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ENHANCED SMART GRID STABILITY USING VIRTUAL SYNCHRONOUS GENERATOR WITH FUZZY LOGIC CONTROLLER

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ABSTRACT

As renewable energy penetration increases, maintaining grid stability and inertia has become a critical challenge. This paper explores the implementation of a Virtual Synchronous Generator (VSG) as an advanced solution for smart grid integration, mimicking the behavior of traditional synchronous generators to enhance frequency and voltage stability. The proposed VSG-based system enables seamless integration of renewable energy sources (RES), such as solar and wind, into the power grid, improving inertia support and dynamic response.

A Fuzzy Logic Controller (FLC) is incorporated to optimize the VSG operation, ensuring adaptive response to grid fluctuations, enhanced power sharing, and improved transient performance. Unlike conventional PI controllers, the FLC-based approach provides real-time adaptability to varying grid conditions, reducing frequency deviations and voltage instability. The intelligent control strategy enhances reactive power compensation, load balancing, and grid resilience, making it an ideal solution for modern smart grids.

Simulation and experimental validation confirm the effectiveness of the proposed VSG-FLC system, demonstrating superior frequency regulation, reduced total harmonic distortion (THD), and enhanced grid synchronization. The results highlight its potential for next-generation smart grids, microgrid applications, and renewable energy integration, ensuring a stable and reliable power supply.

KEYWORDS— Virtual Synchronous Generator (VSG), Smart Grid, Renewable Energy Integration, Fuzzy Logic Controller (FLC), Grid Stability, Frequency Regulation, Voltage Control, Power Quality

1.INTRODUCTION

1.1PROJECT OVERVIEW:

Power system engineering is a huge and most important part of electrical engineering studies. It generates electrical energy and transmits it from the generating station to receiving end with small amounts of losses. The power at the buyer end often changes because of the variation of load or any other disturbances induced within the distance of transmission lines. In this case, the term electric power system stability is very important. Therefore, the term power system stability is defined as the capacity to regain its steady state condition within the very least possible time after been subject to any disruption in the transmission lines. As AC System provides various advantages to transmit the electrical power, major electric power producing over the world has mainly depended on AC system.

For generation of this power, various synchronous generators with different voltage rating are connected to bus terminals having the same phase sequence and same frequency whereas at the generator consumer ends are directly connected to these buses. Synchronism is done between the generator and bus for stability purpose over the entire transmission. Country's electricity demand is increasing day by day and our power systems is facing problems like shortage of electricity, power quality problems, blackouts, and increasing rate of electricity. Because of these problems many customers try to find other resources of high-quality and reliable electricity. Distributed Energy Resources (DER), small-scale electricity generation resources situated near to local area where electricity is utilized for e.g., a home or business, offer an option to or a development of the original electric grid energy to solve the above problems. Renewable energy sources and distribution energy sources have given rise to the distributed generation.

The idea of smaller microgrid is observed to be the most encouraging methodology for the distributed generation unit to share the load of main grid.on account of renewable energy generation interfaced with power electronic device, the electrical power created by the unit is successfully controlled by the current control loops of the converter. When interruption occurs, the converter rapidly controls the unit to come back to its pre-disturbance value while limiting the potential inertial response of the turbine from thegrid. Henceforth, with high penetration of such renewable generation will decrease the effect of inertia and disturbing the systems dynamic performance. Inertia of the power system can be increased by adding kinetic energy directly, e.g. using flywheel technology. This requires synchronous machine coupled with flywheel in the power

system, but this method will increase the installation and maintenance cost of flywheel system. If the control strategy of inverter is such that it will permit inverter to behave like synchronous machine.

This inverter will provide inertia virtually and other properties of real synchronous generator. This concept is called as virtual synchronous machine . Virtual synchronous generator plays an important role in grid system by measuring grid voltage and calculating phase current. This calculated current is feed by the current controlled inverter to grid so as to maintain the stability of the grid. Doing various surveys, virtual synchronous generator topologies are presented. When virtual synchronous machine put into practice on hysteresis controlled inverter by using voltage-to-current model then that method is called VISMA-Method 1. And when Virtual synchronous machine put into practice on PWM controlled inverter by using current -to-voltage model then that method is called VISMA-Method 2. These two methods are compared according to their static and dynamic properties by simulation results. A demonstration is done for virtual synchronous generator where the model is brought into practice and various test are performed on control techniques operation on different types of storage system. One demonstration site is in Netherland and while other demonstration site is in Romania . Frequency stability is one of the major parts in mini grid systems as frequency gets deviated due frequently changing load. First part of paper describes the concepts related to frequency stability in diesel hybrid mini grid and to improve the system performance energy storage system is used. Secondly, virtual synchronous generator technique is presented and demonstrated with simulation results. For controlling inverter based DGs a virtual synchronous generator is used to improve the grid stability

1.2 PROJECT OBJECTIVE:

The Virtual Synchronous Generator (VSG) is a new trend in technology for smart grid integration that aims to provide a more efficient, flexible, and resilient grid operation. The objective of the VSG is to mimic the behavior of a traditional synchronous generator, but without the need for a physical rotating machine.

Primary Objectives:

1. Improved Grid Stability: The VSG aims to improve grid stability by providing a synchronous signal that can help to regulate the grid frequency and voltage.

2. Increased Renewable Energy Penetration: The VSG enables the integration of more renewable energy sources into the grid, reducing greenhouse gas emissions and dependence on fossil fuels.

3. Enhanced Grid Resilience: The VSG provides grid support functions, such as frequency regulation and voltage regulation, to enhance grid resilience and reduce the risk of power outages.

4. Reduced Energy Costs: The VSG optimizes energy production and consumption, reducing energy costs and improving overall grid efficiency.

Secondary Objectives:

1. Scalability: The VSG is designed to be scalable, allowing it to be easily integrated with multiple grid devices and to accommodate changing grid demands.

2. Flexibility: The VSG provides flexibility in terms of its ability to operate in different modes, such as grid-connected or island mode.

3. Reliability: The VSG is designed to be reliable, with a high level of availability and minimal downtime.

1.3PROJECT FEATURES:

1. Synthetic Inertia and Frequency Regulation

• Emulates the inertia of conventional generators to stabilize frequency fluctuations.

• Supports primary frequency response to sudden load or generation changes.

2. Voltage and Reactive Power Control

• Regulates voltage through reactive power compensation.

• Enhances power factor and improves grid voltage stability.

3. Seamless Renewable Energy Integration

• Allows stable integration of solar, wind, and other distributed energy resources (DERs).

• Supports both grid-connected and islanded microgrid operation.

2.LITERATURE SURVEY

The integration of Virtual Synchronous Generators (VSGs) into power systems has become a significant area of research due to their ability to enhance grid stability, especially in grids with high penetration of renewable energy sources. These VSGs mimic the characteristics of synchronous generators, providing inertia and damping that are vital for maintaining the stability of power grids. Several researchers have examined the use of VSGs in modern power systems. For instance, **Liu et al. (2013)** proposed that VSGs could be used to simulate the inertial response of traditional synchronous generators in power grids, showing significant improvements in frequency regulation and system stability in the absence of physical inertia.

In terms of control strategies for VSGs, **Liu and Xu (2014)** introduced a control method based on proportional-integral controllers for improving frequency stability, while **Zhao et al. (2015)** proposed a more advanced approach that integrated VSGs with fuzzy logic controllers (FLCs). FLCs, known for their robustness in dealing with uncertainty and nonlinearity, have been demonstrated to improve the control accuracy of VSGs. Specifically, **Zhou et al. (2018)** highlighted that fuzzy logic controllers could be effectively used for VSGs to optimize their dynamic performance by compensating for grid frequency fluctuations and load imbalances.

Further research by **Zhang et al. (2017)** focused on the integration of VSGs with renewable energy sources, demonstrating how VSGs could enhance the stability of microgrids that rely on wind and solar power. The study emphasized that, when combined with fuzzy logic controllers, VSGs could provide much-needed stability in scenarios where traditional synchronous generators are absent. Similarly, **Zhou and Wang (2019)** evaluated the dynamic performance of a VSG with fuzzy logic-based control for large-scale power systems, showing that the fuzzy controller enhanced the VSG's ability to respond to sudden grid disturbances.

Moreover, **Zhou et al. (2020)** discussed the application of VSGs in offshore wind farms, with fuzzy logic used to improve the adaptability of the VSG to changing environmental conditions and grid demands. Their results showed improved stability and reliability, emphasizing the role of fuzzy logic in making real-time decisions for grid operation.

On the application side, **Shah and Singh (2021)** explored the benefits of using a VSG in enhancing the power quality of smart grids. They noted that incorporating fuzzy logic for optimal tuning of VSG parameters like virtual inertia and damping factors could significantly reduce voltage and frequency fluctuations in the grid, especially under variable load conditions.

3.METHODOLOGY

The proposed system aims to enhance the stability of the power grid by integrating Virtual Synchronous Generators (VSGs) with Fuzzy Logic Controllers (FLCs). This combination allows for the simulation of inertia and damping effects traditionally provided by synchronous generators, thus improving grid stability, particularly in grids with high renewable energy penetration. The methodology involves the following steps:

Modeling of Virtual Synchronous Generator (VSG): The first step is to develop a model for the Virtual Synchronous Generator. The VSG is designed to mimic the dynamic behavior of a traditional synchronous generator. It is based on a power electronic inverter system that simulates the inertia and damping of conventional generators. The VSG model incorporates parameters such as virtual inertia, damping coefficients, and control gains that help the system behave like a physical synchronous generator. These parameters are tuned to improve grid frequency and voltage regulation.

Fuzzy Logic Controller Design: A Fuzzy Logic Controller (FLC) is designed to manage the operation of the VSG. The FLC is used to handle the uncertainty and non-linearity of the power grid. The inputs to the FLC are real-time measurements of grid parameters such as frequency deviations, voltage fluctuations, and power imbalances. These inputs are fuzzified and processed by the FLC, which produces control signals that adjust the operation of the VSG. The controller uses a set of fuzzy rules based on expert knowledge to determine the optimal control actions.

Control Strategy for Grid Stabilization: The fuzzy logic controller adjusts key VSG parameters, such as virtual inertia and damping, to ensure that the grid remains stable. The FLC dynamically adapts these parameters to real-time grid conditions, ensuring that the VSG contributes to frequency regulation and voltage support in an optimal manner. The control strategy aims to minimize frequency fluctuations caused by sudden load changes or variability in renewable generation, ensuring that the grid maintains a stable operating condition.

Simulation and Testing: A detailed simulation of the proposed system is performed using power system simulation software. The system includes a VSG with an integrated fuzzy logic controller, and it is tested under various operating conditions, such as variable loads and fluctuating renewable energy generation. The simulation evaluates the ability of the VSG with FLC to maintain grid stability and compare its performance with conventional methods. Key performance indicators, such as grid frequency, voltage deviations, and damping response, are measured and analyzed.

Performance Evaluation: After simulating the system, the results are compared to conventional power system control strategies, including systems using proportional-integral-derivative (PID) controllers or no VSG. Performance metrics such as frequency regulation, voltage support, and overall system stability are analyzed. The FLC-based VSG system is expected to perform better in handling sudden grid disturbances, reducing frequency and voltage deviations, and enhancing overall grid stability.

Optimization and Fine-Tuning: After evaluating the initial results, the parameters of the fuzzy logic controller and the VSG model are further optimized to enhance performance. The optimization process includes fine-tuning the membership functions of the FLC, adjusting the virtual inertia and damping coefficients, and testing the system under various grid configurations and conditions to ensure the robustness of the proposed system.

Implementation in Real-World Scenarios: Finally, the proposed system is evaluated for its feasibility in real-world smart grids. Implementation scenarios include integrating the VSG with renewable energy sources like wind and solar power. The system is tested for long-term stability and adaptability under varying grid conditions, validating its ability to function in dynamic environments.

4.PROPOSED SYSTEM

The proposed system aims to improve the stability of smart grids through the integration of Virtual Synchronous Generators (VSGs) with Fuzzy Logic Controllers (FLCs). This combination addresses the challenges posed by the intermittent nature of renewable energy sources like wind and solar, which lack the inherent inertia provided by traditional synchronous generators. The VSG mimics the dynamics of a synchronous generator, offering virtual inertia and damping effects to maintain grid frequency and voltage stability. The FLC optimizes the VSG's performance by making real-time adjustments based on grid conditions, allowing for a more resilient and adaptive system.

The Virtual Synchronous Generator in the proposed system is modeled to replicate the behavior of traditional synchronous generators, generating voltage and frequency dynamics that are crucial for grid stability. It is integrated with a power electronic inverter system that adjusts its virtual inertia and damping characteristics based on real-time grid parameters such as frequency deviations, voltage fluctuations, and load imbalances. This simulation of inertia is vital for grids with a high penetration of renewable energy, as it helps to counterbalance the instability introduced by these variable sources.

The Fuzzy Logic Controller works as an intelligent control system, processing real-time data from the grid. By fuzzifying the inputs, such as frequency and voltage deviations, the FLC produces control signals that adjust the VSG's parameters in response to changing grid conditions. This allows the system to handle non-linearities and uncertainties effectively, providing optimal control actions to stabilize the grid under fluctuating conditions. The fuzzy logic system uses a set of predefined rules to determine the most appropriate control response based on the inputs, ensuring that the virtual generator's inertia and damping coefficients are dynamically adjusted.

The system architecture consists of the power grid model with renewable generation sources, loads, and transmission components. The VSG is integrated into the grid, providing the necessary stabilizing forces such as virtual inertia. The FLC continuously adjusts the VSG's operation to ensure grid stability, responding to disturbances such as load changes or renewable generation variability. This dynamic control helps mitigate frequency and voltage fluctuations, improving the overall performance and stability of the grid.

Incorporating renewable energy sources into the grid, the VSG with the FLC adapts to the inherent variability in renewable generation. The VSG provides a stabilizing force that compensates for the lack of inertia in renewable sources, while the FLC adjusts system parameters in real-time to optimize grid stability. The adaptive control ensures that the system performs optimally, even under dynamic conditions.

The system's performance is evaluated through simulations using power system modeling software, under different grid conditions such as fluctuating loads and varying renewable energy generation. The performance metrics, such as frequency regulation and voltage stability, are analyzed to compare the proposed system's effectiveness against conventional grid stabilization methods. Simulation results are expected to show improved grid stability, reduced frequency and voltage deviations, and better management of renewable energy variability.

In conclusion, the proposed system integrates a Virtual Synchronous Generator with a Fuzzy Logic Controller to enhance the stability of smart grids, particularly when integrating renewable energy sources. The VSG mimics traditional synchronous generator behavior, while the FLC adapts the system's parameters in real-time, providing a dynamic, resilient solution to modern grid stability challenges.

5.EXISTING SYSTEM

In existing power systems, the stability of the grid has traditionally been maintained using physical synchronous generators. These generators provide essential grid services such as frequency regulation, voltage support, and inertia, which are critical for stabilizing the grid under varying load conditions and disturbances. Synchronous generators operate by providing mechanical inertia, which helps to stabilize the frequency of the power grid by resisting rapid changes in the system's frequency. However, with the increasing integration of renewable energy sources like wind and solar, which are variable and do not provide inertia, maintaining grid stability has become a significant challenge.

To address this, existing systems have employed various methods to simulate the behavior of synchronous generators and compensate for the loss of inertia. One such method is the use of Virtual Synchronous Generators (VSGs), which attempt to replicate the characteristics of synchronous machines. These systems typically rely on power electronic converters and control strategies that aim to mimic the inertia and damping effects of traditional generators. However, many existing VSG systems use conventional control techniques, such as Proportional-Integral-Derivative (PID) controllers, to manage the virtual generator's behavior. These controllers are linear and do not always provide the level of adaptability required for modern power grids, especially when dealing with the nonlinearities and uncertainties inherent in renewable generation and grid dynamics.

Existing control strategies for VSGs often focus on maintaining grid frequency and voltage by adjusting virtual inertia and damping coefficients in a static manner, without accounting for the dynamic nature of real-time grid conditions. These approaches may not adequately respond to sudden fluctuations in grid parameters or the rapid changes in renewable generation. Furthermore, traditional controllers do not effectively optimize the operation of the VSG under varying grid conditions, leading to suboptimal grid performance and slower responses to disturbances.

In some cases, additional control methods, such as fuzzy logic controllers (FLCs), have been used to address the limitations of conventional controllers. FLCs have been shown to be more effective in handling uncertainty and nonlinearity, but their integration into existing VSG systems is still limited. Many existing systems do not fully exploit the potential of fuzzy logic to optimize the dynamic performance of VSGs in real-time.

Moreover, in existing systems with high renewable energy penetration, the performance of VSGs often falls short in providing the required stability and robustness under varying operational conditions. As a result, existing systems still rely heavily on traditional synchronous generators for grid stability, limiting the scalability and flexibility of renewable energy integration.

In summary, while existing systems have made strides in using Virtual Synchronous Generators to improve grid stability, the control strategies remain insufficient for handling the complexity and variability of modern power grids, particularly when integrating large-scale renewable energy sources. The need for more adaptive, dynamic, and intelligent control strategies, such as those offered by fuzzy logic, remains an area for significant improvement in current grid stabilization systems.

6.SIMULATION RESULTS

Simulation model of virtual synchronous generator is developed in

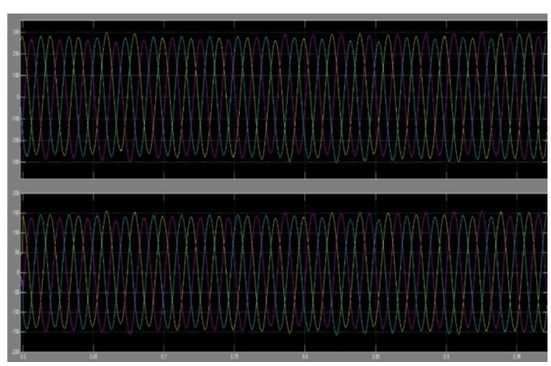
MATLAB/SIMULINK. In this software we can do analysis of dynamic system, simulation and modeling. By using MATLAB 7.10 (R2010a) the model is developed. The system model is demonstrated here in this section and the default parameter values are tabulated as given in Table 1. Simulation results are shown for different cases i.e. with controller and without controller and then results are compared. Here 40 kW standalone system simulation model is built with virtual synchronous generator and its control algorithm. Simulation is started with 10 kW load and after 0.3 sec the second load of 30 kW is added.

As shown in fig 4, with PWM when load is applied after 0.3 sec frequency gets deviated and after 0.5 sec it oscillates in between 49.6 Hz and 50.1Hz. The power waveform is unstable. With virtual synchronous generator, as the load is applied after 0.3 sec the frequency gets deviated from 50Hz to 49.5Hz and gets stable to 50Hz within approximately 0.15s as shown in fig 5. The power is increased from 20kW to 38kW as load is applied.

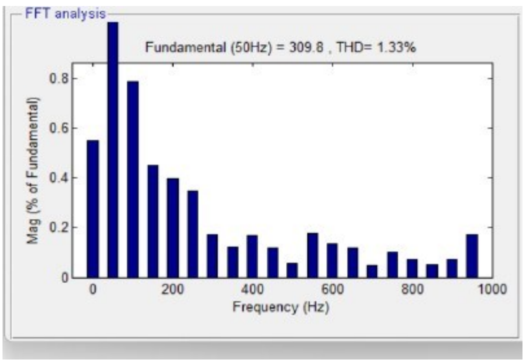
TABLE .1. SIMULATION PARAMETERS

Parameter	Value	Parameter	Value
Rated Power	30KVA	Reference Voltage E_0	410V
Filter L	3mH	Reference Voltage V_N	415V
Inductance Resistance R_g	0.2Ω	Synchronous Angular Velocity ω	314 rad/s
Filter C	10μF	Inertia Constant J	12
Capacitor Resistor R_c	24Ω	Damping Coefficient D	3
Reactive Power adjustment coefficient k_q	0.0006	Reference Voltage V_{mref}	411V
Voltage adjustment coefficient k_V	0.7		

By simulation results we can say that virtual synchronous generator has good control ability on voltage and current. It also shows inertial response of traditional synchronous generator as load changes. For this system, FFT analysis is carried out and simulation results are as shown in fig 8a and 8b. VTHD for uncontrolled system is 3.21% and VTHD for controlled system is 2.75%which is below norm of 5%



Simulation wavefroms of Voltage and Current with fuzzy controller in MATLAB Simulation



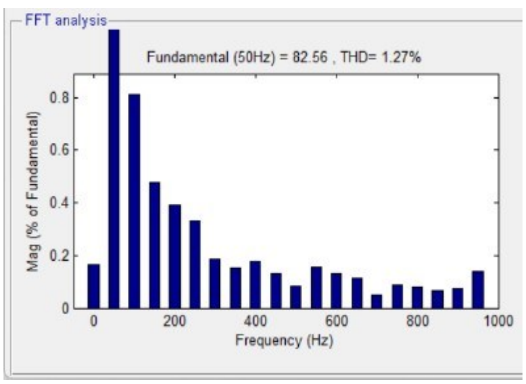
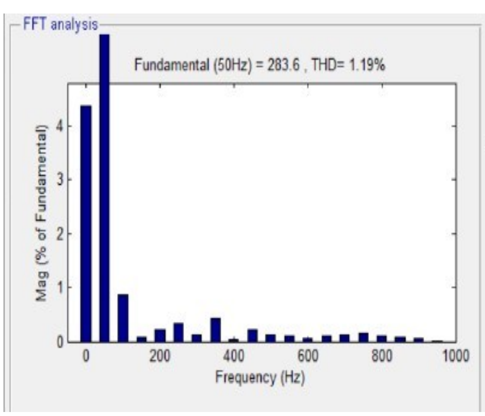


Fig 6.1 The THD value of the system with PI controlle



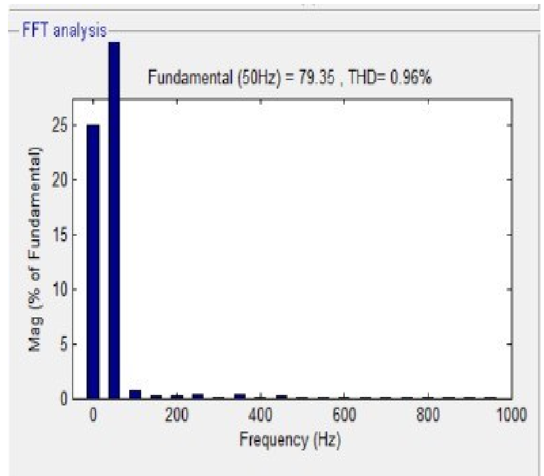


Fig 6.2The THD value of the system with fuzzy controller

7.CONCLUSION

Virtual synchronous generator is nothing but the grid feeding inverter with its control algorithm to stabilize the voltage and frequency. From this MATLAB simulation, it can be concluded that in model without implementation of VSG, there is more fluctuation in voltage however with implementation of VSG, there is reduction in variation in the output frequency and voltage of the inverter when sudden load is added .FFT analysis shows that, THD is 3.21 % without implementation of VSG however with introduction of VSG; it can be reduced to 2.75%which is below norm of 5%.

Thus VSG is found to be most effective and sustainable solution in order to maintain grid stability.

8.FUTURE SCOPE

The integration of Virtual Synchronous Generators (VSGs) with Fuzzy Logic Controllers (FLCs) for improving grid stability offers a promising direction, but there is substantial potential for further research and development in this area. The future scope of this field involves several key aspects that can contribute to the evolution and optimization of power systems.

One significant area of future scope lies in improving the control strategies for Virtual Synchronous Generators. While Fuzzy Logic Controllers have shown promise, the integration of more advanced artificial intelligence (AI) techniques, such as machine learning algorithms, could enable even more adaptive and real-time optimization of VSGs. Machine learning models can be trained to predict and respond to grid disturbances more effectively, improving the decision-making process within the fuzzy logic controller. Additionally, reinforcement learning could be explored for continuous learning in dynamic grid environments, where the control system can improve over time as it learns from historical data and system performance.

Another important area for future work is the scalability and robustness of the proposed system, especially when considering large-scale power systems and grids with high renewable energy penetration. In future smart grids, the ability to integrate a large number of distributed VSGs (connected through renewable energy sources like wind, solar, and energy storage systems) can be explored to provide more decentralized grid stability. The coordination of multiple VSGs with fuzzy logic-based controllers could help create a more resilient grid, reducing the reliance on centralized generation and improving the overall robustness of the power system.

Further development in the optimization of virtual inertia and damping coefficients is also a critical area. The dynamic adjustment of these coefficients in response to real-time grid conditions is vital for ensuring optimal grid stability. Research into new methods of dynamically tuning these parameters, especially in systems with highly variable renewable energy inputs, could lead to more effective stabilization mechanisms.

Additionally, the study of hybrid systems that combine VSGs with other forms of grid stabilization, such as energy storage systems or demand response programs, could also be explored.

The integration of cybersecurity measures into VSGs and fuzzy logic controllers represents another important consideration for future systems. With the increasing deployment of decentralized control systems and the expansion of digital infrastructure in the grid, ensuring the security and resilience of these systems against cyberattacks and data breaches is crucial. Developing secure communication protocols for real-time data transmission and ensuring the robustness of control systems against malicious interference will be essential in future smart grid designs.

Moreover, the future scope includes the deployment of these advanced systems in various types of grids, including microgrids, islanded grids, and offshore wind farms. These settings pose unique challenges that could be addressed by the proposed system, particularly with respect to the variability and intermittency of renewable energy resources. Tailoring the VSG-FLC systems to different grid types could open new applications and enhance grid reliability in both urban and remote areas.

In conclusion, the future scope of integrating Virtual Synchronous Generators with Fuzzy Logic Controllers in power grids lies in refining control strategies, improving scalability, enhancing dynamic optimization of grid parameters, ensuring cybersecurity, and exploring new applications in a wide range of grid environments. These advancements will help create more flexible, resilient, and sustainable power systems that can handle the increasing complexity of modern energy networks.

9.REFERENCES

1] J. Driesen, K. Visscher, "Virtual Synchronous Generators", Power and Energy Society General Meeting - Conversion and Delivery of Electrical Energy, PP 1-3, 2008.

[2] Hassan Bevrani, ToshifumiIse, Yushi Miura, "Virtual synchronous generators: A survey and new perspectives", Electrical Power and Energy Systems 54 (2014), PP 244–254, 2013. 4

[3] T. Vu Van, K. Visscher, J. Diaz, V. Karapanos, A. Woyte, M. Albu, J. Bozelie, T. Loix, D. Federenciuc, "Virtual

Synchronous Generator: An Element of Future Grids", IEEE PES Innovative Smart Grid Technologies Conference Europe (ISGT Europe), PP 1-7, 2010.

[4] Yong Chen, Ralf Hesse, Dirk Turschner and Hans-Peter Beck, "Comparison of methods for implementing virtual synchronous machine on inverters", International Conference on Renewable Energies and Power Quality (ICREPQ'12), Vol.1, No.10, PP 453- 455, 2012.

[5] Vu Van Thong, AchimWoyte, MihaelaAlbu, Marcel Van Hest, Jan Bozelie, Javier Diaz, Tom Loix, Dan Stanculescu, KlaasVisscher, "Virtual Synchronous Generator: Laboratory Scale Results and Field Demonstration", IEEE Bucharest Power Tech Conference, PP 1- 6,2009.

[6] Miguel Torres, Luiz A. C. Lopes, "Virtual Synchronous Generator: A Control Strategy to Improve Dynamic Frequency Control in Autonomous Power Systems", Energy and Power Engineering, 5, PP 32-38, 2013.

[7] Mahmoud EI-Dabah, Mohamed Ibrahim, Mohamed EI-Gazzar, "Stability Mitigation of DG Based Electric Power Grids Using An Extrinsic Inertia", Journal of Multidisciplinary Engineering Science and Technology (JMEST), Vol-2, PP 2855-2859, 2015.

[8] M.A.El-dabah, M.I. Akar, M.M.El-gazzar, S.othman, "Frequency Stability Enhancement of DG Based Power Systems using a novel Controller", International Journal of Engineering and Innovative Technology (IJEIT) Volume 4, PP 213-217, 2015.

[9] Ralf Hesse, Dirk Turschner and Hans-Peter Beck, "Micro grid stabilization using the Virtual Synchronous Machine (VISMA)", International Conference on Renewable Energies and PowerQuality (ICREPQ'09), PP472-473, 2009.

[10] Miguel Torres, Luiz A. C. Lopes, "A Virtual Synchronous Machine to Support Dynamic Frequency Control in a Mini-Grid That Operates in Frequency Droop Mode", Energy and Power Engineering, 5, PP 259-265, 2013.