Power Quality Improvement Using Dynamic Voltage Restorer in Distribution System

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Abstract – *This study evaluates the application of Dynamic Voltage Restorer (DVR) technology to mitigate power quality disturbances in electrical distribution systems. Using PSCAD simulation software, the research analyzes the mitigation of voltage sags and harmonics during symmetrical (three-phase-to-ground) and asymmetrical (single line-to-ground) faults. The DVR utilizes a Proportional-Integral (PI) controller and Pulse Width Modulation (PWM) to inject compensating voltages through an injection transformer. Results quantify the restoration of load-side voltage from a 34% sag to nearly nominal levels. This paper addresses previous limitations by providing a quantitative performance summary and outlining future research directions for modern grid resilience*

Keywords: *Dynamic Voltage Restorer, Power Quality, PSCAD, PWM, Voltage Sags*

Article History
Received 12 February 2026
Received in revised form 31 March 2026
Accepted 08 May 2026

I. Introduction

In terms of voltage, current, and system frequency stability, power quality is a crucial component of modern electrical equipment's electrical performance and dependability. Power quality issues arise from abrupt disturbances including voltage sags, swells, harmonics, and flickers, especially for sensitive loads. Voltage sags, which are reductions of 0.1 and 0.9 p.u. for voltage over periods of 0.5 cycles to one minute, have become one of the most significant issues among these. Short circuits, system overloads, or strong inrush currents during large motor starters are the causes of this. On the other hand, single line-to-ground faults are typically the cause of voltage swells, which are brief increases in voltage that frequently exceed 140% to 170% of the rated value [1] – [4].

The Dynamic Voltage Restorer (DVR) has become a reliable power electronics solution to reduce these disruptions. The load voltage is efficiently increased when the DVR is connected between the voltage source and the load via an injection transformer. A voltage source PWM inverter, coupling transformer, energy storage, and filter make up the DVR's architecture. These devices will react dynamically to both swells and sags, guaranteeing a steady power supply for essential machinery [5] – [9].

The performance of the DVR under various failure scenarios is thoroughly evaluated in this study using PSCAD simulation software. A Dynamic Voltage Restorer (DVR) is essential for improving system reliability and protecting delicate electronic environments. Simulation results from studies consistently confirm that a DVR is very effective at compensating for power quality events, such as voltage sags, swells, and harmonics

II. Literature Review

Introduced in 1996, a Dynamic Voltage Restorer (DVR) is a robust solid-state device that injects compensating voltage into the system to adjust voltage on the load side [10] – [12].

The DVR, which is usually positioned in a distribution system between the power supply and crucial load feeders, is essential for ensuring that sensitive loads continue to receive power during voltage fluctuations. Its main purpose is to prevent power outages by rapidly restoring load-side voltage. The DVR provides other features including controlling fault currents, lowering voltage transients, and minimizing line voltage harmonics in addition to handling voltage sags and swells. An injection transformer, a filter, a voltage source converter (VSC), an energy storage system, a control system, and a bypass switch are the essential parts of a DVR. The DVR is a crucial part of maintaining power quality in contemporary electrical systems since these components cooperate to guarantee the device's effective operation [13] – [15].

III. Methodology

The simulations carried out under various test scenarios using the Dynamic Voltage Restorer (DVR) are presented in this section. Figure 1 depicts the single-line diagram that functioned as the test case, and Figure 2 shows the PSCAD software model of the DVR. 11 kV, 415 V, and 230 V are the three voltage levels at which the distribution network functions. The performance of these levels under fault conditions is evaluated by testing them under constant loads. The distribution network in the simulation is subjected to a single line-to-ground fault and a three-phase short circuit fault, both of which have a fault resistance of 10 ohms. The errors start at 0.2 seconds and last for that amount of time

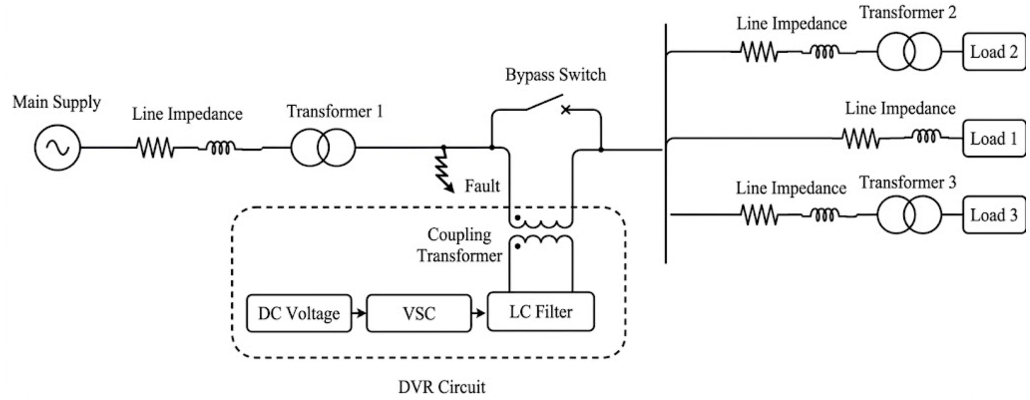

Fig. 1. Single-Line diagram distribution system with DVR

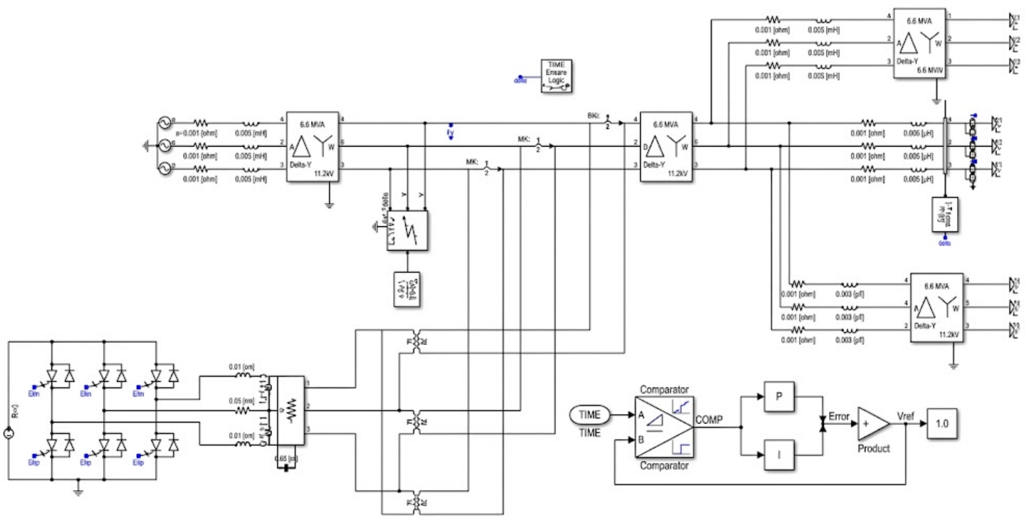

Fig. 2. Simulation circuit with DVR

A. Simulation Parameter

The system parameters used for DVR simulations are given in Tables I and II.

TABLE I
DISTRIBUTION SYSTEM PARAMETER

Components	Parameter
Source	*3-Phase,33kV,50 Hz*
Transformer 2	*11kV/400V, Δ-Y*
Transformer 3	*11kV/230V, Δ-Y*
Source	
Transformer 2	*11kV/400V, Δ-Y*
Fixed Load	*P= 0.005MW* *Q=0.002MVAR*

TABLE II
DVR SPECIFICATIONS

Components	Rating values
Injection Transformer	Turn Ratio: 1:1
Energy Storage	4 kV
LC Filter	L = 0.10mH, C=5.56uF
VSC	GTO based, 6 pulses, 450Hz
Controller	PI Controller

B. Control Circuit Configuration

The Dynamic Voltage Restorer (DVR) control circuit configuration used in the case study is presented in this section. As seen in Figs. 3 and 4, it includes a proportional-integral (PI) controller to maintain dependable performance during fault events and pulse width modulation (PWM) for efficient voltage adjustment

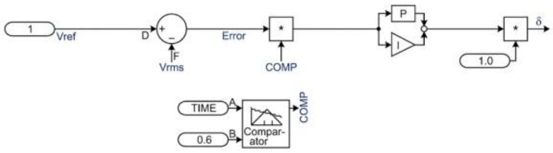

Fig. 3. PI Controller network for DVR control

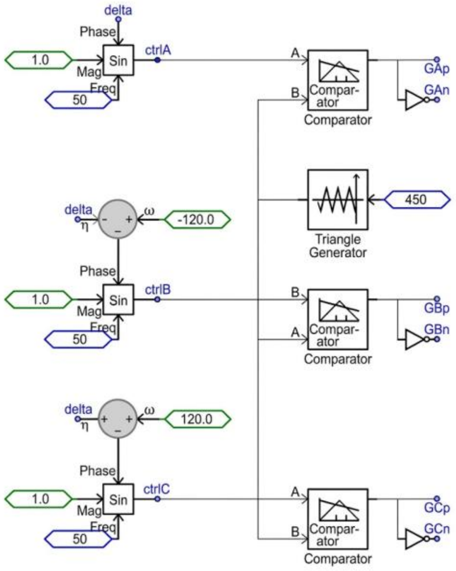

Fig. 4. Configuration pulse width modulation (PWM)

IV. Results and Discussion

The study and discussion of the system's reaction to symmetrical and unsymmetrical failures are presented in this section, with an emphasis on performance both before and after the Dynamic Voltage Restorer (DVR) was installed. The findings illustrate the DVR's function in preserving system stability and safeguarding load by demonstrating its efficacy in reducing voltage sags and enhancing power quality during fault scenarios. Each failure case's unique results are covered in the ensuing subsections, along with the waveform and voltage level changes that correlate to it.

A. Case 1: Symmetrical Fault

The analysis of a symmetrical three-phase-to-ground failure is presented in this section, with an emphasis on the behavior of the system both before and after a Dynamic Voltage Restorer (DVR) was installed. As seen in Fig. 5, a three-phase-to-ground fault resulted in a 34% voltage sag across all three phases prior to the DVR installation. Figure 5 illustrates how the disruption lowers the rated voltage from 6.6 kV to 4 kV, which increases the possibility of equipment damage. The waveform result with DVR installation is shown in Fig. 6. By dynamically injecting the voltage required for restoring the load voltages to their nominal levels, the DVR effectively reduced the voltage sag. The voltage restoration profiles of Loads 1, 2, and 3 had been comparable, and the experiment findings indicated strong consistency. Transient harmonic disturbances were detected at the beginning and end of the fault, although they had little effect on the overall power quality. These results confirm that the Dynamic Voltage Restorer (DVR) is effective in maintaining voltage levels and enhancing system dependability.

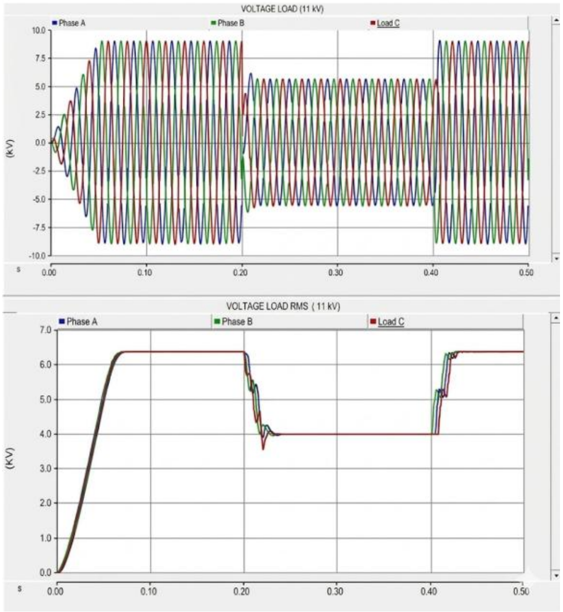

Fig. 5. Waveform results of symmetrical fault at load 1 without DVR

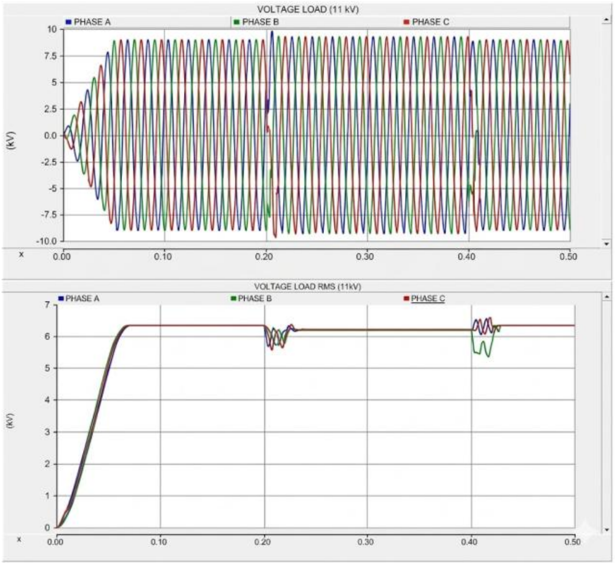

Fig. 6. Waveform result of symmetrical fault at load 1 with DVR

TABLE III
VOLTAGE COMPARISON IN SYMMETRICAL FAULTS

	Without DVR		**With DVR**	
	Voltage (kV)	Voltage RMS (kV)	Voltage (kV)	Voltage RMS (kV)
Load 1	5.763	4.047	9.249	6.539
Load 2	0.212	0.150	0.323	0.228
Load 3	0.119	0.0841	0.199	0.141

Table III shows the voltage impact with and without Dynamic Voltage Restorer's (DVR) during symmetrical faults. From the table, it can be seen that without DVR in action, Load 1 voltage dropped to 5.763 kV (RMS: 4.047 kV), which will compromise power quality and equipment performance. With the DVR, the voltage is restored up to 9.249 kV (RMS: 6.539 kV), thus stabilizing the system. For Load 2 and Load 3, initial voltages of 0.212 kV and 0.119 kV were corrected to 0.323 kV and 0.199 kV, respectively, highlighting the DVR's ability to mitigate sags effectively

B. Case 2: Unsymmetrical Fault

This section discusses the results of a single-phase-to-ground fault in particular phase A, and the impact of DVR on the system's performance before and after its installation as shown in Fig.7.

In the absence of the DVR, a 34% voltage sag occurred at phase A. After DVR installation, it effectively compensated for phase A to the almost nominal level, thus maintaining system stability. The result for phase A restoration with DVR is shown in Fig. 8. Although minor harmonic disturbances were noted, they were minimal and did not affect overall power quality.

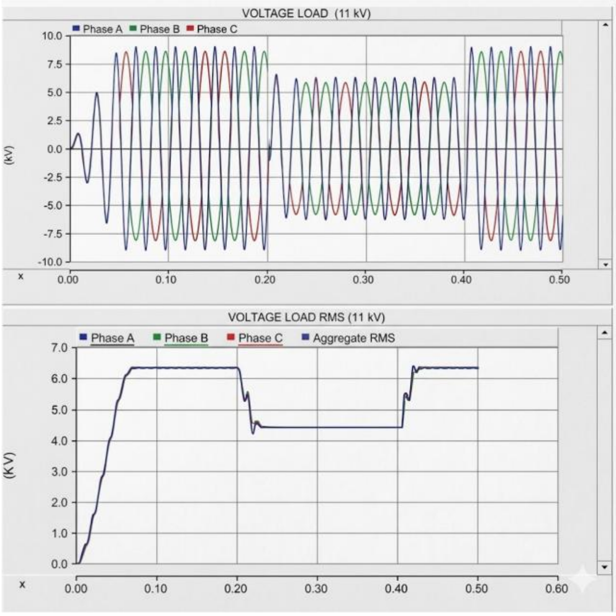

Fig. 7. Waveform result of unsymmetrical fault at load 1 without DVR

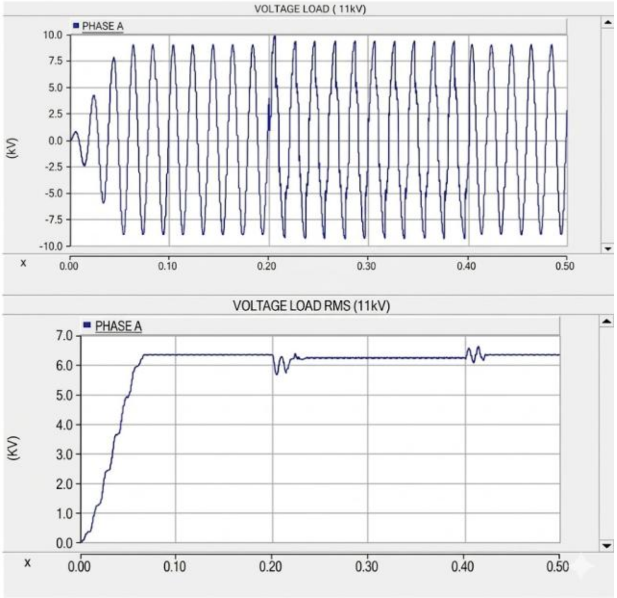

Fig. 8. Waveform result of unsymmetrical fault at load 1 with DVR

Table IV summarizes the DVR's effectiveness in unsymmetrical fault scenarios. Load 1 voltage, reduced to 5.861 kV, was restored to 9.196 kV. Voltage levels at Load 2 and Load 3, initially 0.191 kV and 0.106 kV, were improved to 0.333 kV and 0.198 kV, ensuring consistent power quality.

TABLE IV
VOLTAGE COMPARISON RESULT IN UNSYMMETRICAL FAULTS

	Without DVR		**With DVR**	
	Voltage (kV)	Voltage RMS (kV)	Voltage (kV)	Voltage RMS (kV)
Load 1	5.861	4.144	9.196	6.502
Load 2	0.191	0.135	0.331	0.234
Load 3	0.106	0.075	0.198	0.140

V. Conclusion

The simulation and modeling of the Dynamic Voltage Restorer (DVR) using PSCAD software demonstrate its high efficiency in mitigating power quality disturbances in distribution networks. The results confirm that the DVR is a robust solution for protecting sensitive loads, successfully restoring voltage levels from a 34% sag back to nearly nominal values during both symmetrical and unsymmetrical fault conditions. Quantitatively, the DVR improved the RMS voltage of Load 1 from 4.047 kV to 6.539 kV during symmetrical faults and from 4.144 kV to 6.502 kV during unsymmetrical faults. Similar restoration trends were observed for lower-voltage loads, such as Load 2, which improved from 0.135 kV to 0.234 kV under unsymmetrical conditions.

Acknowledgements

The authors wish to acknowledge the Ministry of Education, Malaysia and Universiti Teknikal Malaysia Melaka, for supporting this research.

Conflict of Interest

The authors declare no conflict of interest in the publication process of the research article.

Author Contributions

Author 1: Methodology, Investigation, Writing draft.
Author 2,3: Supervision, Resources, Writing.
Author 3,4,5: Conceptualization, review, preparation.

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