and organized manner. We present the smart grid's components in a rational fashion so that everyone can comprehend them, and we go over the ways in which we can communicate about their benefits, drawbacks, and improvements. We take a look at the evolving smart grid integration landscape via the lenses of consumer appliances, transmission, distribution, and generation. There is a table with the main features and an introduction to the communication technologies, which are classified as wired and wireless. Presented here are the software and hardware security needs for a smart grid, broken down by cyber and physical structures.

A review of cloud computing's smart grid applications was provided in [18]. The authors of the paper predicted that distributed architecture will allow future smart grids to manage power in a way that is dependable, efficient, secure, and cost-effective. They address these needs by offering a thorough overview of cloud computing applications in three distinct areas: energy management, information management, and security, all of which are integral to the smart grid architecture. Discussing the practicality of cloud computing applications and outlining potential avenues for smart grid advancement, these sections pave the way for the future.

They suggested writing a study on the topic of smart grid power line communications in [19]. Their study provided a synopsis of PLC's current capabilities by outlining its evolution and the most current technological developments in the field. We take a close look at the Smart Grid application scenario of PLC. They also cover two parts of engineering modeling, which is essential for network planning. The PLC channel must first be modeled using fading models. The second part helps us understand the communications needs better; it's the SmartGrid control and traffic modeling problem. At last, this article summarizes current research on a power distribution network sample's electrical and topological characteristics.

Presented research on the effects of smart grid on the layout of distribution systems in [20]. Future distribution systems, smart grids, and other related topics are all up for discussion. A smart grid's functional requirements include the capacity to offer new capabilities like self-healing, high dependability, energy management, and real-time pricing. New technologies

including distributed generation, storage, communication, automation, and improved metering are expected to be incorporated into a smart grid's design. Concerns about the smart grid and their possible effects on distribution system design were the subject of their paper.

The advantages and disadvantages of using wireless sensor networks for smart grid communications were discussed in [21]. Beginning with a review of the benefits and drawbacks of using WSNs in electric power systems, the authors pave the way for future research in a wide variety of smart-grid applications by highlighting numerous untapped areas of study. Furthermore, it details an extensive practical investigation into the statistical description of the wireless channel in several electric-power-system settings, such as a 500 kV substation, an industrial power control room, and an underground network transformer vault [22].

III. METHODOLOGY

To improve power quality, smart grid topologies use current control voltage source inverters to inject current into the grid in a manner that eliminates harmonics and maintains a specific phase-angle relative to the source voltage. The power factor and power quality are both enhanced by the injected current, which cancels out the reactive and harmonic components of the load and induction generator current. The current command for the inverter is generated by sensing and synchronizing the grid voltages, which allows for the accomplishment of these aims. As seen in Figure 1, the suggested smart grid-connected system is put into action to enhance power quality at the point of common coupling (PCC).

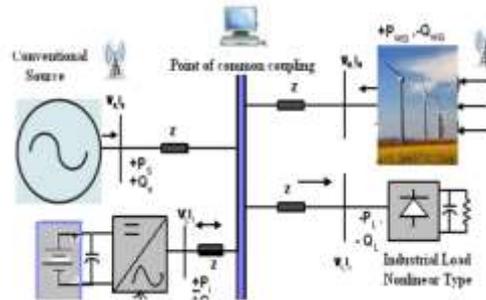


Fig. 1. Improving Power Quality through Grid Topology

Figure 1 depicts a grid-connected system that includes wind and solar power generation, as well as a battery energy storage system that uses a power converter, an inverter that operates on current, to convert voltage. Primary and secondary controls are part of the system.

1.Primary control: This system is made up of power electronics converters that can either take active power off the grid or supply reactive power to it. Power can be shared between the grid and the power converter thanks to the control. There are clear advantages to using these power converters in grid operations. The power quality that can be achieved without too much sacrifice includes controlling the grid voltage, reducing harmonics, and operating in phase.

2.Secondary control: Through a communication system, it controls the electrical parameters inside the grid from a central location with access to all individual controls, and it then transmits the results of this regulation. Additionally, network synchronization is handled by the secondary control.

Grid communication architecture

The foundation of the grid's communications lies in the Experimental Physics and Industrial Control System (EPICS), an open-source suite of tools for creating real-time distributed control systems that connect with one another via Ethernet. A highly secure IP network enables remote access to the facility through the communication architecture, which simplifies system diagnostics and operations. Both online and locally, with the help of the EPICS tools, you may see the installation's essential data in real time [5]-[8]. A smart grid control center, as well as measurement devices connected to the internet and the individual operator control (IOC) of energy suppliers, must be part of the system's architecture in order for it to accomplish its goals.

The dependability of the power system depends on the development of guidelines for appropriate IP protocols for smart grid applications and the identification of domain types. Figuring out the communication architect is illustrated in Figure 2.

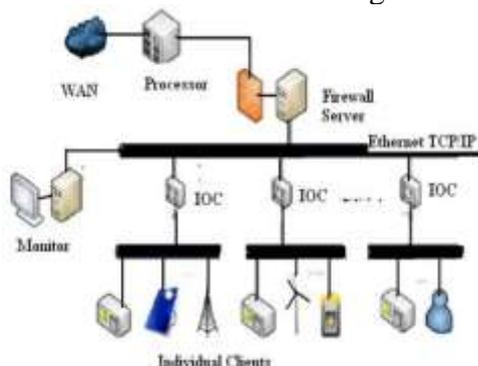


Fig. 2. Architect for Grid Communication.

IV. CONTROL TECHNIQUE

When it comes to applying fuzzy logic, fuzzy reasoning, and fuzzy set theory, the most active study topic is fuzzy logic control (FLC). Industrial process control, biological instruments, and securities are just a few of the many areas where FLC finds use. When dealing with complicated, poorly-defined situations that a skilled human operator can manage effectively without understanding their underlying dynamics, FLC has proven to be more effective than traditional control techniques.

To achieve certain goals in another physical system, a control system can be defined as a configuration of physical components that can be adjusted. Two distinct kinds of control systems are open-loop and closed-loop. An input control action in an open-loop control system does not depend on the physical system's output. In contrast, the output of the physical system determines the input control action in a closed-loop control system. Feedback control systems are another name for closed-loop control systems. Measuring a physical variable is the initial stage in managing it. The regulated signal is measured by a sensor, A physically controlled system is a plant. The input forcing signals of a closed-loop control system are defined by the system's output replies. Here is the fundamental control problem: By means of an error signal, the controlled physical system's output is fine-tuned. The error signal is the discrepancy between the predicted and actual responses of the plant. Adding a second system, known as a controller or compensator, to a closed-loop control system allows it to achieve desired responses and characteristics. Figure 3 is a simplified block diagram of the closed-loop control system. Simply said, fuzzy control rules are IE-THEN rules with a fuzzy twist.

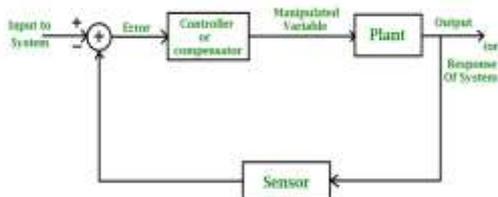


Fig 3: System of Control with a Closed Loop, Block Diagram

Control System Design:

These are the stages involved in designing a physical system controller:

1. Breaking down the complex system into its component parts.

2. Linearizing the nonlinear plane dynamics around a set of operating points and steadily varying the plant dynamics.
3. Assembling a collection of output characteristics, control variables, or state variables for the system in question.
4. Creating elementary P, PD, and PID controllers for the subsystems. Additionally, ideal controllers can be developed.

In addition to the first four processes, there is the possibility that there will be uncertainties that arise as a result of the external environmental conditions. Based on the technical knowledge of the control engineer, the controller design should be developed as close as feasible to the optimal controller design. This should be done in order to achieve the best possible results. This can be accomplished by a variety of numerical measurements of the input-output relationship, which can take the form of verbal, intuitive, and other types of information connected to the dynamics of the plant and the external environment. Last but not least, a supervisory control system, which may be either human or automatic, creates an additional feedback control loop in order to tune and modify the settings of the controller. This is done in order to compensate for the variational effects that are brought about by nonlinear and redesigned dynamics. When compared to the design of a conventional control system, the following assumptions ought to be made in the design of an FLC system, in the event that it is chosen. Both observable and controlled characteristics are required of the plant under evaluation.

It is necessary for there to be a wide range of knowledge that includes a collection of expert language rules, fundamental engineering common sense, a collection of data for input/output, or a controller analytic model that is capable of being fuzzyfied and from which the fuzzy rule foundation can be built. It is also important to note that there should be a solution for the problem that is being considered, and that this solution should be designed in such a way that the engineer is working toward a "good" solution rather than specifically seeking for an optimal one. In this particular scenario, the controller ought to be created to the very best of our abilities and inside a range of precision that may be considered acceptable. It should be brought to everyone's attention that the concerns of optimality and stability are ongoing issues in the design of the fuzzy controller. The procedure of developing fuzzy rules is an essential component in the process of designing a controller that uses fuzzy logic. From Weiss and Donnel's (1979) perspective, the fuzzy production rule system may be broken down into four distinct structures, which are as follows:

1. A collection of guidelines that are intended to serve as a representation of the expert decision-maker's policies and heuristic techniques.
2. A collection of data that are considered in the immediate period leading up to the choice that is actually made.
3. A method for evaluating any suggested action from the perspective of whether or not it conforms to the rules that have been expressed when there is data provided.
4. A strategy for creating promising actions and selecting when to cease looking for better ones to take into consideration.

These membership functions are responsible for defining all of the essential parameters that are utilized in the fuzzy logic controller. For the purpose of evaluating the rules, various methods such as interpolative reasoning and approximation reasoning are utilized. In order to obtain the control surface that establishes a connection between the control action and the measured state or output variable, these four structures of fuzzy rules are of great assistance. It is therefore possible to sample the control surface down to a finite number of points, and a look-up table may be constructed on the basis of the information obtained from this sampling. The information that pertains to the control surface is included in the look-up table, which can

be downloaded onto a memory chip that is only capable of reading data. It is possible that this chip could serve as a permanent controller for the facility.

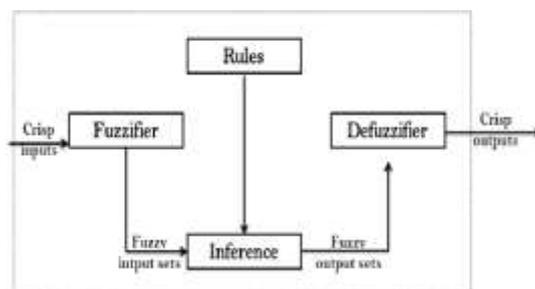


Fig 4: Operations of FLC System

Architecture and Operations of FLC System:

No doubt technology has made so many complex things easier and quicker yet, there is still a large amount of uncountable data that is tangled. This type of information can't be defined in 'Yes' or 'No' from the binary language. IT experts believe that there are many queries and search results that include a range of intermediate probabilities between Yes and No. That's where Fuzzy logic buzzes the industry to provide a valuable insight through flexible reasoning just like humans.

In 1965, Fuzzy Logic was initially proposed by Dr. Lotfi Zadeh. Fuzzy sets were established as a result of his study showing that not all natural languages can be translated into absolute binary terms of 0 and 1.

Fuzzy logic works like a human brain as it reckons the facts and decides a number by counting the possibilities of truth and myths.

Architecture of Fuzzy Logic- 4 categories:

1. **Fuzzification:** This element is used for converting the user inputs by converting the crisp numbers into fuzzy sets like room pressure, temperature, etc. Large positive (LP), medium positive (MP), small (S), medium negative (MN), and large negative (LN) are the five subcategories into which the input is further subdivided.
2. **Knowledge Base:** Also known as "Rule Base", contains "if-then" conditions provided by the experts. In a recent fuzzy theory update, the technology offers advanced methods to reduce the number of fuzzy sets by designing and tuning fuzzy controllers.
3. **Inference Engine:** This process determines the sync between fuzzy input and the rules and forms a percentage accordingly. This categorizes those rules which need reasoning process.
4. **Defuzzification:** This module determines all the fuzzy sets into a crisp value by choosing the right technique that will complement the expert system.

Fuzzy Logic Application Areas and Best Examples

- **Automotive Systems:** Fuzzy logic is used by many companies for automatic gearboxes, four-wheel steering, vehicle environment control, anti-lock brakes, auto engine, and auto transmissions. Nissan and Honda are one of the biggest examples of it.
- **Consumer Electronic Goods:** Giant companies like Canon, Toshiba, Mitsubishi Electric, and Fujitec are using fuzzy logic to improve their products like copy machine, elevator control, and plasma etching.
- **Domestic Goods:** Products like microwave ovens, refrigerators, toasters, washing machines and vacuum cleaners are updating with fuzzy logic. Matsushita and Mitsubishi Chemical Corporation are some of the organizations that are benefiting from it.

- **Environment Control:** Air conditioners, dryers, heaters, and humidifiers are enhancing their features with fuzzy logic.

Fuzzy logic is a method of reasoning that mimics human decision-making behaviour. Many giant companies are controlling and updating features of their consumer products for reaping higher profits while investing less. However, any specific designing approach hasn't been issued, but experts are working continuously to work in the same context to discover its more possibilities and potentials in various sectors.

V. SIMULATION RESULTS

The smart grid connected wind power generating system simulation diagram is shown in figure5

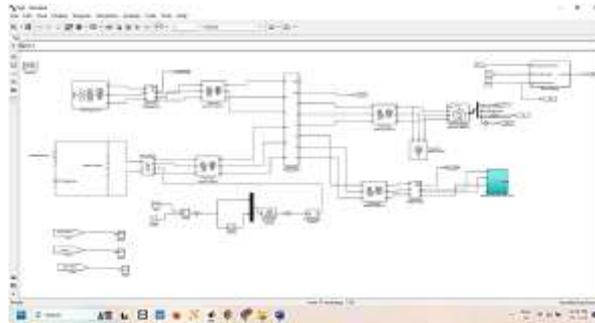


Fig 5: Simulation block diagram.



Fig 6: Source current



Fig 7: Inverter current



Fig 8: Load current.

The simulation of this system takes into account a non-linear load. There will be disruptions to the source current waveform due to these nonlinear loads in the system. It is necessary to inject just the right amount of current to eliminate distortion from the source current. Power quality improvement for these essential loads is measured by running the controller, which provides insight into the system's performance. At 0.2 seconds, the inverter is turned "on." In both the controller-operated and non-operated states, the source current I_s , inverter injected current I_{inv} , and load current I_L are recorded. The moment the controller starts working, as illustrated in Figure 6, the source current becomes sinusoidal and harmonic-free. You can see the inverter-supplied injected current in Figure 7. The system's load current is depicted in Figure 8. The sum of the currents flowing into and out of the source and the inverter, during this time frame, is the load current. Also the THDs are shown in figure 9 and 10.

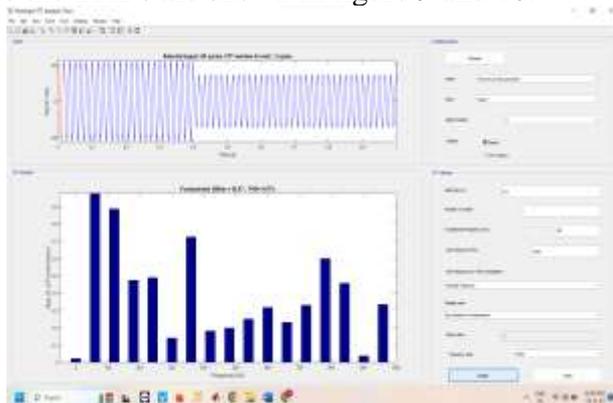


Fig 9: THD for source current.

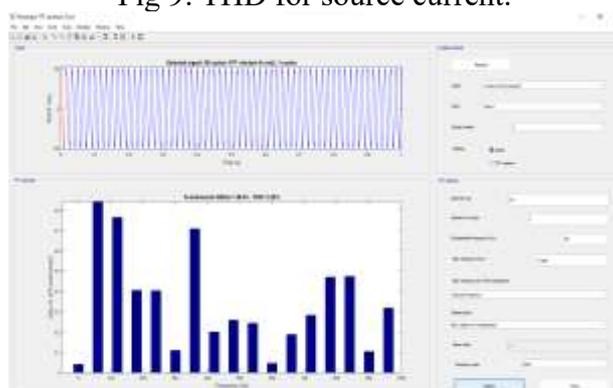


Fig 10: THD for Load current.

CONCLUSION:

An optimization of smart grid operations incorporating wind-based renewable energy systems is achieved by this study, which proves the efficacy of a Fuzzy Logic Controller (FLC). Improved energy distribution, grid stability, and overall system efficiency are achieved through the FLC's approach to wind energy's inherent variability. Reducing losses and improving reliability are outcomes of analyzing Total Harmonic Distortion (THD), which reveals key areas of power quality concerns and offers solutions to these problems. Results show that FLC-based control systems can help renewables integrate into current grids more easily, which could lead to more efficient and environmentally friendly power systems. Future work could explore the application of this approach to other renewable energy sources and expand its scalability for larger grid systems.

REFERENCES

1. Muljadi, E.; Gevorgian, V.; Singh, M.; Santoso, S. Understanding inertial and frequency response of wind power plants. In Proceedings of the 2012 IEEE Power Electronics and Machines in Wind Applications, Denver, CO, USA, 16–18 July 2012; pp. 1–8.

2. Singh, M.; Gevorgian, V.; Muljadi, E.; Ela, E. Variable-speed wind power plant operating with reserve power capability. In Proceedings of the 2013 IEEE Energy Conversion Congress and Exposition, Denver, CO, USA, 15–19 September 2013; pp. 3305–3310.
3. Margaritis, I.D.; Papathanassiou, S.; Hatziargyriou, N.D.; Hansen, A.D.; Sorensen, P. Frequency Control in Autonomous Power Systems with High Wind Power Penetration. *IEEE Trans. Sustain. Energy* 2012, 3, 189–199. [CrossRef]
4. Pradhan, C.; Bhende, C. Enhancement in Primary Frequency Contribution using Dynamic Deloading of Wind Turbines. *IFAC-PapersOnLine* 2015, 48, 13–18. [CrossRef]
5. Camblong, H.; Vechiu, I.; Etxeberria, A.; Martinez, M.I. Wind turbine mechanical stresses reduction and contribution to frequency regulation. *Control Eng. Pract.* 2014, 30, 140–149. [CrossRef]
6. Diaz-Gonzalez, F.; Hau, M.; Sumper, A.; Gomis-Bellmunt, O. Coordinated operation of wind turbines and flywheel storage for primary frequency control support. *Int. J. Electr. Power Energy Syst.* 2015, 68, 313–326. [CrossRef]
7. Miao, L.; Wen, J.; Xie, H.; Yue, C.; Lee, W. Coordinated Control Strategy of Wind Turbine Generator and Energy Storage Equipment for Frequency Support. *IEEE Trans. Ind. Appl.* 2015, 51, 2732–2742. [CrossRef]
8. Van de Vyver, J.; de Kooning, J.D.M.; Meersman, B.; Vandoorn, T.L.; Vandeveldel, L. Optimization of constant power control of wind turbines to provide power reserves. In Proceedings of the 2013 48th International Universities' Power Engineering Conference (UPEC), Dublin, Ireland, 2–5 September 2013.
9. El Mokadem, M.; Courtecuisse, V.; Saudemont, C.; Robyns, B.; Deuse, J. Experimental study of variable speed wind generator contribution to primary frequency control. *Renew. Energy* 2009, 34, 833–844. [CrossRef]
10. Singarao, V.Y.; Rao, V.S. Frequency responsive services by wind generation resources in United States. *Renew. Sustain. Energy Rev.* 2016, 55, 1097–1108. [CrossRef]
11. Moutis, P.; Papathanassiou, S.A.; Hatziargyriou, N.D. Improved load-frequency control contribution of variable speed variable pitch wind generators. *Renew. Energy* 2012, 48, 514–523. [CrossRef]
12. Badihi, H.; Zhang, Y.; Hong, H. Active power control design for supporting grid frequency regulation in wind farms. *Annu. Rev. Control* 2015, 40, 70–81
13. Dreidy, M.; Mokhlis, H.; Mekhilef, S. Inertia response and frequency control techniques for renewable energy sources: A review. *Renew. Sustain. Energy Rev.* 2017, 69, 144–155. [CrossRef]
14. Žertek, A.; Member, S.; Verbi, G.; Member, S.; Pantoš, M. A Novel Strategy for Variable-Speed Wind Turbines' Participation in Primary Frequency Control. *IEEE Trans. Sustain. Energy* 2012, 3, 791–799. [CrossRef]
15. Erlich, I.; Wilch, M. Primary frequency control by wind turbines. In Proceedings of the IEEE PES General Meeting, Providence, RI, USA, 25–29 July 2010.
16. Camblong, H.; Nourdine, S.; Vechiu, I.; Tapia, G. Control of wind turbines for fatigue loads reduction and contribution to the grid primary frequency regulation. *Energy* 2012, 48, 284–291. [CrossRef]
17. Satpathy, G.; Mehta, A.K.; Kumar, R.; Baredar, P. An overview of various frequency regulation strategies of grid connected and stand-alone wind energy conversion system. In Proceedings of the International Conference on Recent Advances and Innovations in Engineering (ICRAIE-2014), Jaipur, India, 9–11 May 2014.
18. Motamed, B.; Chen, P.; Persson, M. Comparison of primary frequency support methods for wind turbines. In Proceedings of the 2013 IEEE Grenoble Conference, Grenoble, France, 16–20 June 2013.

19. Wang, Y.; Bayem, H.; Giralt-devant, M.; Silva, V.; Guillaud, X.; Francois, B. Methods for Assessing Available Wind Primary Power Reserve. *IEEE Trans. Sustain. Energy* 2015, 6, 272–280. [CrossRef]
20. Qian, D.; Tong, S.; Liu, H.; Liu, X. Load frequency control by neural-network-based integral sliding mode for nonlinear power systems with wind turbines. *Neurocomputing* 2016, 173, 875–885
21. Tielens, P.; de Rijcke, S.; Srivastava, K.; Reza, M.; Marinopoulos, A.; Driesen, J. Frequency support by wind power plants in isolated grids with varying generation mix. In *Proceedings of the 2012 IEEE Power and Energy Society General Meeting, San Diego, CA, USA, 22–26 July 2012*.
22. Díaz, G.; González-Morán, C.; Gómez-Aleixandre, J.; Diez, A. Scheduling of droop coefficients for frequency and voltage regulation in isolated microgrids. *IEEE Trans. Power Syst.* 2010, 25, 489–496