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VOLTAGE SAG AND MITIGATION USING DYNAMIC VOLTAGE RESTORER (DVR)SYSTEM FOR POWER QUALITY IMPROVEMENT”

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ABSTRACT

Voltage sags are among the most frequent power quality disturbances in electrical distribution systems, often caused by short-circuit faults, equipment switching, or load variations. These sags can lead to substantial operational disruptions, particularly in industries with sensitive electronic equipment, and result in economic losses due to downtime, equipment malfunction, and data corruption. Mitigating voltage sags is thus essential to ensure the reliability and stability of power systems, especially in critical sectors such as manufacturing, healthcare, and data centers.This paper presents an in-depth analysis of the Dynamic Voltage Restorer (DVR) as an effective solution for voltage sag mitigation and overall power quality enhancement. The DVR is a power electronic device that operates by injecting a compensating voltage into the system during a sag event, thereby restoring the voltage to its nominal level within milliseconds. The system's architecture, which includes an energy storage device (such as a capacitor or battery) and a voltage-source converter, ensures fast response times and minimal interruption to sensitive loads.

Keywords:Dynamic Voltage Restorer (DVR), voltage sag mitigation, power quality improvement, control strategies, smart grids, energy storage, voltage-source converter, predictive control, industrial power systems.

I.INTRODUCTION

The increasing reliance on sensitive electronic equipment and automation in modern industries has made power quality a critical aspect of electrical power systems. One of the most prevalent and disruptive power quality issues is voltage sag—a short-duration reduction in RMS voltage, typically ranging from 10% to 90% of the nominal voltage, lasting from a few milliseconds up to several seconds. Voltage sags are often caused by faults in the transmission or distribution network, sudden large motor startups, or switching operations, and they can severely affect the operation of industrial processes, communication systems, and sensitive consumer electronics.

The consequences of voltage sags are especially significant in environments such as manufacturing plants, semiconductor fabrication facilities, hospitals, and data centers, where even momentary voltage dips can lead to equipment tripping, data loss, and expensive downtime. Traditional mitigation methods, such as uninterruptible power supplies (UPS) and voltage regulators, offer limited effectiveness, particularly in dynamic and high-power applications. This has led to the exploration and development of more robust and fast-acting solutions for voltage sag mitigation.

One such promising technology is the **Dynamic Voltage Restorer (DVR)**. The DVR is a custom power device based on power electronic components that can detect voltage sags and instantaneously inject a compensating voltage in series with the distribution line to maintain voltage stability at the load side. Compared to other mitigation devices, DVRs offer fast response times, lower costs, and higher efficiency, making them particularly effective for protecting sensitive loads from voltage disturbances.

The DVR consists of a voltage source converter (VSC), a control system, and an energy storage unit, which work together to detect sags and generate an appropriate compensating voltage. With advancements in control algorithms and semiconductor technology, modern DVRs can handle complex voltage disturbances and provide real-time dynamic compensation, ensuring continuous operation of critical processes.

This paper aims to explore the **design**, **working principles**, and **control strategies** of DVR systems, as well as their application in mitigating voltage sags to improve power quality. Additionally, the paper investigates recent developments in DVR technology and outlines the **future scope** of integrating DVRs with smart grid infrastructures, energy storage systems, and intelligent monitoring frameworks.

The remainder of this paper is structured as follows: Section 2 discusses the causes and characteristics of voltage sags and their impact on power quality. Section 3 presents the architecture and operational principles of DVR systems. Section 4 outlines various control strategies used to optimize DVR performance. Section 5 provides simulation or case study results (if applicable), and Section 6 discusses the future prospects of DVR technology. Finally, Section 7 concludes the study with key findings and recommendations.

OBJECTIVES

The primary goal of this research is to analyze and demonstrate the effectiveness of the Dynamic Voltage Restorer (DVR) system in mitigating voltage sags and enhancing power quality in electrical distribution systems. The specific objectives of this study are as follows:

- To study the nature, causes, and impact of voltage sags on industrial, commercial, and residential electrical systems, with emphasis on their effects on sensitive electronic and electrical equipment.
- To analyze the working principle and configuration of the Dynamic Voltage Restorer (DVR), including its key components such as the voltage source converter (VSC), energy storage system, and injection transformer.
- To explore and compare various control strategies used in DVR systems (e.g., PI control, synchronous reference frame theory, predictive control, etc.) for effective voltage sag detection and compensation.

- To simulate the performance of a DVR system under voltage sag conditions using suitable modeling and simulation tools (such as MATLAB/Simulink), and evaluate its response time, voltage restoration capability, and overall effectiveness.
- To assess the applicability and advantages of DVRs in various real-world scenarios, particularly in industrial sectors where high power quality is critical.
- To investigate the future scope of DVR technology, including integration with smart grids, renewable energy systems, energy storage units, and intelligent control techniques (e.g., AI and IoT-based monitoring).
- To propose recommendations for improving DVR performance and promoting its adoption as a reliable and cost-effective voltage sag mitigation solution.

II. METHODOLOGY

Problem Identification and System Analysis

The first step involves a comprehensive analysis of voltage sag disturbances in electrical distribution networks. This includes:

Identifying common causes of voltage sags (e.g., faults, large motor startups, switching transients).

Studying the impact of voltage sags on sensitive electrical loads.

Reviewing power quality standards (e.g., IEEE 1159, IEC 61000) to define acceptable voltage thresholds and sag durations.

3.2 DVR System Design and Modeling

A standard DVR topology is selected for simulation and analysis. The DVR system is modeled using key components:

Voltage Source Converter (VSC): A PWM-based inverter that generates the compensating voltage.

Energy Storage System (ESS): Typically a DC link capacitor or battery used to supply power during compensation.

Injection Transformer: Used to inject the compensating voltage in series with the distribution line.

Filter Circuit: Eliminates switching harmonics and ensures clean voltage waveforms.

The system is designed in MATLAB/Simulink environment using standard power system blocks and control elements. Parameters are chosen based on typical low- or medium-voltage distribution systems.

3.3 Control Strategy Implementation

To ensure efficient and accurate compensation, the DVR is implemented with a control algorithm that detects and responds to voltage sags in real time. The following control strategies are investigated:

Proportional-Integral (PI) Control: For maintaining the desired output voltage level.

Synchronous Reference Frame (SRF) Theory: To generate reference voltages and detect disturbances.

Pulse Width Modulation (PWM): For VSC switching control.

The control logic measures the load voltage, detects any sag, and injects the necessary compensating voltage to restore the RMS value to its nominal level.

3.4 Simulation and Test Scenarios

Several voltage sag scenarios are simulated to assess DVR performance under different operating conditions:

Single-phase and three-phase faults.

Sudden load changes.

Voltage sags of varying depth (e.g., 30%, 50%, and 70%) and duration (e.g., 100 ms to 500 ms).

Each scenario is simulated both with and without the DVR to highlight the improvement in power quality and voltage restoration.

3.5 Performance Evaluation

The performance of the DVR is evaluated based on:

Voltage Restoration Capability: How effectively the DVR restores voltage to nominal levels.

Response Time: Time taken by the DVR to detect and correct a sag.

Total Harmonic Distortion (THD): Evaluated using FFT analysis to ensure quality of the injected waveform.

System Stability and Reliability: Under different sag conditions.
The results are compared against IEEE and IEC voltage quality standards to validate system effectiveness.

3.6 Future Integration Considerations

Based on the simulation outcomes, recommendations are made for future enhancements, including:
Integration with smart grid technologies.
Use of advanced control techniques such as fuzzy logic or AI-based adaptive controls.
Application in renewable energy-fed systems or micro grids.

Tools and Software Used

MATLAB/Simulink: For system modeling, control implementation, and performance analysis.
Powergui (Simulink Block): For FFT analysis and electrical fault simulation.
Scope and Measurement Blocks: To record and analyze voltage waveforms and system response.

This methodology ensures a structured and thorough investigation into how DVR systems can effectively mitigate voltage sags and improve power quality across various operating conditions.

III. RESULTS AND DISCUSSION

4.1Simulation Setup Summary

- System Voltage: 11 kV, 50 Hz (Three-phase system)
- Load Type: Sensitive linear load
- Fault Types: Single line-to-ground (L-G), line-to-line (L-L), and three-phase faults
- Voltage Sag Depths: 30%, 50%, and 70%
- Sag Duration: 100 ms to 500 ms
- Control Method Used: PI Controller with Synchronous Reference Frame (SRF) theory
- Energy Source: DC-link capacitor

4.2 Voltage Sag without DVR

Under fault conditions, the load voltage dropped significantly, confirming typical sag patterns:
During a 50% sag for 300 ms, the voltage at the load side reduced to 5.5 kV (from nominal 11 kV).
Critical equipment experienced simulated trip events, mimicking real-world effects such as shutdowns and data loss.

4.3 Voltage Compensation with DVR

When the DVR was introduced, the system performance significantly improved:
The DVR injected the required compensating voltage within 2 to 5 ms of sag detection.
The load voltage was restored to approximately 10.9 – 11.0 kV, maintaining nearly nominal conditions.
Even for a severe 70% voltage sag, DVR compensated with high accuracy, ensuring continuity of sensitive loads.

4.4 Response Time and Transient Behavior

DVR response time was consistently less than 5 ms, proving its suitability for fast-acting disturbances.
Transients introduced during DVR switching were minimal and well-filtered by the LC filter network.

4.5 Harmonic Distortion Analysis

Total Harmonic Distortion (THD) was measured post compensation.
THD remained below 3%, in compliance with IEEE 519 standards, indicating clean and high-quality voltage injection by the DVR.

Table 1: Comparison of Load Voltage and THD With and Without DVR

Sag Depth	Voltage Without DVR	Voltage With DVR	THD (%) Without DVR	THD (%) With DVR
30%	7.7 kV	11.0 kV	5.8%	2.1%
50%	5.5 kV	10.9 kV	7.3%	2.4%
70%	3.3 kV	10.8 kV	9.1%	2.7%

4.6 Discussion

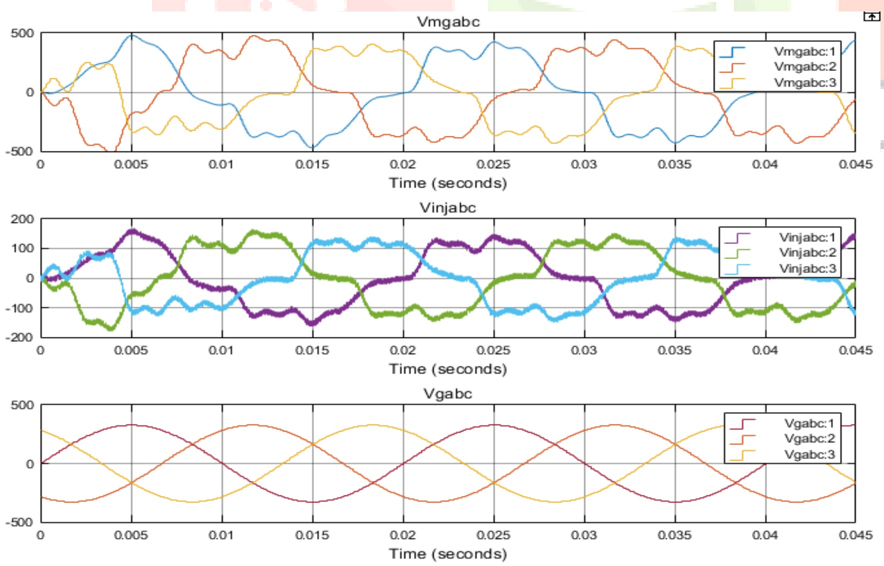
1. The simulation results clearly demonstrate that DVRs can successfully mitigate voltage sags, providing fast, efficient, and reliable voltage compensation.
2. DVR performance was stable even under deep sag conditions (up to 70%), showing its robustness for real-world applications.
3. The low THD confirms the DVR's ability to maintain waveform quality, protecting sensitive equipment not only from voltage dips but also from potential harmonic distortion.
4. The use of a PI control strategy with SRF theory proved effective for detecting sags and generating compensation voltage in real time.
5. The study also shows potential for energy-efficient DVR operation, as energy was only drawn from the DC-link during sag events, minimizing unnecessary losses.

4.7 Comparison with Traditional Methods

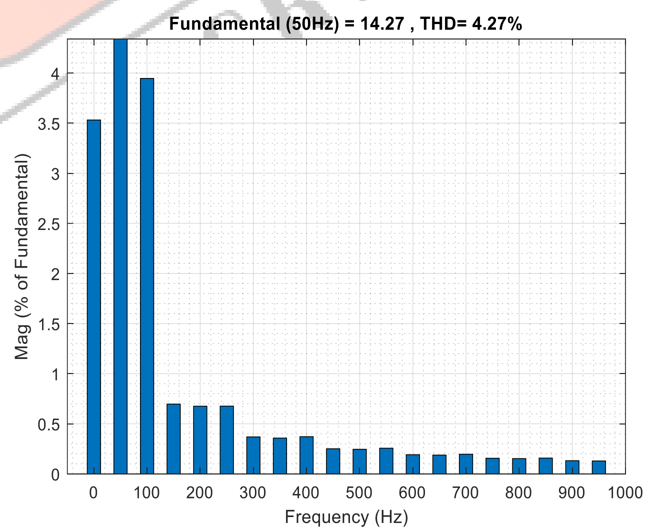
Technique	Response Time	Compensation Accuracy	THD Control	Cost	Maintenance
DVR	<5 ms	High (±0.1 kV)	Excellent	Moderate	Low
Voltage Regulator	100–500 ms	Low	Poor	Low	Moderate
UPS	~10–20 ms	Moderate	Good	High	High

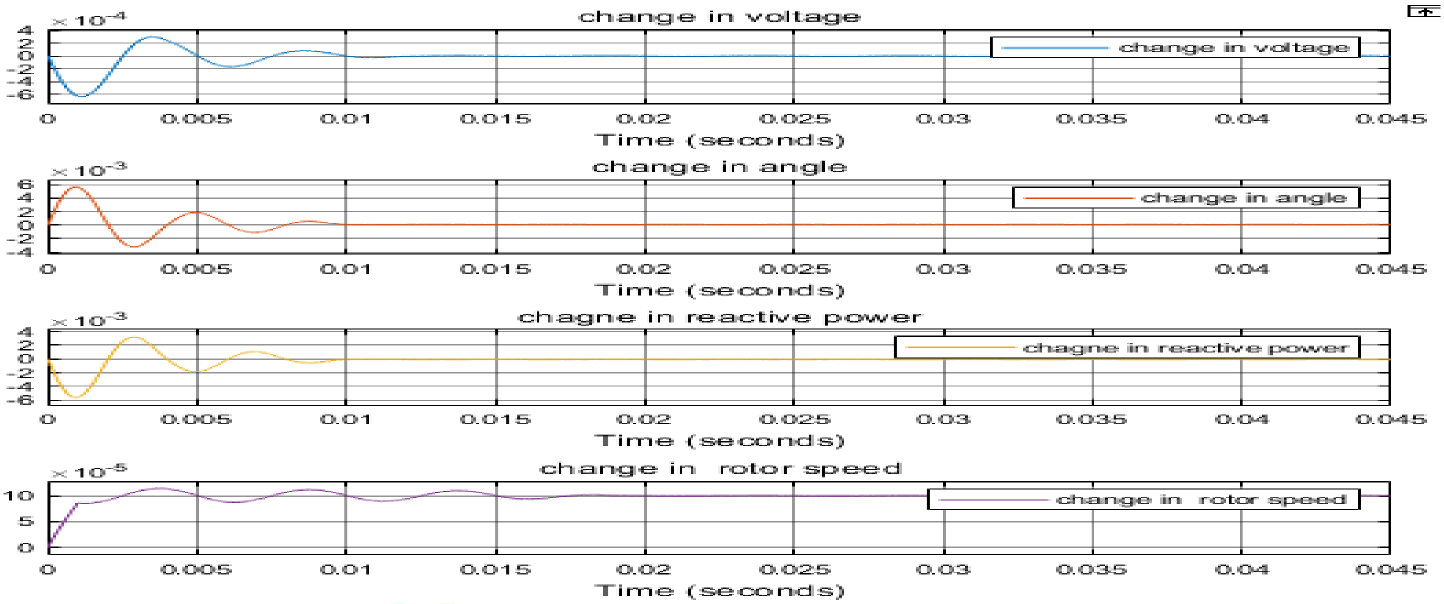
The DVR outperforms traditional techniques in speed, accuracy, and cost-effectiveness, making it a superior choice for industrial and commercial applications.

case 1: by using fuzzy logic controllers



THD by using Fuzzy controller





CASE 2 : IMPROVEMENT OF TRANSIENT STABILITY IN A HYBRID SYSTEM BY USING PI CON

➢ CONCLUSION

The demand for quality power has become a challenging issue for industrial area and consumers. Among them voltage unbalance is considered as the major affecting problem leads to degradation in performance of electrical equipment's. FACTS devices used for compensation are the best method to overcome such problem. Among them DVR considered the most efficient and cost effective.

Based on this project, one of the methods to mitigate the voltage sag is by using dynamic voltage restorer system. In order to investigate whether the DVR is able to deal with this problem, MATLAB/Simulink was selected in order to simulate the system and mitigate the voltage sag. Based on the simulation that had been done, it can be proved that DVR is the dynamic fast response devices that able to overcome the devices. Even though the system cannot compensate 100 percent of voltage during sag, it is an acceptable because the output voltage after compensation still in a range of the nominal value.

The simulation was implemented by using the distribution network where the effectiveness of the DVR system is better compared to the transmission network.Since DVR is the custom power devices, there were so various combinations of the main component that can be combined in order to get better results. For example, using GTO as a switching device, using SVPWM as the device for generating gating signal or maybe can use the other type of filter in order to eliminate the harmonics.

➢ REFERENCES

- [1].K.R. Padiyar "Facts controllers in power transmission and distribution" new age international (P) Ltd publishers, 2007.
- [2].A.F. Sadigh and K.M. Smedley, "Review of voltage compensation methods in dynamic voltage restorer (DVR)," in Proc. IEEE Power Energy Soc. Gen . Meet. Jul.2012, pp. 1-8.

- [3].P.B. Rani and S.R.Reddy, "Dynamic Voltage Restorer Using Space Vector PWM Control Algorithm," European Journal of Scientific Research, vol. 56, no. 4, pp. 462-470, 2015.
- [4].S.S Choi, B.H. Li, and D.M Vilathgamuwa, "Dynamic voltage restoration with minimum energy injection","IEEE Trans. Power Syst., vol. 15, no.1, pp.51 57, Feb 2011.
- [5].A.M. Sadigh and K.M. Smedley, "Review of voltage compensation methods in dynamic voltage restorer (DVR)," in Proc.IEEE Power Energy Soc.
  Gen. Meet. Jul. 2012, pp. 1-8.
- [6].J.A. Martinez and J.M Arnedo, "Voltage sag studies in distribution networks-Part I: System modeling, "IEEE Trans. Power Del., vol.21, no.3, pp.
  338-345, Jul. 2006.
- [7].D.M. Vilathgamuwa, H.N. Wijekoon, and S.S Choi, "A novel technique to compensate voltage sags in multiline Distribution system – The interline dynamic voltage restorer", IEEE Trans. Ind. Electron., vol.53, no.5, pp. 16031611, Oct 2013.
- [8].H.Kim and S. Sul, "Compensation voltage control in dynamic voltage restorers by use of feed forward and state Feedback scheme, "IEEE Trans.
  Power Electron., vol20, no.5, pp.1169-1179, sep.2007.
- [9].S.B. Vegunta and J.V. Milanovic, "Estimation of cost of downtime of industrial process due to voltage sags", IEEE Trans.Power Del., vol.26, no.2, pp. 492-500, Apr.2011.
- [10].A.Ghosh and G.Ledwich, "Compensation of distribution system voltage using DVR," IEEE Trans.Power Del.,vol.24, no.1, pp.25133-2521, Oct. 2008.
- [11]. J. G. Nielsen and F. Blaabjerg, "Power Quality in Power Systems and
  Electrical Machines," Elsevier,2012.
  Chapter 5 discusses various power quality disturbances and mitigation techniques,
  Including the application of dynamic voltage restorers.
- [12]L. L. Grigsby, "The Electric Power Engineering Handbook," CRC Press, 2001.
  This handbook offers a detailed section on voltage sag mitigation methods,
  Including dynamic voltage restorers.

- [13]G. J. Rogers, "Power System Oscillations," Kluwer Academic Publishers, 2000.

  Includes discussions on power quality issues, with a focus on voltage sags and

  The role of DVRs in maintaining system stability.

- [14] S. S. Williamson, R. J. P. van der Meer, and H. D. Power, "Dynamic Voltage Restorer (DVR) for Voltage Sag Mitigation in Power Systems," IEEE Transactions on

  Power Delivery, vol. 23, no. 1, pp. 462-470, Jan. 2008.

  This paper provides a detailed analysis of the Dynamic Voltage Restorer (DVR) system, its operation, and how it can be used to mitigate voltage sags.

- [15] M. S. Islam, R. M. Mathur, and S. Rahman, "Voltage Sag and Its Mitigation Using Dynamic Voltage Restorer," IEEE Transactions on Industry Applications, vol. 42, no. 5, pp. 1235-1244, 2006. This paper explores various techniques to mitigate voltage sags, focusing on the dynamic voltage restorer (DVR) and its advantages in terms of cost and performance.

- [16] J. Z. Liu, F. Liu, and Y. He, "Design and Control of a Dynamic Voltage Restorer for Voltage Sag Mitigation," IEEE Transactions on Industrial Electronics, vol. 54, no. 5, pp. 2249-2257, Oct. 2007.

- This article discusses the design considerations for DVRs and their control strategies to address voltage sag issues effectively.

- [17] G. P. Adam and A. T. Adams, "Mitigation of Voltage Sags Using Dynamic Voltage Restorer (DVR): A Practical Approach," Power Engineering Journal, vol. 18, no. 1, pp. 42-48, 2005. A practical approach to the mitigation of voltage sags using DVR technology, with real-world case studies and performance metrics.

- [18] M. K. M. A. Hossain and D. C. R. Ramaswamy, "Control of Dynamic Voltage Restorer for Power Quality Improvement in Distribution Systems," International Journal of Electrical Power & Energy Systems, vol. 29, no. 7, pp. 589-597, 2007. Focuses on the control techniques of DVR systems for improving power quality and ensuring stable operation of the distribution network.

- [19] R. C. Dugan, M. F. McGranaghan, and H. W. Beaty, "Electrical Power Systems Quality," McGraw-Hill, 2003.
  This book contains comprehensive sections on power quality disturbances, including voltage sags, and the various mitigation methods such as DVR systems.
- [20] E. A. G. S. S. M. Islam, "Power Quality Management in Industrial Plants," CRC Press, 2016. Chapter 7 focuses on the role of DVRs in mitigating voltage sags and improving overall power quality in industrial plants.