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Research Article

Model for the Power Quality (PQ) Mitigation of Voltage Sag using a Dynamic Voltage Restorer (DVR)

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ABSTRACT

Voltage sag is a significant power quality disturbance that can lead to operational disruptions, equipment damage, and financial losses in industrial and commercial sectors. Dynamic Voltage Restorer (DVR) is an effective custom power device designed to mitigate voltage sags and ensure uninterrupted power supply. This research focuses on modeling a DVR-based compensation system to analyze its performance in mitigating voltage sags under various fault conditions. A comprehensive mathematical model is developed, and simulations are conducted using MATLAB/Simulink to evaluate the DVR's response in restoring voltage levels. The results demonstrate that the DVR effectively compensates for voltage sags with minimal response time and improved voltage stability. The study highlights the DVR's potential as a cost-effective and efficient solution for enhancing power quality in modern power distribution systems.

Keywords: Voltage Sag, Power Quality, Dynamic Voltage Restorer, Voltage Compensation, MATLAB/Simulink, Custom Power Devices.

INTRODUCTION

The quality of electrical power supply is of paramount importance in ensuring the seamless operation of various electrical and electronic devices. However, power systems are often susceptible to disturbances, such as voltage sags, which can lead to momentary drops in voltage levels. These voltage sags can have detrimental effects on sensitive equipment, causing malfunctions and disruptions.

In recent years, significant advancements have been made in developing power electronic devices to address power quality issues and mitigate voltage sags effectively. One such innovative solution is the Dynamic Voltage Restorer (DVR). The DVR is a fast-acting voltage compensation device that dynamically injects voltage into the power system during sags, restoring the voltage to its nominal level and safeguarding connected equipment from any adverse impacts.

This project aims to design and implement a MATLAB Simulink model for the Power Quality (PQ) mitigation of voltage sag using a DVR. Through this simulation, we will explore the functionality and effectiveness of the DVR in compensating for voltage sags and enhancing power system stability. The model will allow us to analyze the performance of the DVR under different operating conditions and assess its capability in mitigating voltage sags in real-time.

By developing and evaluating this MATLAB Simulink model, we seek to contribute to the understanding and advancement of power quality improvement techniques, which are crucial in ensuring reliable and uninterrupted power supply in various industries and applications. Moreover, this research will pave the way for future developments in power electronics and grid resilience, ultimately benefiting both industrial and residential consumers

POWER QUALITY PROBLEMS

One of the most common power quality issues is voltage sag, which refers to a temporary reduction in voltage levels, typically lasting between a few milliseconds to several seconds. Voltage sags are often caused by sudden increases in load demand, short circuits, or faults within the power system.

These fluctuations can severely impact sensitive industrial and commercial equipment, leading to process interruptions, data loss, and potential equipment damage. The effects of voltage sags are particularly critical in sectors relying on automation, where even a brief drop in voltage can halt production lines. To mitigate voltage sags, solutions such as Dynamic Voltage Restorers (DVRs), Uninterruptible Power Supplies (UPSs), and voltage regulators are widely implemented. Proper monitoring and mitigation strategies are essential to maintaining a stable and reliable power supply, minimizing operational losses, and ensuring efficient energy usage.

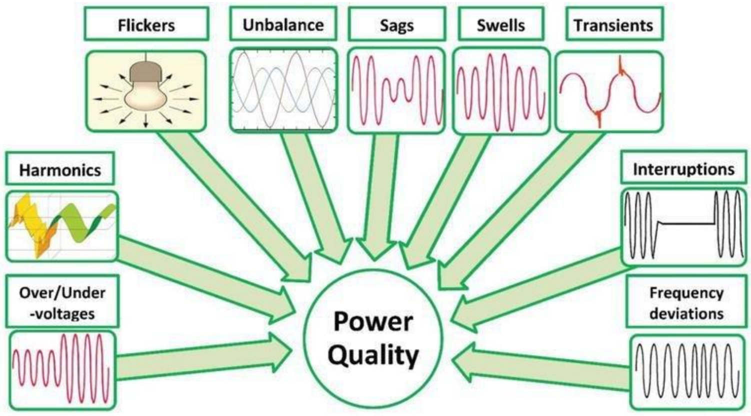

Figure : 1 Power Quality Problems

DYNAMIC VOLTAGE RESTORER (DVR)

It is a power electronics-based device used to mitigate voltage sags and swells in electrical distribution systems. The DVR is connected in series with the load to inject compensating voltage during disturbances.

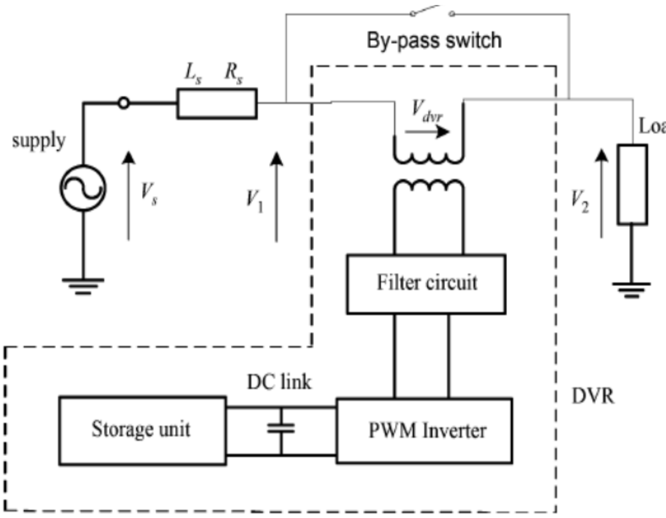

Figure 2 Schematic Diagram of DVR

The main components of a DVR and its configuration are as follows:

1. **Voltage Source Inverter (VSI)**
    - Converts DC power into AC to generate the required compensating voltage.
    - Uses Pulse Width Modulation (PWM) techniques for precise voltage control.
2. **Energy Storage System (ESS)**
    - Provides the necessary power during voltage sags.
    - Can include batteries, supercapacitors, or flywheels depending on application needs.

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3. **Injection Transformer**
   - Couples the DVR to the power system by injecting the compensating voltage in series with the supply voltage.
   - Provides electrical isolation between the DVR and the power system.
4. **Control and Protection System**
   - Monitors the supply voltage and detects disturbances in real time.
   - Uses controllers like **Proportional-Integral (PI)** or **Fuzzy Logic Controllers (FLC)** to determine the required compensation.
   - Includes circuit breakers, relays, and surge protection devices to ensure safe operation.
5. **Bypass Switch**
   - Used to isolate the DVR from the system during faults or maintenance.
   - Ensures uninterrupted supply by allowing direct power flow when DVR operation is not needed.

Modeling of DVR in MATLAB:

The model consists of the following blocks:

Three-phase source: This block generates a three-phase sinusoidal voltage waveform.

DVR: This block is a shunt compensator that injects a voltage waveform in parallel with the source to compensate for the voltage sag. The DVR is controlled by a PI controller.

Load: This block represents a nonlinear load that is sensitive to voltage sags.

Measurements (supporting blocks): These blocks measure the voltage and current waveforms at the load.

The model uses a DLG fault (double line-to-ground fault) to cause the voltage sag. The fault is applied at 0.1 seconds and cleared at 0.16 seconds. The DVR is activated at 0.1 seconds and remains active until 0.16 seconds. The simulation time is 0.1 seconds.

The PI controller in the DVR is used to track the voltage waveform at the load. The controller output is used to control the voltage waveform injected by the DVR.

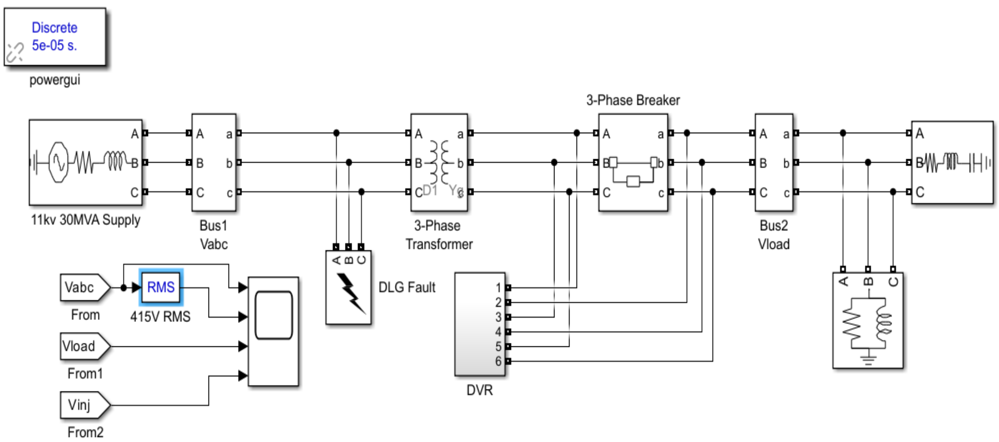

Figure 3. Simulink model of the system with DVR.

DVR Circuit:

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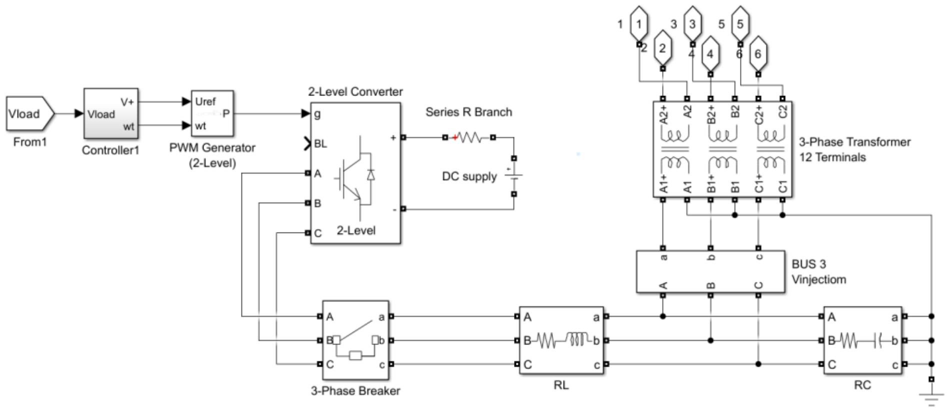

Figure 4. DVR circuit

TABLE 1 : Parameter and value of system :

Parameter	Values
Supply Voltage	415 volt
Frequency	50 Hz
Load Power Factor	0.86
Load Active Power	10 kW
Load Reactive Power	7.4 kVA

MATHEMATICAL MODEL FOR OPERATING PRINCIPLE OF PROPOSED DYNAMIC VOLTAGE RESTORER

The power (active) that load absorbed is as follows:

The power (active) that load absorbed is as follows:

$$P_L = V_L I_L \cos\theta \quad (1)$$

While if the active power of the DVR is given,
When DVR gives active power,

$$P_{DVR} > 0 \quad (2)$$

When active power is taken by DVR

$$P_{DVR} < 0 \quad (3)$$

When the active power is not exchanged.

$$P_{DVR} = 0 \quad (4)$$

$$\theta_r = \theta_l + \theta_s - \cos^{-1}\left(V_L \cos\theta_L / V_S\right) \quad (5)$$

where, VS > VL cos θL, this condition should be satisfied. By ignoring the limitations of the voltage, the exchange of active power for the voltage swell is zero. But in the circumstance of the voltage sag, the active power is supplied by the equipment, and if the voltage sag has a magnitude that is very deep that it could not satisfy the condition, thus injection voltage is as follows.

$$V_{INJ} > \sqrt{V_s^2 + V_L^2 - 2V_s V_L \cos(\theta_S - \theta_L)} \quad (6)$$

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GRAPHICAL RESULTS AND DISCUSSION

The load of 1 MVA with 0.86 power factor is considered as a sensitive load. The sensitive load is supplied by the 400V load and 50Hz frequency to a 3-phase supply system. The single line diagram of the test system without DVR is shown in Figure 2. It shows that the test system contains a Three-Phase, a programmable voltage source, an RL source, and a sensitive active and reactive load is connected with it. Table 1 below is presenting the parameters and the values of the testing system.

The below figure 5 shows the source voltage waveform where there is a sag occurred from the time 0.1 sec to 0.16 sec

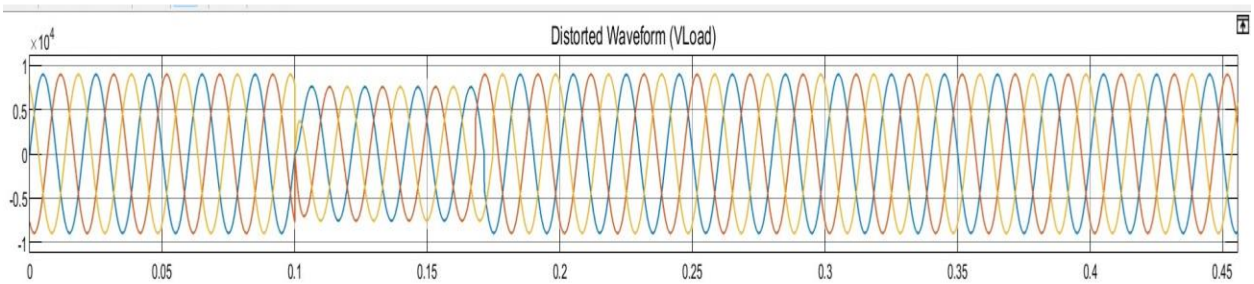

Figure 5. Distorted waveform (VLoad) in system without DVR

The below figure shows the output voltage waveform. Even though as shown in above figure there is a sag occurred in source voltage, the output voltage waveform is constant in magnitude because DVR is injecting the voltage.

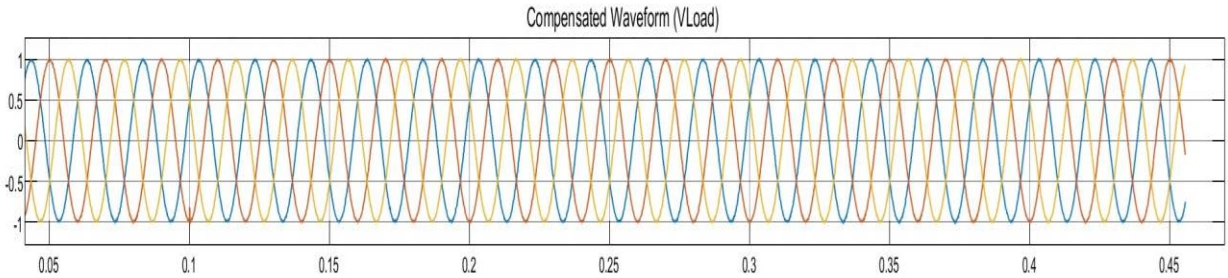

Figure 6. Compensated signal (VLoad) in system with DVR

The figure 20 below shows the injected voltage of the DVR. It shows that when a sag that is occurred at 0.1 sec to 0.16 sec DVR is acted at that particular time and is injecting voltage into the line through transformers

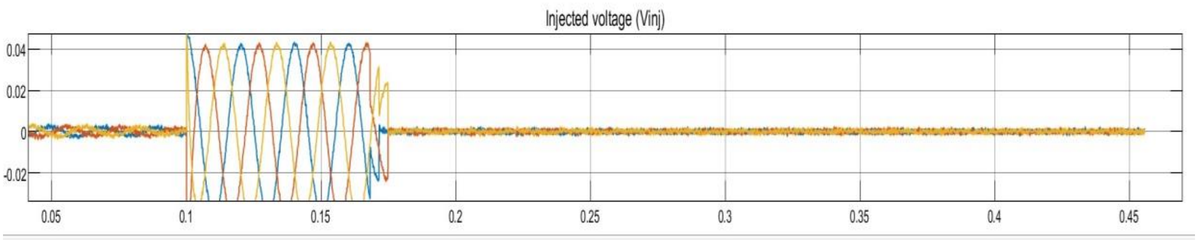

Figure 7. Injected voltage (Vinj) by DVR in all three phases

TABLE 2 : THD% of system with and without DVR.

Phase	THD% (Without DVR)	THD% (With DVR)
Phase R	12.60	0.74
Phase Y	12.60	0.74
Phase B	12.60	0.74

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The three-phase injection transformer is used to connect the DVR system to that of the test system's transmission line. The control circuit of the DVR is used for the amplification of the pulses and produced by the PWM. Then through the transformer, the injected of the voltage in the transmission line occurs.

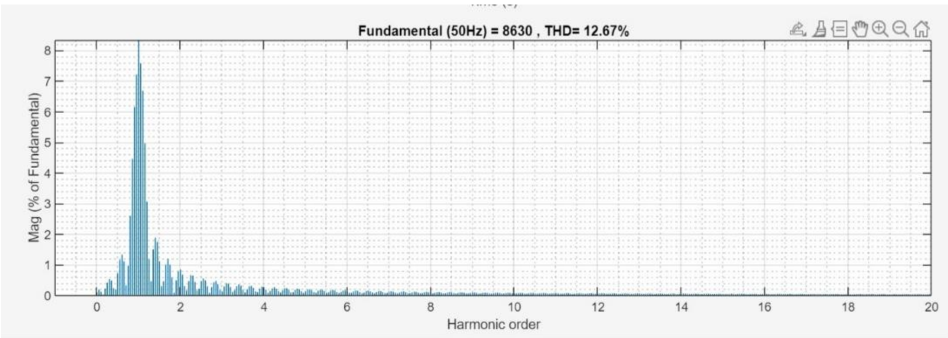

Figure 8. Phase R Harmonic

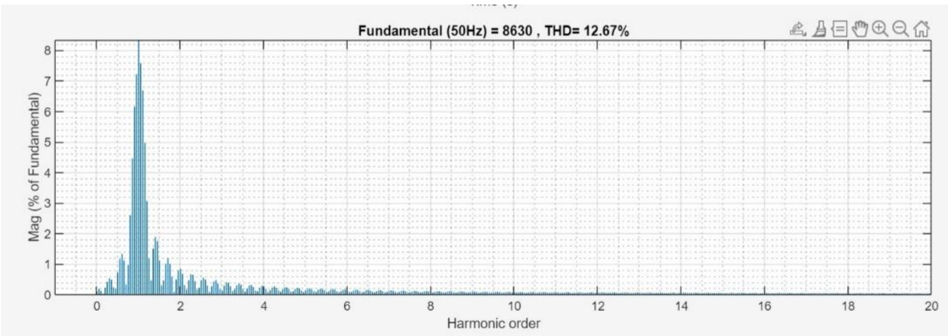

Figure 9. Phase Y Harmonic

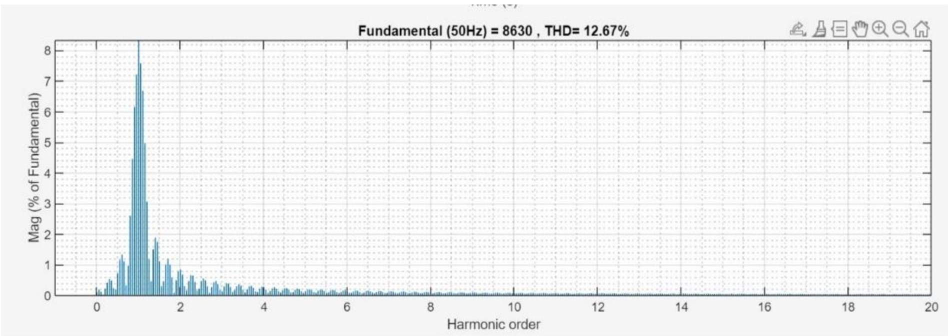

Figure 10. Phase B Harmonic

After taking the DVR in line it was observed that the sag in the waveform has been eliminated to a great extent and you can see it in the graph

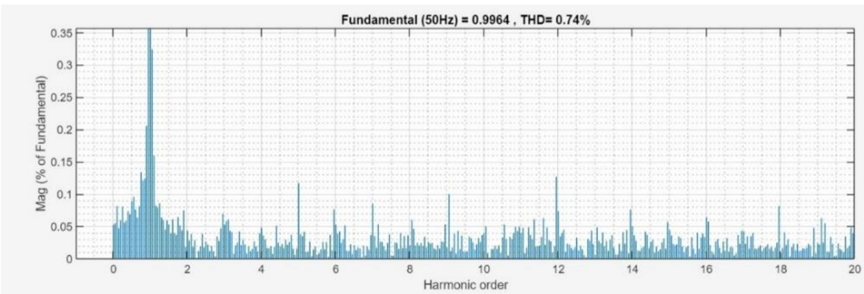

Figure 11. With DVR THD% in Phase R

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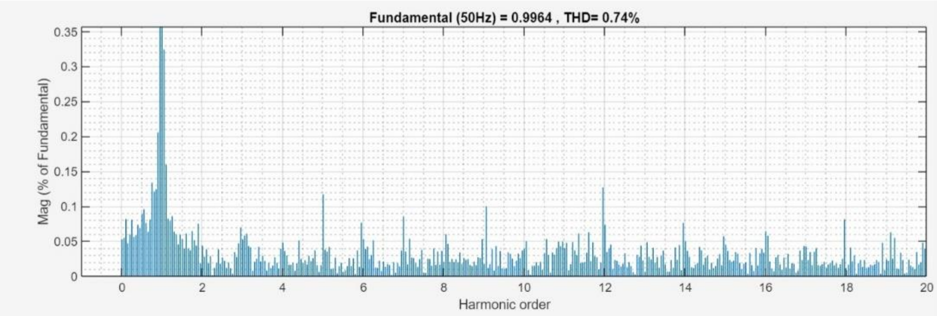

Figure 12. With DVR THD% in Phase Y

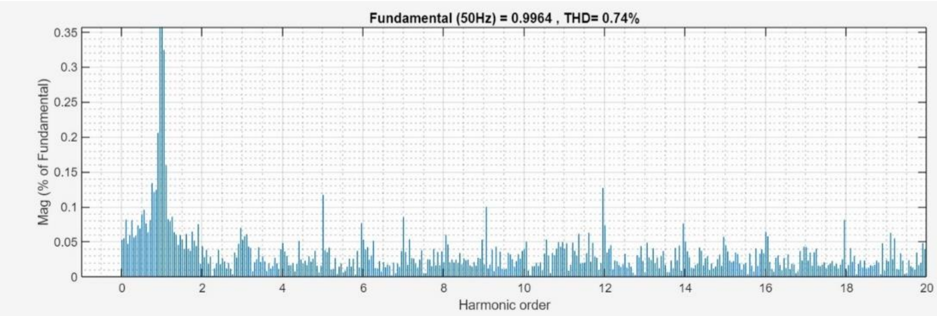

Figure 13. With DVR THD% in Phase B

The simulation results indicate that the DVR successfully mitigates voltage sags by injecting the required compensating voltage within a few milliseconds. The THD analysis confirms that the restored voltage maintains quality within acceptable limits. The DVR's dynamic response under different load conditions is analyzed, demonstrating its ability to provide continuous voltage support with minimal power losses. A comparative analysis with conventional mitigation techniques highlights the advantages of the DVR in terms of efficiency and cost-effectiveness.

CONCLUSION

The study concludes that DVR is a reliable and efficient solution for mitigating voltage sags in power distribution systems. The developed mathematical model and simulation results confirm its effectiveness in restoring voltage levels and ensuring stable power supply. Future research should focus on enhancing DVR control algorithms and exploring hybrid mitigation strategies to further improve power quality and system reliability.

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CONFLICT OF INTEREST

The authors declare no conflict of interest.

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