Fault Response Improvement in Power System Using ANN Controlled DVR

Sonu Kumar Singh[1] Sachindra Kumar Verma[2]
[1,2]Department of Electrical and Electronics Engineering
[1,2]NRI Institute of research and Technology (NIRT), Bhopal, India

Abstract — This research article proposes an advanced fault response improvement technique for power systems using an Artificial Neural Network (ANN)-controlled Dynamic Voltage Restorer (DVR). The DVR, a versatile FACTS device, is capable of mitigating voltage sags and swells, improving power quality, and enhancing system stability. By integrating an ANN into the DVR control system, the proposed approach aims to significantly enhance the device's response time and accuracy in addressing power quality disturbances. The ANN is trained on a comprehensive dataset of fault scenarios, enabling it to learn optimal control strategies. The effectiveness of the proposed ANN-controlled DVR is evaluated through extensive simulations under various fault conditions. The results demonstrate substantial improvements in voltage recovery time, overshoot, and undershoot, leading to enhanced system reliability and performance.

Keywords: Fault Detection, Type of Fault, DVR, ANNWavelet

I. INTRODUCTION

Power systems are increasingly susceptible to various disturbances, such as faults, load fluctuations, and switching operations [1]. These disturbances can result in voltage sags and swells, which can adversely impact sensitive loads like computers, electronic equipment, and industrial processes. To mitigate these power quality issues, various FACTS devices have been developed, including the DVR [2]. Implementing an ANN-controlled DVR involves several key steps. First, an ANN is designed and trained using data on voltage disturbances like sags and swells, and their corresponding corrective actions. The ANN's architecture typically includes an input layer for voltage measurements, hidden layers for processing, and an output layer for generating control signals. Once trained, the ANN is integrated into the DVR system, which comprises a VSI, a series transformer, and potentially energy storage [3]. In a simulation environment like MATLAB/Simulink, the power system, DVR, and ANN are modeled together. Real-time voltage data is fed into the ANN, which outputs control signals to the VSI to inject the necessary voltage through the series transformer, stabilizing the load voltage[4]. The system is tested under various voltage disturbances to ensure the ANN-controlled DVR effectively mitigates these issues, providing a stable voltage profile with minimal response time and high accuracy. Adjustments and optimizations are made based on simulation results to enhance performance[5]. A Dynamic Voltage Restorer (DVR) is an advanced power electronics device that protects sensitive electrical equipment from voltage disturbances like sags, swells, and transients. It ensures a stable and reliable voltage supply by dynamically adjusting voltage levels. Implementing a DVR involves system analysis to identify critical loads and fault scenarios, designing and installing the device with components like a Voltage Source Converter (VSC) and energy storage, integrating its control system with the power management system, conducting rigorous testing, and establishing continuous monitoring and maintenance [6]. This comprehensive approach enhances power quality, protects sensitive equipment, and maintains stable and efficient operation of the electrical network [7]. The DVR system is designed with components like a Voltage Source Converter (VSC) and energy storage units (capacitors or batteries) to meet specific requirements [8]. The VSC converts DC power from storage into AC power to correct voltage disturbances. The DVR is installed in series with critical load lines and integrated with the power management system for real-time monitoring and control [9]. Rigorous testing ensures its ability to detect faults and compensate for disturbances. Continuous monitoring and maintenance, including updating control algorithms, guarantee long-term reliability and performance [10]. This comprehensive approach effectively manages voltage sags, swells, and harmonics, protecting sensitive equipment and maintaining stable and efficient network operation.

II. OPERATIONAL PRINCIPLE OF DVR

A Dynamic Voltage Restorer (DVR) is a device that ensures high-quality voltage supply to critical loads. It identifies and corrects voltage fluctuations, dips, and surges that can disrupt operations or damage equipment. When a disturbance occurs, the DVR measures the voltage deviation from the reference level at the point of common coupling (PCC). It then injects a corrective voltage through a series transformer to restore the supply voltage to the optimal level for the load. The DVR typically consists of a voltage source inverter (VSI), a DC-link capacitor, and a series transformer. The VSI, controlled by PWM techniques, generates the necessary corrective voltage waveform. Due to their rapid response capabilities, DVRs protect equipment from voltage disturbances, safeguarding power quality in industrial and commercial applications. A DVR protects sensitive loads by ensuring quality power supply. It detects and compensates for low or high voltage fluctuations (sags and swells) that can disrupt or damage connected devices. When a disturbance occurs, the DVR measures the voltage deviation at the point of common coupling (PCC) from the reference level. It then injects a corrective voltage through a series transformer to restore the voltage to the optimal level for the load, ensuring its uninterrupted operation.

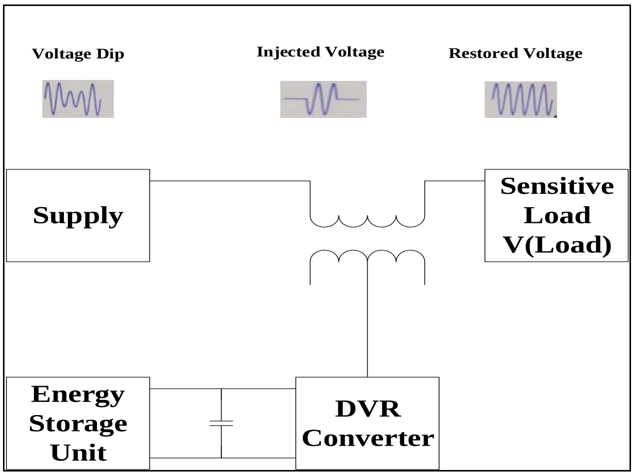

Fig. 1: Power Stage Single line diagram of DVR

Two common DVR structures use a voltage source inverter (VSI) with a series transformer and a DC link capacitor. The VSI generates corrective voltage waveforms based on control system signals. PWM techniques are employed to adjust the amplitude and phase of the injected voltage, matching the nominal voltage level. DVRs excel at rapidly responding to voltage fluctuations, mitigating adverse effects on electrical equipment and improving power quality. This enhances system reliability, reduces downtime caused by power disturbances, and restores critical equipment operation. DVRs are essential for applications requiring uninterrupted power supply, such as manufacturing facilities, data centers, and healthcare facilities.

III. Controller Scheme for DVR

This control system manages and improves power quality in a microgrid or power distribution system by controlling a power converter.

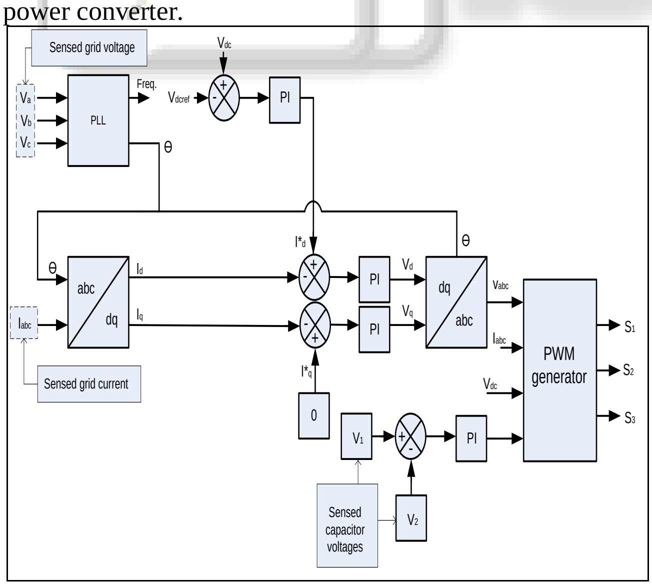

Fig. 2: Controller scheme

Key Components and Their Functions in control scheme:
Phase-Locked Loop (PLL):

A. Synchronizes with the grid voltage.

– Outputs frequency (Freq) and phase angle (θ\theta) of the grid voltage.
– Ensures that the control system remains in phase with the grid.

B. dq/abc and abc/dq Transformers:

– Perform coordinate transformation between the stationary (abc) frame and the rotating (dq) frame.
– Essential for simplifying the control of AC signals by converting them to DC quantities in the dq frame.

C. Voltage Regulation (Outer Loop):

– The PI controller maintains the desired DC voltage (Vdc) by adjusting the control signal based on the error between the reference and actual DC voltage.

D. Current Regulation (Inner Loop):

– These components are compared with their reference values (i*d, i*q), and the errors are processed by PI controllers.

E. PWM Generator:

– PWM generator uses the transformed three-phase voltages (Vabc) to generate the gate signals (S1, S2, S3) for the power switches. Converts control signals into Pulse Width Modulation (PWM) signals.
– The controller drives the power converter's switching devices to regulate output voltage and current, ensuring stable operation and high-power quality. Using phase synchronization (PLL), coordinate transformation (dq/abc, abc/dq), PI control loops, and PWM generation, the system effectively manages reactive power, harmonics, and other power quality issues. Feedback loops based on sensed voltages and currents enable dynamic response to changing load and grid conditions, optimizing performance.

IV. Application of ANN in DVR

An ANN-based DVR can use voltage measurements as input to generate control signals for the inverter, mitigating voltage sags and swells.

The figures show the output voltage ripple spectrum of three rectifier types: Vienna, active front end, and SCR. They reveal the harmonic content and DC output quality for each rectifier.

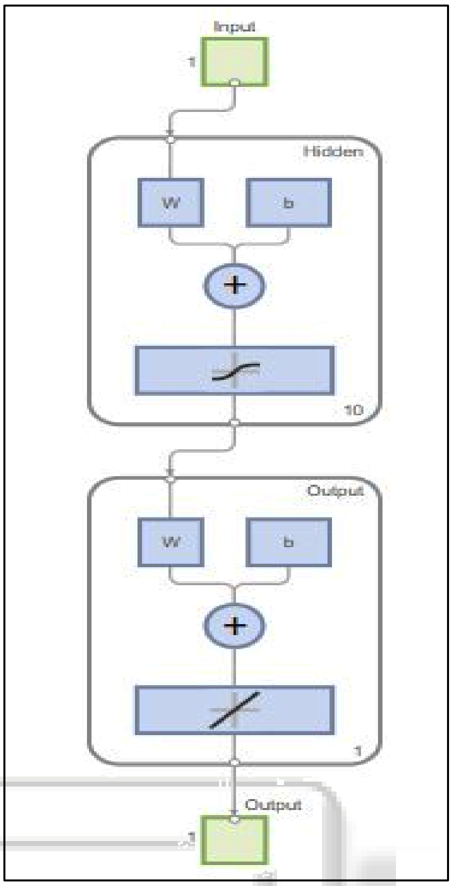

Fig. 3: ANN Architecture

A. Data collection

Data collection for training an ANN-controlled DVR involves gathering data on voltage sags, swells, and the corresponding DVR responses. This can be done through simulations and real-world measurements. Simulation tools like MATLAB allow for creating detailed power system and DVR models to systematically introduce voltage disturbances and record the DVR's responses. Real-world data is collected using sensors and data loggers at strategic points in the power system. The collected data is cleaned, normalized, and segmented for analysis. Proper storage and version control ensure data availability for training, validation, and improving the ANN's performance in mitigating voltage disturbances and maintaining system stability.

B. Network Architecture

– Input Layer: Voltage measurements (e.g., voltage magnitude, phase angle). The input layer receives voltage measurements from the power system, which serve as the features for the ANN.
– Hidden Layers: Multiple layers to capture complex relationships. The hidden layers are responsible for processing the input data and learning the underlying patterns and relationships. The number of hidden layers and the number of neurons in each layer can vary depending on the complexity of the problem. For DVR control, multiple hidden layers are often used to capture the intricate relationships between voltage disturbances and the required control actions.
– Output Layer: Control signals for the DVR (e.g., PWM signals). The output layer generates the final control signals for the DVR based on the processed information from the hidden layers.
– Designing an ANN-based DVR involves carefully selecting the network architecture and parameters to enable effective learning and prediction of control signals from voltage measurements.

C. Evaluation and Testing

Evaluating and testing the trained ANN is crucial to ensure its performance in real-world scenarios. The model is tested on a separate test set to assess its ability to generalize to new data using metrics like MSE, RMSE, and MAE. Its performance is evaluated under various voltage disturbances to ensure robustness. If performance is suboptimal, adjustments like modifying network architecture, tuning hyperparameters, or augmenting training data can be made. Iterative evaluation, adjustment, and retraining continue until the ANN achieves satisfactory performance on the test set, ensuring reliable control signal generation for the DVR to maintain voltage stability under diverse conditions.

D. Integration with DVR

Integrating a DVR (Dynamic Voltage Restorer) controlled by an ANN (Artificial Neural Network) involves several critical steps to ensure that the system can effectively mitigate voltage disturbances and maintain power quality. This process encompasses the design and training of the ANN, its integration with the DVR hardware, and the development of real-time control algorithms.

– Use real-time voltage measurements as input to the ANN.
– Generate control signals to adjust the DVRs output, maintaining stable voltage at the load.

Integrating an ANN-controlled DVR involves designing and training an ANN with historical data, integrating it with DVR hardware, and developing a real-time control algorithm. This integration enhances DVR performance and responsiveness by leveraging ANNs' pattern recognition and predictive capabilities to effectively mitigate voltage disturbances, ensuring stable and reliable power supply for sensitive equipment.

V. RESULT AND DISCUSSIONS

Leveraging Dynamic Voltage Restorers (DVRs) is a crucial strategy for fault compensation in modern power systems. DVRs effectively mitigate voltage disturbances, ensuring reliable electricity supply and protecting sensitive equipment. Simulation results demonstrate their ability to improve fault management by rapidly detecting and compensating for disturbances. This integration enhances system resilience and maintains high-quality power delivery.

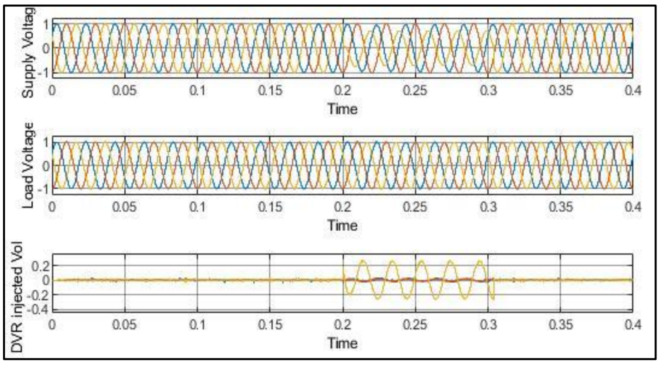

Fig. 4: Performance of DVR in Mitigating Voltage Sag during Line-to-Ground Fault

The graph illustrates the performance of a Dynamic Voltage Restorer (DVR) in mitigating a voltage sag during a Line-to-Ground fault. The Supply Voltage Waveform shows a voltage dip around 0.2 seconds, indicating a fault occurrence. The DVR effectively compensates for the voltage sag, maintaining a stable voltage at the load.

The Load Voltage waveform shows the voltage supplied to the load. The DVR effectively mitigates the voltage sag in the supply voltage, ensuring a stable load voltage throughout the disturbance. This demonstrates the DVR's ability to maintain a steady voltage supply to the load during faults.

The DVR Injected Voltage waveform shows the voltage injected by the DVR to compensate for the supply voltage sag. During the fault period (0.2 to 0.3 seconds), the DVR injects a compensating voltage, maintaining a stable load voltage.

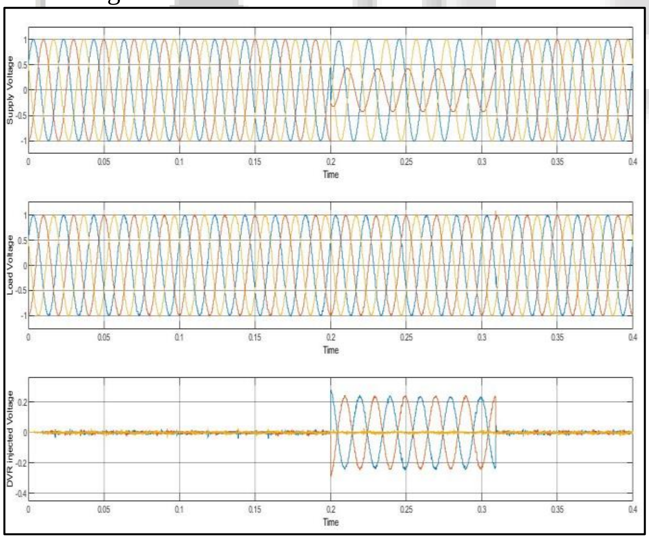

Fig. 5: Performance of DVR in Mitigating Voltage Sag during Line-to-Line Fault

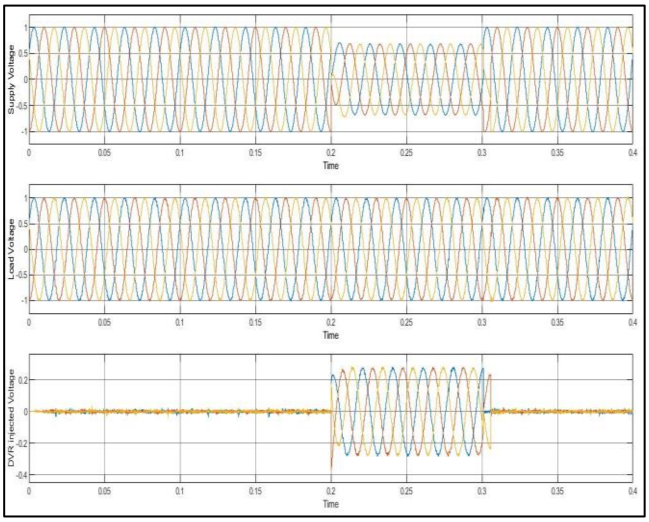

Fig. 6: Performance of DVR in Mitigating Voltage Sag during three phase Fault

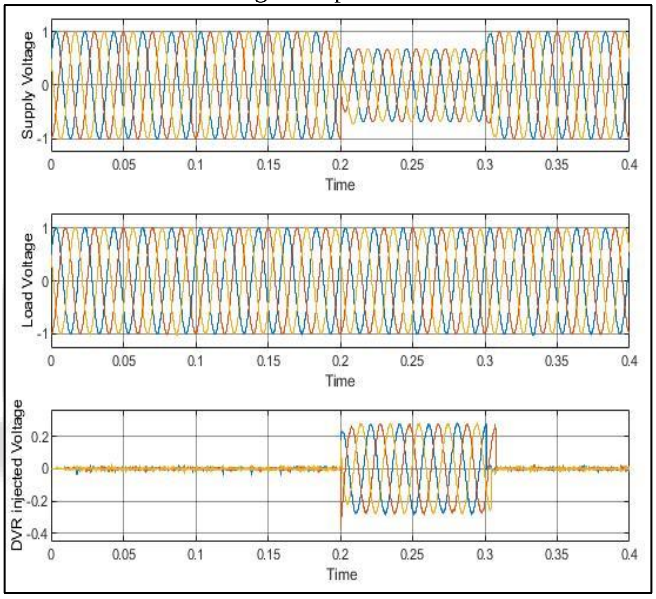

Fig. 7: Performance of DVR in Mitigating Voltage Sag during three phase to ground Fault

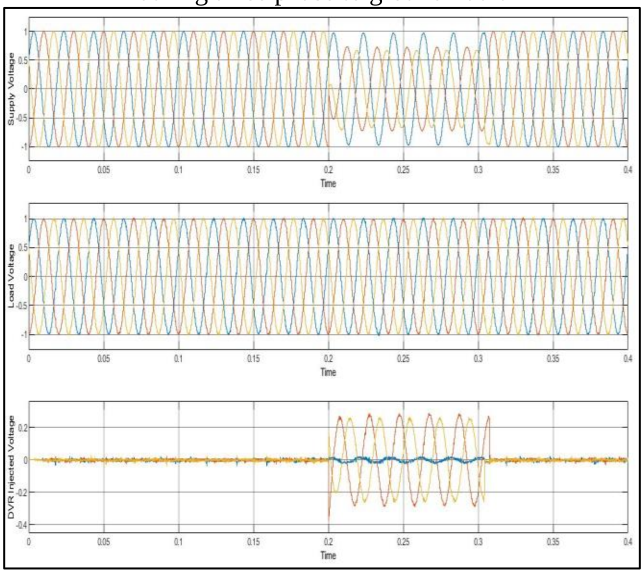

Fig. 8: Performance of DVR in Mitigating Voltage Sag during double line to ground Fault.

Learning with different types of faults in a power system: line-to-ground, double line-to-ground, three-phase fault or three-phase-to-ground and the usage of DVR to handle such faults. detailed explanation of each graph: detailed explanation of each graph.

VI. Conclusions

The load voltage waveform shows the voltage supplied to the load. The DVR effectively mitigates the voltage sag in the supply voltage, ensuring a stable load voltage throughout the disturbance. This demonstrates the DVR's ability to maintain a steady voltage supply to the load during faults. Dynamic Voltage Regulators (DVRs) are crucial for modern power systems, ensuring voltage stability and protecting sensitive equipment from voltage disturbances. Their real-time response and ability to maintain consistent voltage levels make them essential in various applications, from industrial facilities to commercial buildings and renewable energy systems. By improving power quality and reliability, DVRs contribute to enhanced system performance and reduced downtime.

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