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Original Article

Active Voltage Restoration Technique for Elevating Power Quality

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Abstract: *This paper illustrates the design of a device to mitigate voltage sag for the improvement of power quality. The significant need for reliable and high-quality electrical power involves the development of advanced technologies to mitigate various power quality issues. This research focuses on addressing voltage sag which is prevalent disturbances in power systems. To enhance power quality, a custom power device is proposed as a solution by providing effective mitigation of this disturbance. An advanced control algorithms and innovative circuitry are employed by the custom power device to detect and respond to voltage variations in real time. For voltage sag mitigation, the device employs Voltage compensating technology to inject compensating voltages and the voltage waveform is restored to its nominal value. Furthermore, active filters are incorporated with the custom power device to maintain a sinusoidal voltage waveform. Adaptively, to adjust the compensation parameters advanced control strategies are employed based on the specific characteristics of the disturbance encountered, ensuring efficient and timely mitigation. Simulation studies are done using matlab and experimental validations are done to evaluate the effectiveness of the custom power device under various power quality scenarios. Results demonstrate significant improvements in voltage stability, waveform quality, and system reliability. To mitigate various power quality issues, the proposed solution provides a versatile and comprehensive approach, contributing to the overall enhancement of the electrical power infrastructure.*

Keywords: *Voltage Compensation, Voltage Sag, Power Quality, Reliability.*

I. INTRODUCTION

Power quality defines that how well the electricity is delivered to the electrical equipment which meets the desired characteristics. It is an important aspect of electrical power consumption and distribution, and a wide range of parameters are encompassed that impact the performance, safety and reliability of the electrical equipment. In today's digital world, power quality is more important than ever before. Most electrical and electronic equipment used in industries, companies and homes require good quality power to function correctly without causing any failures. The efficiency of the equipment depends highly on power quality. The measure of electrical power capacity is influenced by many factors such as voltage level, unbalanced voltage, voltage sag, voltage swell, voltage interruption, etc. The proposed device detects and compensates voltage sag of the AC power source. The device works by adding the 'missing' voltage during the voltage sag. The device injects a voltage of required magnitude and frequency into the system in-order to restore the voltage back up to the level required by the load. Injection of voltage is achieved by a switching system coupled with a transformer connected in series with the load.The proposed kit may provide good solutions for end-users subject to unwanted power quality disturbances. However, there is a caution regarding their application in systems that are subject to prolonged reactive power deficiencies (resulting in low voltage conditions) and in systems that are vulnerable to voltage collapse.

II. LITERATURE REVIEW

- M. T. L. Gayatri et al. (2016): This paper focuses on the utilization of a unified power quality conditioner to mitigate voltage sag/swell in microgrids. It likely discusses the benefits and applications of this technology in enhancing power quality within microgrid systems.[1]
- S. Whaite et al. (2015): The authors explore power quality issues specific to DC power distribution systems and microgrids. This study could offer insights into challenges and solutions related to maintaining high-quality power in DC-based systems.[2]
- Ali O Al-Mathnani (2007): Al-Mathnani proposes a photovoltaic-based dynamic voltage restorer for voltage sag mitigation. The study likely delves into how photovoltaic systems can be used to enhance voltage quality.[3]

- Alexander Kusko and Marc T. Thompson (2007): This book by McGraw-Hill provides a comprehensive overview of power quality in electrical systems. It covers various aspects of power quality, possibly including causes, effects, and mitigation techniques.[4]
- C. Sankaran (2017): Sankaran's "Power Quality" book from CRC Press likely offers an in-depth exploration of power quality concepts, issues, and solutions, providing a broad understanding of the field.[5]
- Angelo Baggini (2008): Baggini's "Handbook of Power Quality" is likely a detailed reference guide covering various aspects of power quality, from fundamentals to advanced topics.[6]
- Arindam Ghosh and Gerard Ledwich (2002): This paper discusses power quality enhancement using custom power devices. It might focus on the design, implementation, and benefits of custom devices in improving power quality.[7]
- Brice J. Quirl et al. (2006): The authors propose a method for mitigating voltage sags using a dynamic voltage restorer with phase jump. The study likely investigates the effectiveness of this approach in addressing voltage sags.[8]
- D. Rajasekaran et al. (2011): This paper discusses the mitigation of voltage sags and swells using a dynamic voltage restorer. It could provide insights into the operational aspects and performance of dynamic voltage restorers.[9]
- Ghosh and G. Ledwich (2002): Similar to reference 7, this paper by Ghosh and Ledwich focuses on power quality enhancement using custom power devices, possibly providing additional perspectives or case studies.[10]
- H. Hingorani (1995): Hingorani's paper "Introducing Custom Power" likely introduces the concept of custom power and its potential in enhancing power quality. It could cover the principles, benefits, and applications of custom power technologies.[11]
- This literature review gives an overview of the topics covered by each reference, but for a more detailed understanding, one would need to delve deeper into each source individually.

III. PROPOSED METHOD

This proposed work implements a device to address voltagesag. The device will detect deviations from the nominal voltage, inject compensating voltages, and restore the voltage waveform to its desired level. Integrate an energy storage system comprising batteries or supercapacitors to provide short-term power during interruptions. This ensures continuous power supply and prevents downtime in critical applications. Incorporate rapid-switching devices, such as solid-state switches or fast-acting relays, to facilitate quick and seamless switching between power sources during interruptions. This minimizes disruption to connected loads. Implement active filters using power electronics components, such as insulated gate bipolar transistors (IGBTs) and filter capacitors, to suppress harmonics in the power system.

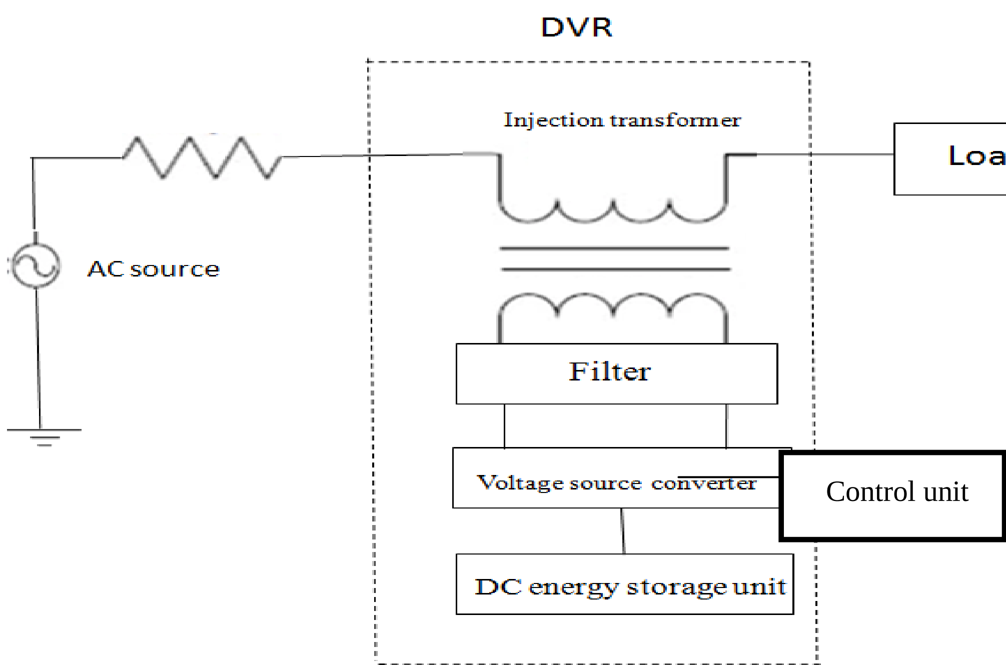


Figure 1: Block Diagram of Proposed System

A. Proposed Topology

A Dynamic Voltage Restorer (DVR) is a device used to mitigate voltage sags and other disturbances in electrical distribution systems. It operates by injecting voltage into the system to compensate for the sag.The DVR requires an energy storage system to supply the compensating voltage during a sag. This energy storage can be provided by capacitors or batteries. Capacitors are commonly used due to their fast response time. The inverter is a key component of the DVR. It converts the DC voltage from the energy storage into AC voltage that is injected into the distribution system. The inverter must be capable of delivering the required voltage magnitude and frequency.The output of the inverter may contain harmonics or other unwanted components. Filtering components such as inductors and capacitors are used to remove these unwanted elements and ensure that the injected voltage is clean and sinusoidal. In some cases, an injection transformer may be used to interface the DVR with the distribution system. This transformer steps up or steps down the voltage as required to match the system voltage.

IV. WORKING PRINCIPLE

Dynamic Voltage Restorers (DVRs) are custom power devices designed to mitigate voltage sag, interruption, and harmonics in electrical distribution systems. The working principle of DVRs involves sensing the voltage disturbances in the system and injecting appropriate voltage to compensate for these disturbances.

A. Here's a breakdown of how DVRs work:

Voltage Injection: Upon detecting a voltage disturbance, DVRs inject a compensating voltage of appropriate magnitude and phase angle to restore the voltage to its nominal value. This injection is achieved using power electronics devices such as insulated gate bipolar transistors (IGBTs) or gate turn-off thyristors (GTOs).

Energy Storage: DVRs typically incorporate energy storage devices, such as capacitors or batteries, to provide the necessary energy for voltage injection during transient events. This ensures rapid response times and sufficient compensation for voltage disturbances.

Control System: DVRs employ sophisticated control algorithms to determine the magnitude and phase of the compensating voltage based on the detected disturbances and system requirements. These control algorithms ensure accurate and timely voltage restoration while minimizing the impact on the rest of the electrical system.

Filtering: DVRs may also incorporate filters to mitigate harmonics and other undesirable effects introduced by the voltage injection process. These filters help ensure that the injected voltage is clean and do not introduce additional disturbances into the system.

By dynamically injecting compensating voltage, DVRs can effectively mitigate voltage sags, interruptions, and harmonics, thereby improving the quality and reliability of electrical power delivery to sensitive loads. They are particularly valuable in industrial and commercial settings where even brief disturbances in voltage can lead to significant downtime or damage to equipment.

V.SIMULATION

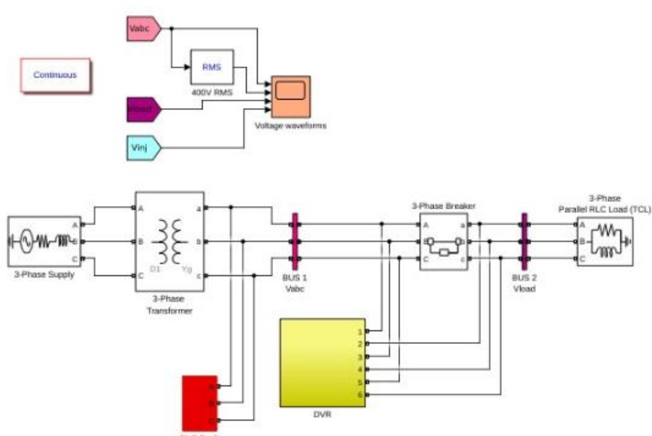


Figure 2: Matlab Simulation Diagram of Mitigating Voltage Sag using DVR with PI Controller

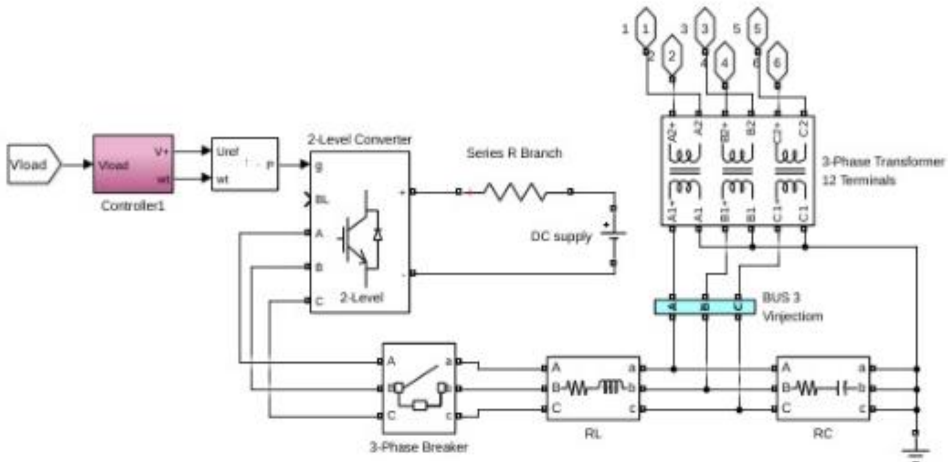
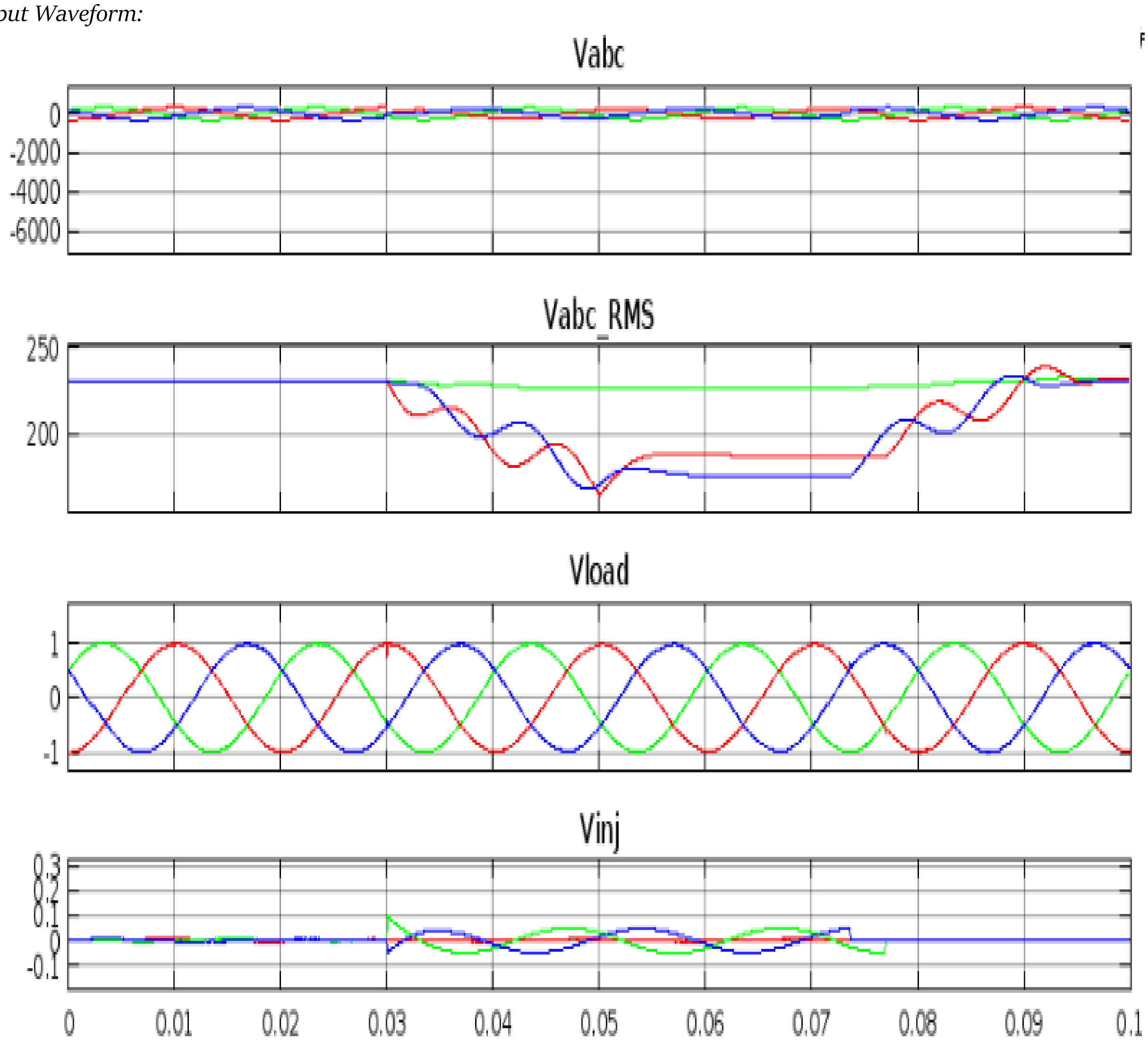


Figure 3: Matlab Simulation Diagram of DVR Design

a) Output Waveform:



B. Explanation for the Simulation Diagram Fig 2:

The Matlab simulation diagram (Fig 2) shows the circuit using a DLG fault (at phase B, C and Gnd) for the cause of volt sag. There are 4 waveform for the simulated circuit which are the supply (Vabc), rms waveform for a better voltage sag analysis (Vabc_RMS), load voltage (V_load) and the injected voltage (V-inj) which is the DC supply used to mitigate the volt sag. The shown simulation diagram havepq problem of volt sag. This PQ problem(voltage sag) was mitigated by using dynamic voltage restorer (DVR).The Matlab simulation diagram (Fig 3) shows the design of a DVR(Dynamic Voltage Restorer).The simulation diagram output denotes time in x-axis and voltage in y-axis.

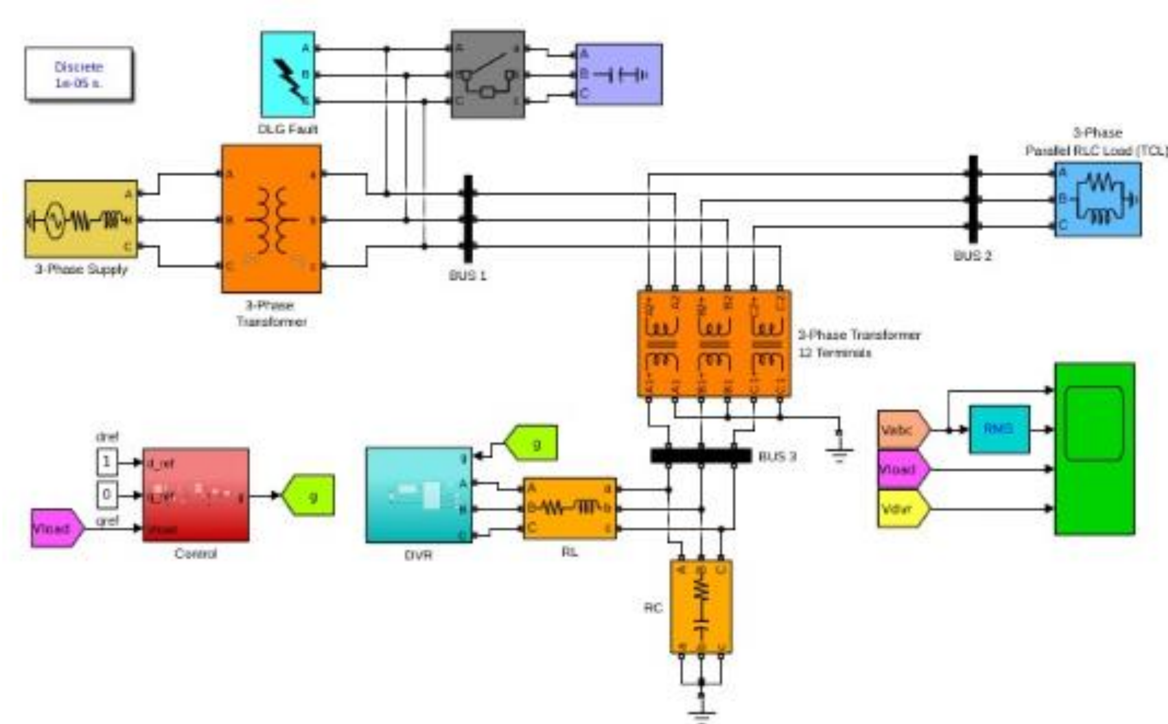


Figure 4: Matlab Simulation Diagram of Mitigating voltage sag by Fuzzy Logic Controller with DVR (Dynamic Voltage Restorer)

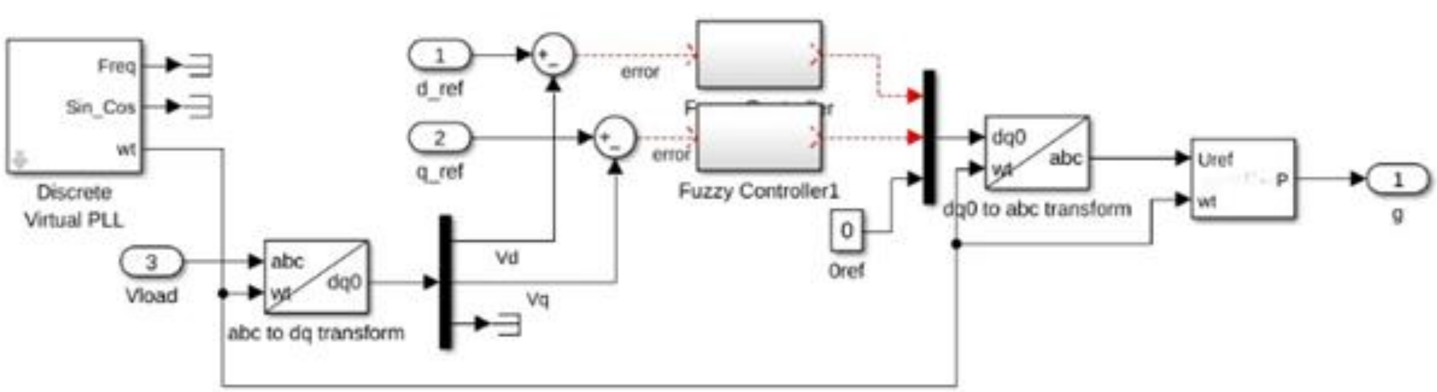
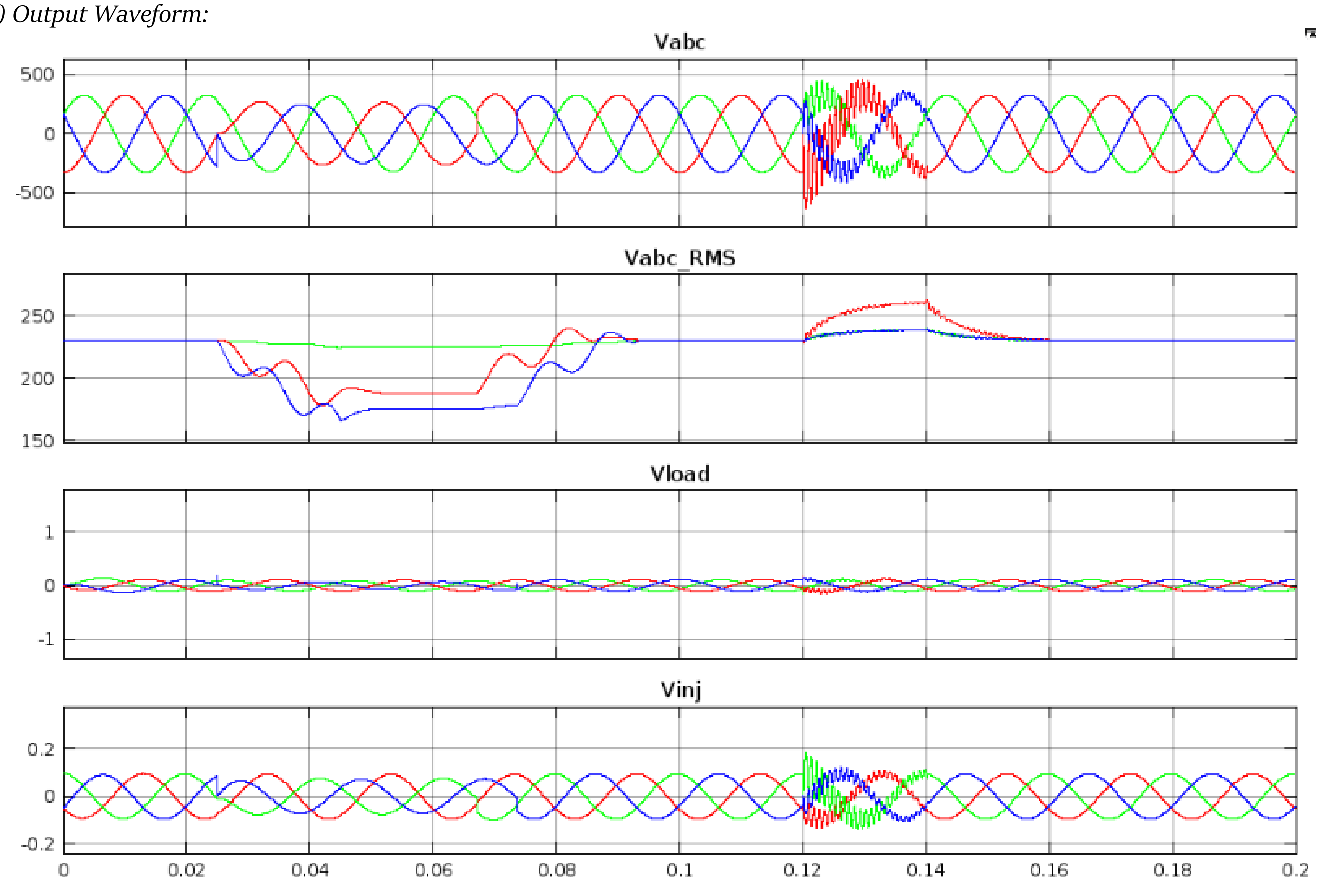


Figure 5: Matlab Diagram of Fuzzy Logic Controller

a) Output Waveform:



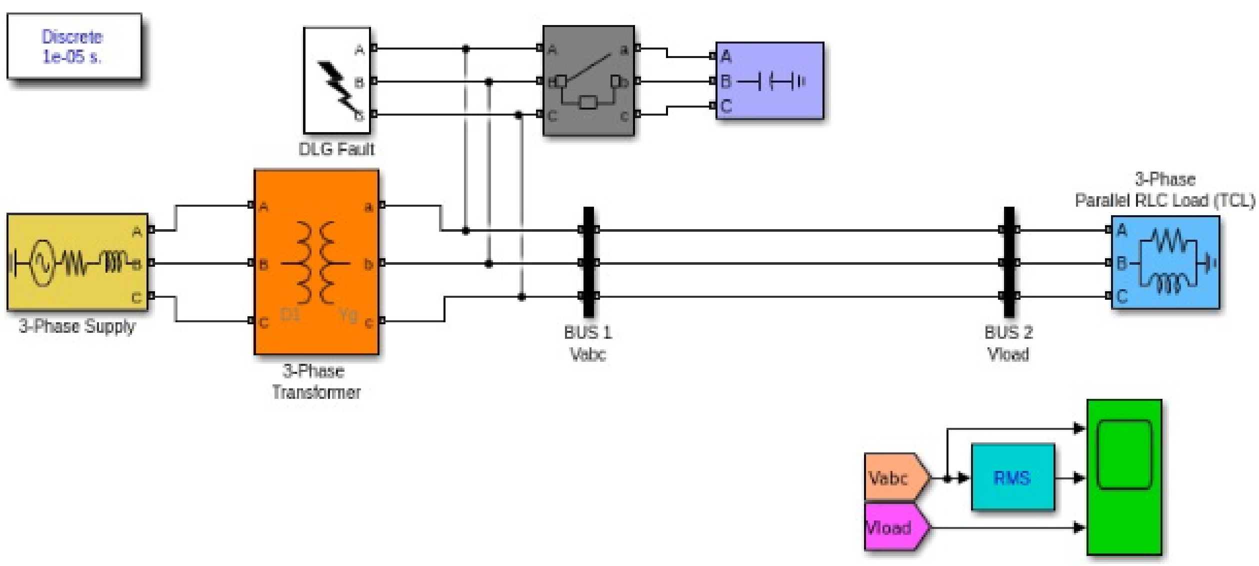
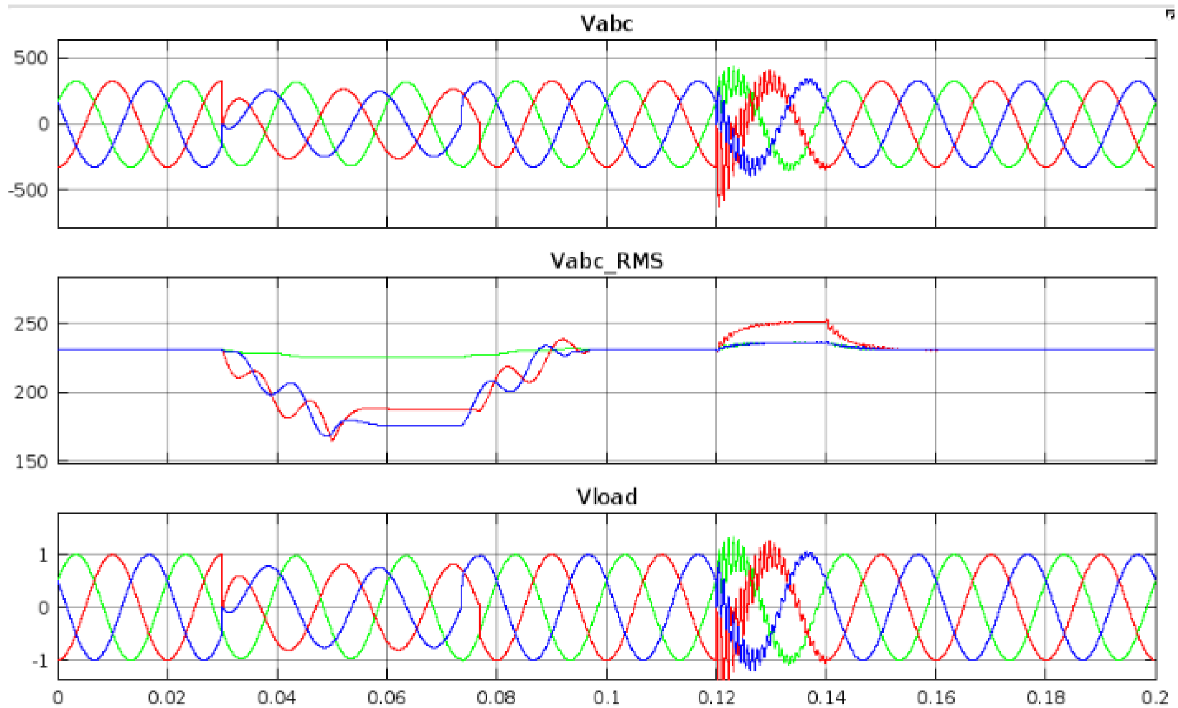


Figure 6: Matlab Simulation Diagram of Mitigating Voltage Sag by Fuzzy Logic Controller without DVR (Dynamic Voltage Restorer)

b) Output Waveform:



C. Explanation for the Simulation Diagram Fig 4:

The simulation package includes MATLAB/Simulink models that replicate the operation of a three-phase DVR system in the presence of voltage sag. The fuzzy logic controller is developed to analyze the severity of the disturbances and generate appropriate control signals to adjust the compensation voltages injected by the DVR. The simulation considers various scenarios of voltage disturbances, system parameters to evaluate the performance of the fuzzy logic-based DVR controller in terms of voltage restoration.

Table 1: Comparison between PI Controller and Fuzzy Logic Controller

	PI CONTROLLER	**FUZZYLOGIC CONTROLLER**
Control Strategy	Employs a fixed set of mathematical rules based on proportional and integral terms to adjust control output.	Utilizes linguistic variables and fuzzy logic rules to determine control actions based on imprecise or uncertain information.
Complexity	Generally simpler in structure and implementation compared to FLCs.	Can handle complex systems and nonlinearities but may require more computational resources and tuning effort.
Adaptability	Suitable for linear systems and well-defined control objectives.	Better suited for handling nonlinear systems and vague control objectives due to its linguistic approach.
Tuning	Parameters (proportional and integral gains) can be tuned using well-established methods such as Ziegler-Nichols or trial-and-error.	Tuning involves defining linguistic rules and membership functions, which may require expert knowledge or experimental tuning.
Robustness	Generally robust for systems with known dynamics and linear behaviour.	Offers robustness against uncertainties and variations in system dynamics due to its adaptive nature and ability to handle imprecise inputs.
Performance	Effective for systems with well-defined mathematical models and linear behavior.	Particularly useful for systems with nonlinearities, uncertainties, and complex relationships between inputs and outputs.

In summary, while both PI controllers and Fuzzy Logic Controllers serve as effective control strategies in various applications, the choice between them depends on the specific characteristics of the system, including linearity, complexity, uncertainty, and control objectives. PI controllers are favored for linear systems with well-defined dynamics, while Fuzzy Logic Controllers excel in handling nonlinearities and uncertainties.

V.RESULTS AND DISCUSSION

The mitigation of voltage sag with a PI controller using a Dynamic Voltage Restorer (DVR) involves several key aspects that are typically discussed in the results and discussion section of a study:

a) Performance Evaluation:

Discuss how well the PI controller in conjunction with the DVR mitigates voltage sag. This can be quantified through various metrics such as voltage deviation, restoration time, and system stability.

b) Comparison:

Compare the performance of the proposed method with other existing methods or control strategies for mitigating voltage sags. Highlight the advantages and disadvantages of using a PI controller with a DVR.

c) Simulation Results:

Present simulation results showing the effectiveness of the proposed method in mitigating voltage sags under different operating conditions and fault scenarios. Discuss any limitations encountered during the simulations.

d) Controller Tuning:

Discuss the process of tuning the PI controller parameters for optimal performance. Explain how the controller parameters were selected and justify the chosen values.

e) System Stability:

Evaluate the stability of the system with the implemented control strategy. Discuss any stability issues encountered and how they were addressed.

f) Practical Considerations:

Discuss practical aspects such as cost, complexity, and feasibility of implementing the proposed method in real-world power distribution systems.

VI. CONCLUSION

In conclusion, the implementation of a PI controller in conjunction with a Dynamic Voltage Restorer (DVR) presents a promising solution for mitigating voltage sag in power distribution systems. The proposed method effectively mitigates voltage sags by injecting compensating voltages into the system, thereby restoring the voltage to acceptable levels in a timely manner. The performance of the PI controller with the DVR was evaluated under various operating conditions and fault scenarios, demonstrating its robustness and reliability in mitigating voltage sags. The tuning of the PI controller parameters is critical for optimal performance. By carefully selecting and adjusting the proportional and integral gains, the controller can effectively respond to voltage sag events while maintaining system stability.Comparative analysis with other voltage sag mitigation techniques highlights the advantages of using a PI controller with a DVR, such as improved response time and reduced system complexity. While the proposed method shows promise, practical considerations such as cost, complexity, and feasibility of implementation in real-world systems need to be carefully evaluated. Future research should focus on further optimization of the control strategy, integration of advanced control techniques, and validation through experimental testing in real-world power distribution systems.

Overall, the integration of a PI controller with a DVR offers an effective and efficient solution for mitigating voltage sag, contributing to the enhancement of power quality and reliability in electrical distribution networks.

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