Fault Detection and Power Quality Compensation Using Fuzzy Logic Based Dynamic Voltage Restorer

Kumari Santosh[1], Seema Agrawal[1] and Tapesh Yogi[2]
[1]*Department of Electrical Engineering, Rajasthan Technical University Kota, Kota, India*

Keywords: Power Quality, Dynamics Voltage Restorer, Fuzzy Logic, Voltage Sag, PI, PID, Voltage Swell.

Abstract: The current vitality situation faces a significant challenge in power quality. With the increasing use of sensitive hardware, power quality has become a crucial aspect, particularly in terms of input power supply. Power quality issues can lead to the failure of advanced devices due to unusual current and voltage frequencies. The primary concern lies in voltage enlargement and dips. A specific system is proposed to address this issue to prevent voltage enlargement and dips. Modified power equipment, such as Dynamic Voltage Restorers (DVRs), are employed to resolve this issue. DVRs are advanced, customized control devices used in power distribution systems, offering advantages like compact size, low cost, and excellent dynamic response to disturbances. This study presents MATLAB 2021 results for a model based on Fuzzy Logic (FL) and DVR controllers. FL-based DVR controllers are used in the suggested method to improve the composite microgrid system's performance. The goal is to develop a faster and more efficient controller than traditional procedures. The performance will be evaluated using MATLAB simulation tools.

1 INTRODUCTION

Now a days Power distribution lines are crucial for transmitting electricity over long distances to consumers. However, these lines are vulnerable to various hazards, including harsh weather, mechanical damage, and insulation failure.

Faults in a power system refer to any abnormal condition that disrupts the normal flow of electrical current. These faults can occur due to various reasons such as equipment failure, human error, natural disasters, or aging infrastructure. Faults can be classified into several types, including symmetrical faults, such as three-phase faults, and unsymmetrical faults, such as phase-to-phase faults, phase-to-ground faults, and open circuit faults. When a fault occurs, it can cause a short circuit, leading to an increase in current flow, which can damage equipment and pose a risk to human safety. Therefore, it is essential to detect and clear faults quickly to prevent damage and ensure the reliable operation of the power system. This is typically achieved through the use of protective devices, such as circuit breakers and fuses, which can detect abnormal conditions and interrupt the flow of current to prevent further damage. (Khandakar, Rabbi, et al. , 2024). Fault detection in power systems is a critical concern for maintaining system reliability. Consequently, numerous techniques have been proposed to address this challenge(Manglik, Li, et al. , 2016).

Increasing power quality by addressing voltage sags, a prevalent issue within power systems. To mitigate sags arising from diverse fault scenarios, the use of a Dynamic Voltage Restorer (DVR) with a Proportional-Integral (PI) controller is suggested in the study (Srinivas., Amarendar, et al. , 2024). Power quality indicators and employs a detection system to pinpoint faults within distribution networks. The study emphasizes the system's efficacy in improving power quality, enhancing fault identification accuracy, and ultimately bolstering the overall reliability of power supply (Wanru, He., et al. , 2023).

Dynamic Voltage Restorers (DVRs) are versatile power devices that can effectively address various voltage quality issues. By being connected in series with the power system, DVRs can inject or absorb reactive power to regulate voltage levels. This paper provides a comprehensive exploration of DVR implementation and simulation, with a particular emphasis on the crucial aspect of switching control strategy. A pulse width modulation (PWM) scheme is employed to regulate the output voltage of the DVR, and detailed results demonstrating its effectiveness are presented (Rajesh, Mishra, et al. , 2023).

Santosh, K., Agrawal, S. A. and Yogi, T.
Fault Detection and Power Quality Compensation Using Fuzzy Logic Based Dynamic Voltage Restorer.
DOI: 10.5220/0013609500004664

In *Proceedings of the 3rd International Conference on Futuristic Technology (INCOFT 2025) - Volume 3*, pages 106-113
ISBN: 978-989-758-763-4

DVRs are specialized power devices designed to counteract voltage sags, swells, and harmonics within distribution networks. Their construction involves a combination of power electronic components, control systems, and energy storage elements. By strategically injecting or absorbing reactive power, DVRs effectively mitigate voltage quality issues, ensuring reliable and efficient power delivery. **Dynamic Voltage Restorers (DVRs) are versatile power electronic devices used to improve voltage quality in power systems** (Abas, Dilshad, et al. , 2020). They are particularly effective in addressing voltage sags, swells, and harmonics, which can negatively impact the performance of sensitive equipment. By injecting or absorbing reactive power, DVRs can maintain voltage levels within acceptable limits, ensuring reliable and efficient power delivery. This is especially important in modern power grids with increasing penetration of renewable energy sources and sensitive electronic loads (AppalaNaidu, 2016).Fuzzy logic controllers (FLCs) have gained significant attention from researchers due to their simplicity and effectiveness in various control applications, including power converters, motor drives, and process control. Compared to other intelligent control techniques(Thaha and Prakash, 2020). FLCs are relatively straightforward to integrate into systems. This simplicity, coupled with their ability to provide superior performance compared to conventional controllers, has made FLCs a popular choice for a wide range of control tasks (Elkhateb, Rahim, et al. , 2014).Dynamic Voltage Restorers (DVRs) often employ Proportional Integral (PI) controllers to regulate their output. While effective, PI controllers can be further optimized by integrating fuzzy logic. Fuzzy logic enhances the PI controller's adaptability by adjusting its error and rate of error parameters. This intelligent approach enables the DVR to perform more effectively under diverse operating conditions, surpassing the capabilities of traditional PI controllers (Saha and Biswas, 2021), (Bhatnagar and Yadav, 2020). A Type-2 fuzzy logic controller is developed from a Type-1 fuzzy logic controller optimized using Bee Colony Optimization for engine speed control (Gurjar, Yadav, et al. , 2020). A shunt active power filter with a self-tuned harmonic filter and fuzzy logic controller for harmonic mitigation, reactive power compensation, and power factor correction (Agrawal, Sharma, et al. , 2017).

2 PROPOSED DVR ARCHITECTURE

In a power system, faults can be broadly classified into two main categories: symmetrical faults and unsymmetrical faults. Symmetrical faults occur when all three phases are involved equally, such as a three-phase fault, which is the most common type of symmetrical fault. Unsymmetrical faults, on the other hand, occur when one or two phases are involved. These include phase-to-ground faults, which occur when one phase comes into contact with the ground, phase-to-phase faults, which occur when two phases come into contact with each other, and phase-to-phase-to-ground faults, which occur when two phases come into contact with each other and with the ground. Additionally, open circuit faults can also occur, which involve the disconnection of one or more phases. Each type of fault has distinct characteristics and effects on the power system, and understanding these differences is crucial for the design and operation of protective devices and systems to detect and clear faults quickly and efficiently.

Now a days Power distribution lines are crucial for transmitting electricity over long distances to consumers. However, these lines are vulnerable to various hazards, including harsh weather, mechanical damage, and insulation failure. These factors can lead to short circuits or shunt faults. Shunt faults can be classified as symmetrical or unsymmetrical, and further categorized into ten main types based on the phases involved (LG, L-L-L, L-L-L-G, L-L). In a typical power system, faults occur when there is an abnormal flow of current in an electrical circuit, often leading to disruptions in power supply and potential damage to equipment. Accurate and timely detection of these faults is essential to prevent power outages and protect connected equipment. Power systems employ various protection devices, such as relays, circuit breakers, and fuses to mitigate the impact of faults. These devices are designed to detect faults, isolate the affected area, and restore power to the rest of the system. (Khandakar, Rabbi, et al. , 2024).

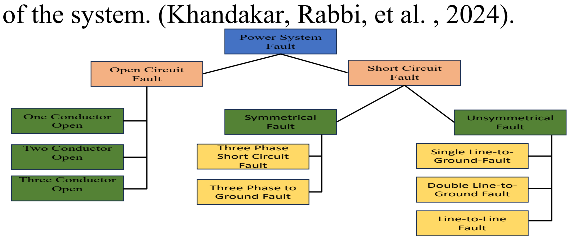


Figure 1: Classification of fault in power system

2.1 Dynamic Voltage Restorer (DVR)

A DVR typically consists of four main components: an energy storage unit, an injection transformer, a voltage source inverter, and a filtering section. The provided image illustrates the operational principle of a Dynamic Voltage Restorer (DVR), a power electronic device used to improve voltage quality in power systems. The DVR consists of several components, including a source voltage, impedance, series injection transformer, the DVR itself, a voltage source converter (VSC), a harmonic filter, and a load.

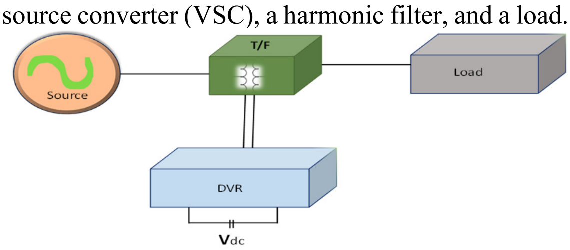


Figure 2: Schematic Layout of DVR

The DVR system comprises several key components. These include a storage device for energy, an injection transformer to interface with the power system, a voltage source inverter to control power flow, and a filter to mitigate harmonic distortion. As given in Figure 1.Power system disturbances, such as voltage sags and swells, can significantly impact the reliability and quality of power supply. Dynamic Voltage Restorers (DVRs) are a type of Flexible AC Transmission Systems (FACTS) device that are designed to mitigate these voltage fluctuations. This paper delves into the principles of operation, control strategies, and applications of DVRs in power systems. The paper also discusses the advantages and limitations of DVRs, as well as future trends and challenges in their implementation (Abas, Dilshad, et al. , 2020).

2.2 Block diagram

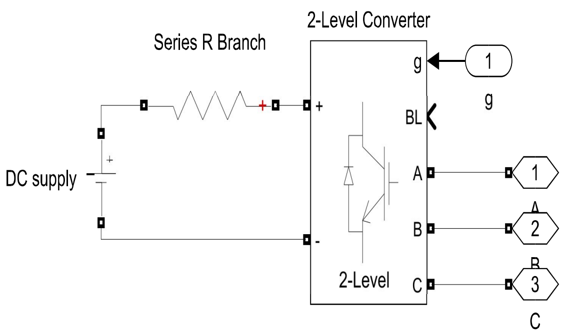


Figure 3: Circuit diagram of DVR

The given diagram illustrates a 2-level converter system, which is a key component in various power electronic applications. The system comprises a series R branch, a 2-level converter, and a DC supply. The series R branch consists of a resistor, which is crucial for controlling the current flow within the circuit. The 2-level converter is a power electronic circuit that converts DC power into AC power, enabling the efficient transfer of energy.

The DC supply provides the necessary input voltage for the converter. The diagram also includes a block labelled "g," which likely represents a control signal that regulates the operation of the 2-level converter. The numbered blocks (1, 2, 3) might indicate different switching states of the 2-level converter, influencing the output waveform.

Overall, this diagram provides a simplified representation of a 2-level converter system, highlighting its key components and their interactions.

2.3 Operation of DVR

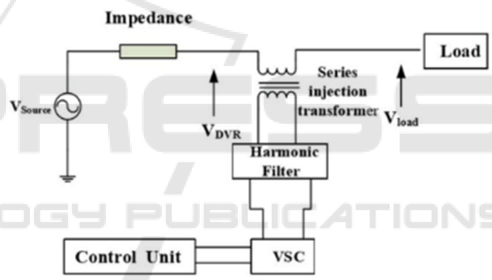


Figure 4: Operation of DVR

The Dynamic Voltage Restorer (DVR) operates on a fundamental principle: it compensates for voltage disturbances by injecting a compensating voltage to maintain the desired load voltage. Specifically, whenever the source voltage experiences unbalance or distortion, the DVR injects a voltage of appropriate magnitude to restore the load-side voltage to its desired amplitude. In essence, the primary function of the DVR is to continuously regulate the load voltage waveform. In the event of a voltage sag or swell, the DVR injects the necessary voltage to maintain the desired load voltage at the point of common coupling. Mathematically, the principle of DVR operation can be represented by the following equation, which must always be satisfied.

$$V_{Source} + V_{DVR} = V_{Load} \quad (1)$$

A DVR consists of a voltage source inverter (VSI), a coupling transformer, and a control system. The VSI generates a voltage waveform that is injected into the power system through the coupling transformer to compensate for voltage fluctuations. The control system monitors the system voltage and generates the necessary control signals to regulate the output voltage of the VSI (Rajesh, Mishra, et al. , 2023). DVR control strategies involve detecting voltage sags/swells and injecting compensating voltages. Common techniques include proportional-integral (PI) control for its simplicity, and synchronous PI decoupling for improved linearity. The control circuit determines the magnitude, frequency, and phase shift of the injected voltage, generated by the power circuit. DVRs can compensate for both balanced and unbalanced voltage disturbances, ensuring load voltage remains within acceptable tolerances. Various control schemes exist, including energy-optimal, in-phase, and pre-sag compensation, depending on the specific requirements and load characteristics.

2.4 Control strategies of DVR

DVR control strategies involve detecting voltage sags/swells and injecting compensating voltages. Common techniques include proportional-integral (PI) control for its simplicity, and synchronous PI decoupling for improved linearity. The control circuit determines the magnitude, frequency, and phase shift of the injected voltage, generated by the power circuit. DVRs can compensate for both balanced and unbalanced voltage disturbances, ensuring load voltage remains within acceptable tolerances. Various control schemes exist, including energy-optimal, in-phase, and pre-sag compensation, depending on the specific requirements and load characteristics (Bhatnagar and Yadav, 2020). DVRs combined with fuzzy logic offer a robust and adaptable solution for power quality improvement. Fuzzy logic controllers excel at handling uncertainties and non-linearity inherent in power systems, making them ideal for DVR control. By employing fuzzy logic, DVRs can effectively mitigate voltage sags and swells, dynamically adjust compensation levels based on real-time system conditions, and improve overall system stability. This integration enhances the reliability and efficiency of power distribution networks, safeguarding sensitive loads and ensuring uninterrupted power supply(Thaha and Prakash, 2020).

3 PROPOSED METHODOLOGY

3.1 Fuzzy logic internal circuit

Fuzzy logic controllers (FLCs) have gained significant attention among researchers due to their ease of integration with various systems and their ability to deliver superior performance compared to conventional controllers. FLCs are particularly well-suited for applications such as converter control, motor drives, and process control, where their ability to handle uncertainty and provide flexible control strategies is advantageous.

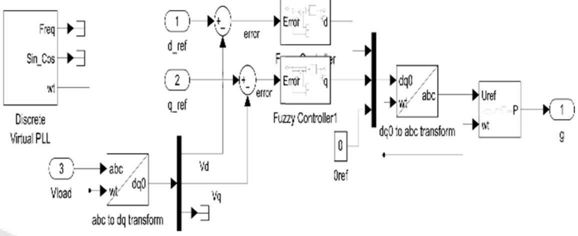


Figure 5: Circuit diagram of fuzzy logic

The test framework suggested in this paper is to simulate the model for the FL Controller as shown in Fig.4. The figure illustrates a control system for a power converter, likely a three-phase inverter.

The system appears to employ a fuzzy logic controller to regulate the output voltage. The control system includes a reference generation block, a Discrete Virtual PLL, a fuzzy controller, and a transformation block to convert between the abc and dq reference frames.

The Fuzzy Logic Controller (FLC) operates by evaluating two inputs at every sampling interval: error and error derivative. These inputs are then fuzzified using fuzzy set membership functions and processed through a set of 'if/then' rules to generate linguistic or verbal variables. The output of the FLC is a control signal for each phase, which is defuzzied and used to regulate the signals. These regulated signals are then compared with a generated carrier signal to produce gating pulses for the VSI inverter (Thaha and Prakash, 2020).

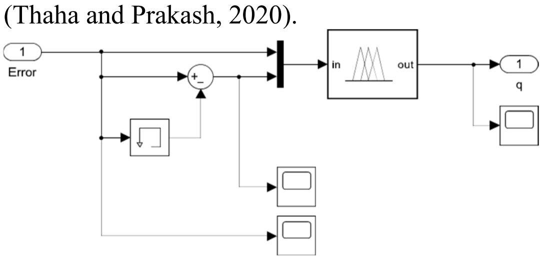


Figure 6: Circuit diagram inside fuzzy logic controller 1

The diagram illustrates a basic feedback control system. The system starts with an "Error" signal, which is the difference between the desired output and the actual output. This error signal is then fed into a summing junction, where it's combined with another input signal (not explicitly shown). The resulting combined signal is then processed by a Fuzzy Inference System (FIS).

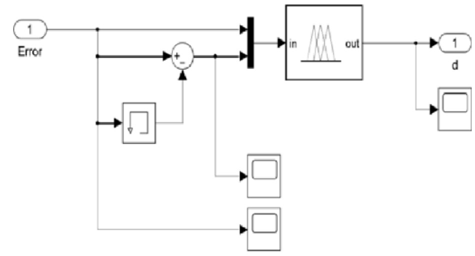


Figure 7: Circuit diagram inside fuzzy logic controller 2

Fuzzy logic controllers (FLCs) have gained significant attention among researchers due to their ease of integration with various systems and their ability to deliver superior performance compared to conventional controllers. FLCs are particularly well-suited for applications such as converter control, motor drives, and process control, where their ability to handle uncertainty and provide flexible control strategies is advantageous (Elkhateb, Rahim, et al. , 2014).

3.2 Fuzzy Logic Control

Fuzzy logic provides a robust and flexible approach to fault detection in power systems.

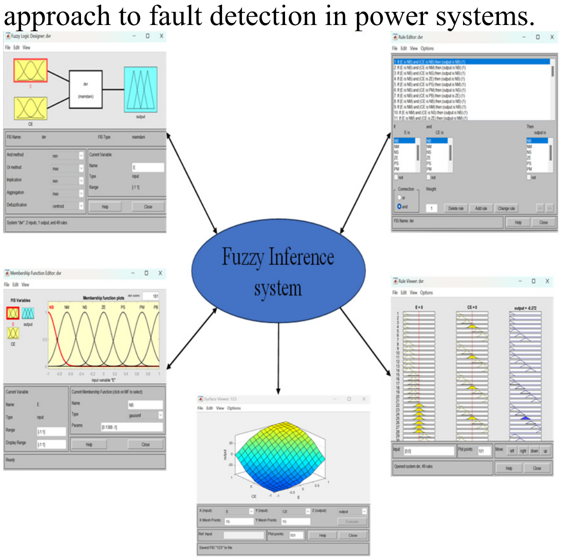


Figure 8: MATLAB/SIMULINK fuzzy logic base editor

By employing linguistic terms and fuzzy rules, it can effectively identify fault conditions, such as short circuits, open circuits, and unbalanced loads, even in noise and uncertainties. Fuzzy logic-based systems can analyse parameters like voltage, current, and power flow to detect anomalies and trigger appropriate protective actions. Additionally, it can handle complex fault scenarios and adapt to changing system conditions, making it a valuable tool for ensuring the reliability and safety of power systems (Gurjar, Yadav, et al. , 2020).

Table 1: Rule matrix

E/EC	NB	NM	NS	ZE	PS	PM	PB
NB	NB	NB	NB	NB	NM	NS	ZE
NM	NB	NB	NB	NM	NS	ZE	PS
NS	NB	NB	NM	NS	ZE	PS	PM
ZE	NB	NM	NS	ZE	PS	PM	PB
PS	NM	NS	ZE	PS	PM	PB	PB
PM	NS	ZE	PS	PM	PB	PB	PB

The proposed strategy utilizes linguistic variables like " negative medium (NM)," "negative small (NS)," "positive small (PS)," "positive medium (PM)," Zero (ZE)", "Big negative (BN)," and "Big positive (BP)" to define the error and its derivative. These linguistic variables are associated with membership functions, which are curves that assign a membership value between 0 and 1 to each point in the input space (Elkhateb, Rahim, et al. , 2014).

3.3 Power Quality

Dynamic Voltage Restorers (DVRs) are a powerful tool for improving power quality in distribution systems. They rapidly inject voltage waveforms to compensate for voltage sags, swells, and interruptions, ensuring a stable and reliable power supply to sensitive loads. DVRs are particularly effective in mitigating voltage fluctuations caused by faults, load switching, and system disturbances. By rapidly responding to voltage deviations, DVRs significantly improve the system's overall power quality, protecting sensitive equipment and improving the reliability of power supply (Rajesh, Mishra, et al. , 2023).

4 SIMULATION

To simulate the system, a step load disturbance was introduced at time 0 to 0.5 second. The simulation was conducted using MATLAB 2021b-Simulink software on a computer equipped with an Intel i3 11th generation processor clocked at 3.00 GHz and 8 GB of RAM, running Windows 11.

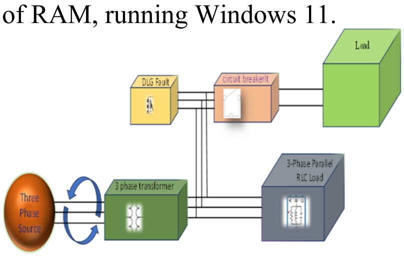


Figure 9: Block diagram of model without DVR

The image depicts a power system with a 3-phase supply connected to a 3-phase transformer. An LLG (Line-Line-Ground) fault has occurred somewhere in the system, represented by the "Fault" block. This fault creates a direct connection between two phase conductors and the ground, causing a significant increase in fault current. The fault disrupts the normal operation of the loads connected to the system, including the 3-phase series RLC load and the 3-phase parallel RLC load. LLG faults can lead to various consequences, such as damage to equipment, voltage imbalances, and potential system instability. Power systems employ various protection schemes, such as distance protection, differential protection, overcurrent protection, and ground fault protection, to detect and isolate LLG faults quickly, minimizing their impact on the system and ensuring the continuity of power supply.

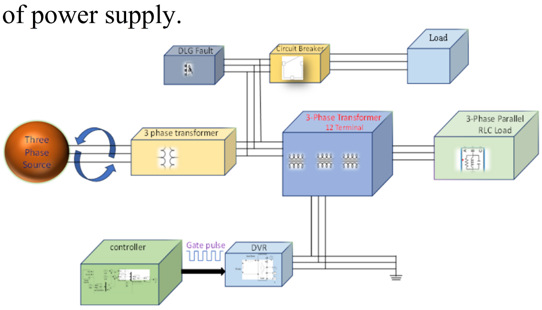


Figure 10: Block diagram of model with DVR and fuzzy logic

The image depicts a power system with a 3-phase supply connected to a 3-phase transformer. An LLG (Line-Line-Ground) fault has occurred somewhere in the system, represented by the "Fault" block. This fault creates a direct connection between two phase conductors and the ground, causing a significant increase in fault current. The fault disrupts the normal operation of the loads connected to the system, including the 3-phase series RLC load and the 3-phase parallel RLC load.

Additionally, the system includes a 12-terminal 3-phase transformer and a DVR (Dynamic Voltage Restorer). The DVR is a device used to mitigate the impact of voltage sags and swells on the system. In the event of an LLG fault, the DVR can be used to inject voltage into the system to compensate for the voltage drop caused by the fault. This can help to maintain the voltage level at the load and prevent system instability.

Power systems employ various protection schemes, such as distance protection, differential protection, overcurrent protection, and ground fault protection, to detect and isolate LLG faults quickly, minimizing their impact on the system and ensuring the continuity of power supply.

Table 2: Simulink Modelling Parameters

AC Source	f_s = 50 Hz, R_s = 0.2 ohm, L_s= .5mH
X-mer	50Hz 11000/400V
Simulation time	0 to 0.5sec.
RLC Load	P= 4.42000 W Q_L= (positive var): 100 Q_C = (negative var): 0
Three-Phase Breaker (link)	Switching times : [0.12 0.14]Sec R_{on} : 0.01 Ohm, R_s : 1e6 Ohm, C_s: inf(f)
Block Parameters: 3-ph Transformer 12 Terminals	[Three-phase rated power(VA) Frequency (Hz) = [1.5e3 50] Winding 1: [V_{ph}(Vrms) R(pu) X(pu)]: [10 0.00001 0.0003] Winding 2: [V_{ph}(Vrms) R(pu) X(pu)]: [100 0.00001 0.0003] Magnetizing branch: [Rm(pu) Xm(pu)]: [200 200]
Three-ph Source (mask) (link)	Specify internal voltages for each phase V_{ph}: 11000 V_{rms} Phase angle of phase A : 0 degrees Frequency (Hz): 50

5 GRAPHICAL RESULTS AND DISCUSSION

Experimental and simulation results validate the effectiveness of the proposed system in mitigating voltage sags within power systems. Under LG, LLG, and LLLG fault conditions, the integrated DVR and PI controller consistently demonstrate rapid and accurate voltage compensation. Voltage profiles are swiftly restored to acceptable levels, ensuring the protection of sensitive loads from disruptions. The PI controller plays a critical role in optimizing the DVR's response, dynamically adapting to diverse fault scenarios through a finely tuned compensation strategy. The system's ability to maintain stability during fault occurrences is a significant achievement, highlighting its reliability for practical applications.

The results section will present the outputs generated by the simulation under various fault conditions. These outputs have been integrated into a single body of work to address the simulation's scope comprehensively.

5.1 With LLG fault

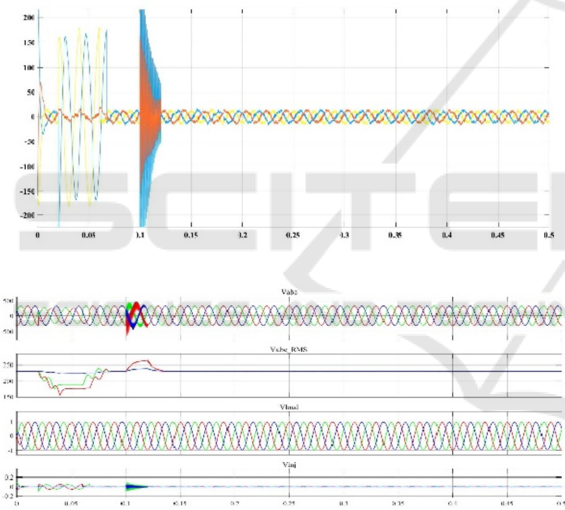
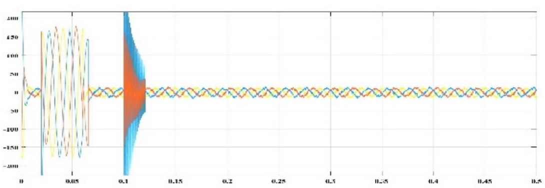


Figure 11: L-L-G Fault Current & Voltage Waveform

5.2 With LLL fault



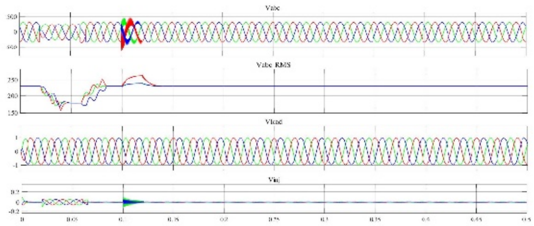


Figure 12: L- L-L Fault Current & Voltage Waveform

5.3 With LG fault

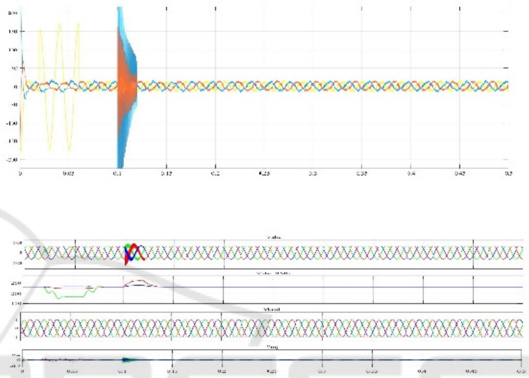


Figure 13: L-G Fault Current & Voltage Waveform

This power system model focuses on an L-G fault, representing a single-line-to-ground fault. To enhance waveform readability, the simulation duration is set. Assuming a 50 Hz sampling frequency, the system base voltage for the three-phase source. Three 3-phase VI measurement blocks are incorporated within the system. Upon fault occurrence, the differential relay, with both inputs connected to the current parameter, detects the abrupt current surge. This triggers the circuit breaker to open, isolating the fault i.e., a transient condition. The waveforms in both figures exhibit a characteristic spike during the fault. As is well-known, generators operate asynchronously. However, a rapid fault leads to an increase in speed and a corresponding current rise. Concurrently, a significant voltage drop, approaching zero, and waveform interruptions are observed during the fault. Similar behaviour is expected for other fault types.

6 CONCLUSION

This presented work focuses on fault identification and detection using MATLAB Simulink for a 3-bus power system employing a fuzzy logic controller and dynamic voltage regulator (DVR). Considering LG, LLG and LLL faults, a Simulink model is made and waveforms are obtained.The major problem of power quality disruptions in modern power networks, namely voltage swells and sags. Strong solutions must be used to ensure a consistent and dependable power supply due to the growing dependence on delicate electronic devices. In order to do this, this study suggested a novel method that makes use of Dynamic Voltage Restorers (DVRs) controlled by Fuzzy Logic (FL) in a composite microgrid system. The efficiency of the suggested FL-based DVR controller in reducing voltage disturbances was shown by the simulation results produced with MATLAB 2021. The FL controller performed better in terms of speed and efficiency than conventional control techniques. The intrinsic capacity of FL to manage the uncertainties and nonlinearities present in actual power systems is responsible for this improved performance.

REFERENCES

Khandakar, Rabbi, Ahmed., Khandokar, Shadman, Shayer., Jahidul, Islam, Shuvo., Fatin, Farhan, Haque., Towfika, Salam., Shafiun, Miraz., Abdullah, Al, Noman., Md., Shohanur, Islam, Sobuj., Muhammad, Yasser, Arafat., MD, Istiak, Hasan, Rial. (2024). Enhancing Power Grid Resilience: Advanced Strategies for Detecting and Analyzing Faults in Three-Phase Transmission Lines. 1-5. doi: 10.1109/iciteics61368.2024.10625140.

Manglik, W. Li and S. U. Ahmad, "Fault detection in power system using the Hilbert-Huang Transform," *2016 IEEE Canadian Conference on Electrical and Computer Engineering (CCECE)*, Vancouver, BC, Canada, 2016, pp. 1-4, doi: 10.1109/CCECE.2016.7726627.

N., Srinivas., M, Amarendar, Reddy., M., Shiva, Kumar., K, Sruthi. (2024). Power Quality Improvement Using Custom Power Devices. 1-4. doi: 10.1109/sefet61574.2024.10717912.

Wanru, He., Chunhong, He., Zongjie, Zhang., Bin, Ren. (2023). Design of Online Intelligent Detection System for Power Quality and Fault Identification in Distribution Networks. Applied mathematics and nonlinear sciences, doi: 10.2478/amns.2023.2.01454.

Saripalli Rajesh*, Mahesh K. Mishra"Design and Simulation of Dynamic Voltage Restorer (DVR) Using Sinusoidal Pulse Width Modulation (SPWM) "16th NATIONAL POWER SYSTEMS CONFERENCE, 15th-17th DECEMBER, 2010 ,pg-317-322.

N. Abas, S. Dilshad, A. Khalid, M. S. Saleem and N. Khan, "Power Quality Improvement Using Dynamic Voltage Restorer," in *IEEE Access*, vol. 8, pp. 164325-164339, 2020, doi: 10.1109/ACCESS.2020.3022477.

AppalaNaidu, T. (2016). *The Role Of Dynamic Voltage Restorer (DVR) in improving power quality. 2016 2nd International Conference on Advances in Electrical, Electronics, Information, Communication and Bio-Informatics (AEEICB).* doi:10.1109/aeeicb.2016.7538259.

H. S. Thaha and T. R. D. Prakash, "Use of Fuzzy Controller Based DVR for the Reduction of Power Quality Issues in Composite Micro-Grid," *2020 International Conference on Renewable Energy Integration into Smart Grids: A Multidisciplinary Approach to Technology Modelling and Simulation (ICREISG)*, Bhubaneswar, India, 2020, pp. 131-136, doi: 10.1109/ICREISG49226.2020.9174536.

Elkhateb, N. A. Rahim, J. Selvaraj and M. N. Uddin, "Fuzzy-Logic-Controller-Based SEPIC Converter for Maximum Power Point Tracking," in *IEEE Transactions on Industry Applications*, vol. 50, no. 4, pp. 2349-2358, July-Aug. 2014, doi: 10.1109/TIA.2014.2298558.

S. K. Saha and S. Biswas, "Fuzzy Logic and PI Controller Implementation on Dynamic Voltage Restorer," *2021 2nd Global Conference for Advancement in Technology (GCAT)*, Bangalore, India, 2021, pp. 1-6, doi: 10.1109/GCAT52182.2021.9587827.

Bhatnagar, M., & Yadav, A. (2020). *Fault Detection and Classification in Transmission Line Using Fuzzy Inference System. 2020 5th IEEE International Conference on Recent Advances and Innovations in Engineering (ICRAIE).* doi:10.1109/icraie51050.2020.9358386.

G. Gurjar, D. K. Yadav and S. Agrawal, "Illustration and Control of Non-Isolated Multi-Input DC - DC Bidirectional Converter for Electric Vehicles Using Fuzzy Logic controller," *2020 IEEE International Conference for Innovationin Technology (INOCON)*, Bangluru, India, 2020, pp. 1-5, doi: 10.1109/INOCON50539.2020.9298307.

S. Agrawal, D. Sharma and D. K. Palwalia, "Performance analysis of SAPF based on self tuned harmonic filter with fuzzy logic controller," *2017 Recent Developments in Control, Automation & Power Engineering (RDCAPE)*, Noida, India, 2017, pp. 487-492, doi: 10.1109/RDCAPE.2017.83583