INTELLIGENT CONTROL STRATEGIES FOR ENHANCING POWER QUALITY USING ARTIFICIAL NEURAL NETWORK-BASED DYNAMIC VOLTAGE RESTORERS

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Abstract- Dynamic Voltage Restorers are becoming essential tools for improving power quality in distribution networks by reducing voltage swells and sags. The dynamic and nonlinear nature of grid disturbances may not be sufficiently addressed by traditional DVR control strategies, which are based on established algorithms. In this paper, we suggest a unique method for controlling DVRs that makes use of ANNs and provides improved responsiveness and adaptability to changing grid conditions. The architecture of the ANN-based DVR is intended to learn from past data and modify its control strategy in real-time, allowing for accurate and effective voltage restoration. The ANN-based DVR control strategy's theoretical foundation is presented in this research, along with its capacity to understand intricate linkages between grid disruptions and the best course of action for remediation. Additionally, we go over how simulation data representative of various grid conditions is used to train the ANN model. Through thorough simulation experiments, the effectiveness of the proposed ANN-based DVR system is assessed in relation to traditional control strategies under a range of fault circumstances and load profiles. The outcomes show that the ANN-based method performs better in terms of response time, accuracy of voltage restoration, and flexibility to changing grid dynamics. Furthermore, the suggested method's resilience and scalability are examined, indicating encouraging possibilities for its application in real-world distribution systems. Overall, by presenting a novel and astute method of DVR control based on Artificial Neural Networks, this research advances the state-of-the-art in power quality enhancement technologies.
Keywords: Artificial Neural Network, Dynamic voltage restoration, PID, Power Quality.

1. INTRODUCTION

Worldwide, electrical energy is considered a basic consumer necessity and is a universal commodity[1]. The main energy demand is met by renewable energy sources like wind, solar, and so on. Reactive power difficulties, harmonics, and the erratic nature of renewable energy sources all impede power system performance by interfering with power system stability [2], [3]. Devices known as FACTS are frequently included in order to control voltage stability, enhance power quality, and compensate reactive power [4], [5]. However, FACT devices also alter several system parameters [6] in order to examine power quality and identify the reasons for and remedies for these power quality problems. Power quality is crucial in power systems when supplying variable power to the load. Consequently, low power quality will have an impact on residential and commercial clients with sensitive loads. Any disruption in the load voltage causes transients in the voltage, as well as sag, swell, harmonics that result in high distortions, and faults that result in THD. The DVR can prevent tripping and the associated losses by managing the voltage in the event of these issues. Energy-optimized DVR control and balanced voltage in a three-phase system are two examples of DVR-related issues and their solutions that have been documented [7]. The examination of several control strategies for different types of voltage sag is provided by references [8], [9]. A comparison of several DVR topologies and control strategies is provided in [10]. The design of a DVR backed by a capacitor that guards against distortions, sags, swells, or imbalances in supply voltages is covered in Paper [11]. The performance of the DVR with a high frequency-link transformer is covered in [12]. This study describes the VSC regulation and performance of DVR. This research uses an ANN controller in conjunction with synchronous reference frame theory to operate a DVR. Through a cascaded H-bridge multilevel inverter, the DVR is engineered to balance load side voltage with little active power injection, even in the face of unbalanced disturbances adjustment [9]. One economical method of reducing sensitive load voltage sags and swells is to use DVR. The ANN controller is used to address the drawbacks of the current approach. In order to enhance power quality and reduce harmonic distortions in sensitive loads, the ANN controller is utilized in the design and simulation of DVRs [9]. DVR is used to boost the inverter's actual power during any disruption. Using a delta linked transformer between the power supply and booster transformer, the DVR can be utilized as a voltage sag restorer and a voltage distortion compensator with ANN to reduce harmonics and voltage sag/swell created by zero sequence components.

An ANN is a network of distinct nodes that are arranged in layers to mimic the structure of animal brains. Each node transfers information to the next node after completing the required steps. Every layer processes any input to produce an output. All of the nodes in an ANN must be trained with pertinent data before it can carry out any given task. Transfer functions in layers are used in a back propagation optimization process to train a feed forward artificial neural network. The history of errors and potential disruptions makes up the training data, which is condensed and chosen at random to avoid overtraining. Because of its adaptability and capacity to be trained on any scenario, it is a resilient ANN technique [16], [20]. Simulation of the work is done using MATLAB/Simulink software.

In order to lessen voltage sag and swell in the distribution system using an ANN controller, this study proposes the Dynamic Voltage Restorer. The DVR is controlled by an ANN controller using the synchronous reference frame theory. In order to validate the efficacy of the suggested ANN control approach in conjunction with DVR over conventional method, simulation results based on the MATLAB/SIMULINK model were presented here. The suggested system's block diagram is displayed in Figure 1.1.

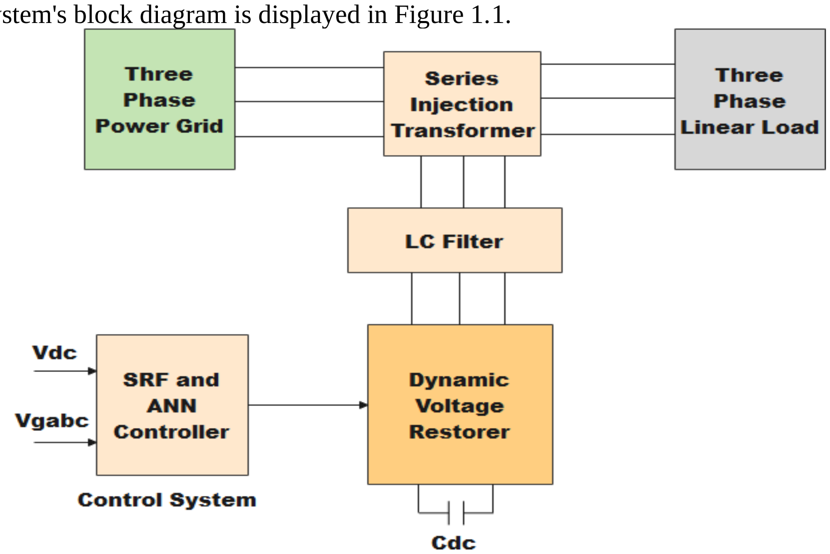

Fig. 1.1 Schematic Block Diagram of Suggested System

2. PRINCIPLES OF DVR FUNCTIONING AND CONTROL

Reducing voltage-based issues, such as PCC voltage harmonics, is the primary goal of the DVR. The DVR provides sinusoidal balanced voltages with the injection of necessary voltages between PCC and load, even for linear loads with self-supporting DC-bus. The goal of the DVR is accomplished separately or in concert with the configuration, specifications, and control method as required for suitable selection. The fundamental circuit of a DVR for a three-phase AC system is shown in Figure 2. DVR is the result of combining a DC bus capacitor with an IGBT-based voltage source converter (VSC). As a DVR, the VSC determines the reference voltages and uses a control algorithm in close proximity to the reference voltages to directly manage the sensed voltages.

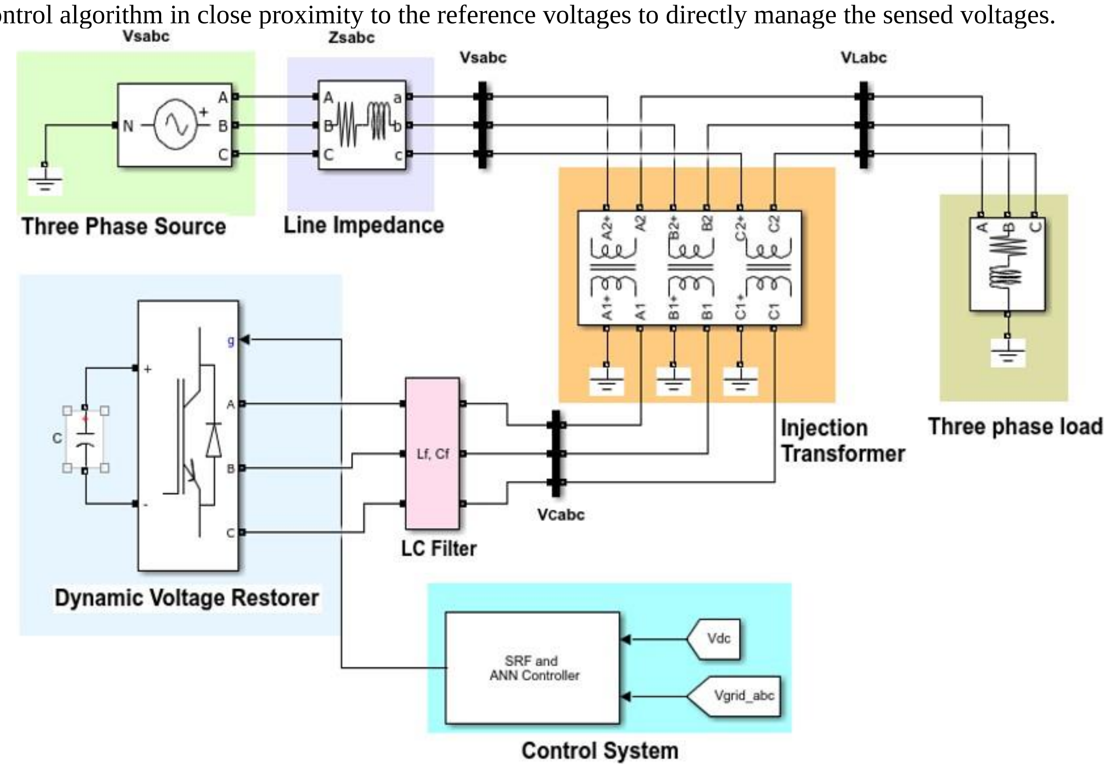

Fig. 2.1 Establishing up a Three-Phase Dynamic Voltage Restoration System

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2.1 Principle of DVR Operation

The DVR's circuit schematic includes a three-phase VSC converter that is coupled in series with a three-phase supply through three single-phase coupling transformers. It is thought that a DVR equipped with a DC bus capacitor is a three-phase VSC. An RC filter with a low rating is put across each transformer to eliminate large switching ripples at the voltage injected by the DVR. At PCC, a series filter has been fitted to eliminate voltage harmonics across linear or nonlinear loads. More protection is necessary for this design, though, in case there is a short circuit in the utility line.

In the event of voltage-sensitive loads, where voltage harmonics are minimized and zero voltage control is maintained at PCC, DVR must be directly controlled to inject the necessary voltage into the supply. As a result, the total voltage across the load that comes from the supply and the voltage injection is sinusoidal. With a low impedance at fundamental frequency, the DVR functions as a highly valued resistor for harmonic voltages at ac mains and is controlled as a harmonic voltage regulated source. This stops the harmonic voltages from entering the AC source and satisfies the requirement for harmonic load voltages.

2.2 Dynamic Voltage Restorer Control

A DVR control algorithm's primary job is to estimate reference voltages using feedback signals according to their intended uses. PWM gating signals for VSC IGBTs are obtained by comparing the reference voltage with a corresponding detected voltage in PWM generators. Control algorithms are used to estimate the DVR control reference voltages, which must be obtained appropriately. The various DVR control algorithms fall into two categories: easily modifiable frequency-domain and time-domain control algorithms.

2.21 Voltage harmonic removal control algorithm

The DVR control algorithm, illustrated in Fig. 3, employs the SRF theory to operate a self-supported DVR. Park's transformation converts the voltages at PCC into a spinning reference frame. Low-Pass Filters are used to eliminate the harmonics and the oscillating parts of the voltages (LPFs). The voltage components along the d- and q-axes are

$$V_{sd} = V_{dDC} + V_{dAC} \quad (1)$$

$$V_{sq} = V_{qDC} + V_{qAC} \quad (2)$$

To compensate for issues with voltage quality, the compensation method requires the voltage at the load end to be at its rated magnitude and undistorted. The DVR's PI controller can be used to maintain the self-supported VSC Capacitor's DC bus voltage.

Thus, the direct axis load voltage reference is

$$V^*_d = V_{dDC} + V_{loss} \quad (3)$$

Another PI controller is used to control the load terminal voltage amplitude (VL) at its reference voltage (V*L). The reactive voltage component (vqr) is the PI controller's output for controlling the voltage across the load terminal.

Thus, the quadrature axis load voltage reference is

$$V^*_q = V_{qDC} + V_{qr} \quad (4)$$

Referential loads inside the ABC structure. Reverse park's transformation yields v*La, v*Lb, and v*Lc. The discrepancies between the detected load voltages (vLa, vLb, vLc) and the references load voltages (v*La, v*Lb, v*Lc) are used by a PWM controller to create the gating pulse of the DVR.

3. ARTIFICIAL NEURAL NETWORKS (ANN)

The controller's main goals are a high interactive reaction to the intended DVR compensation and fast, extremely accurate disruptive signal detection. The conventional controller cannot function properly in the presence of parameter changes, load disturbances, non-linearity, etc. According to a recent survey, an ANN-based controller maintains the DVR steady throughout a variety of operating settings and offers quick dynamic reactions.

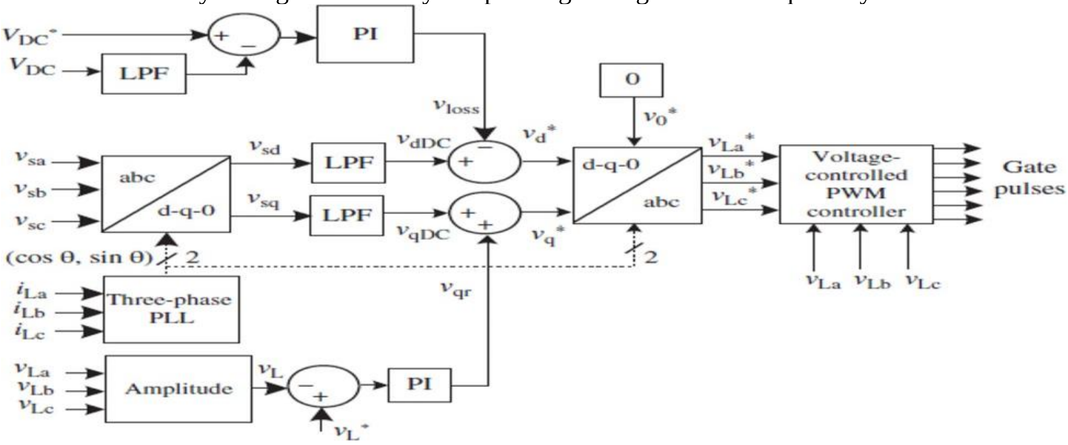

Fig. 3.1 DVR Control Technique for eliminating Voltage Harmonics

The networked artificial neural network (ANN) is composed of nonlinear components called neurons. Generally speaking, it is a collection of linked, extremely basic nonlinear pieces with the ability to adapt and learn. Neural networks' architecture, training methodology, environment-communication style, and information-processing capacity are among their primary features.

To optimize the DVR's performance attributes, a multi-layer neural network-based control system is created. Three layers make up the ANN-based controller: an input layer with one neuron, a hidden layer with twenty neurons, and an output layer with one neuron. The PI controller data are kept in the MATLAB workspace and are utilized for the offline training of the neural network controller. In this case, the input layer and hidden layers are activated using TrainLM, and the output layer is activated using pure linear. This study uses Levenberg Marquardt back propagation (LMBP) as its training algorithm.

The compensating performance of the ANN controller is determined by development and input. The chosen arrangement has two inputs and one output for the reference signal of the PI controller, the measured voltage of the dc connection, and both. Neural network training is carried out in order to obtain a reference signal (PI controller output). The received signal is sent to a hysteresis control in order to generate the required gating pattern.

4. SIMULATION RESULTS

MATLAB/SIMULINK is used to simulate the proposed DVR model. Two different control strategies have been simulated for the proposed system. The performance of the two controllers was simulated with MATLAB/Simulink. Fig.4 and fig.5 present the simulation results of conventional PI controller-based DVR for voltage sag and voltage swell.

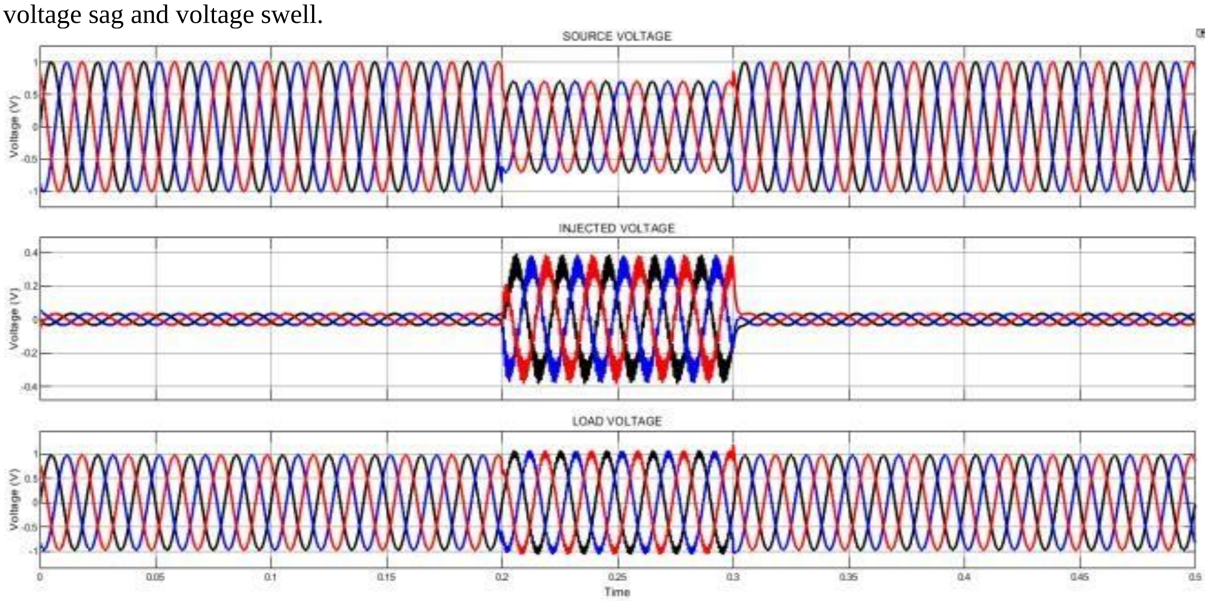

Fig. 4.1 DVR's Source, injected, and Load Voltages for a Voltage sag using a PI Vontroller

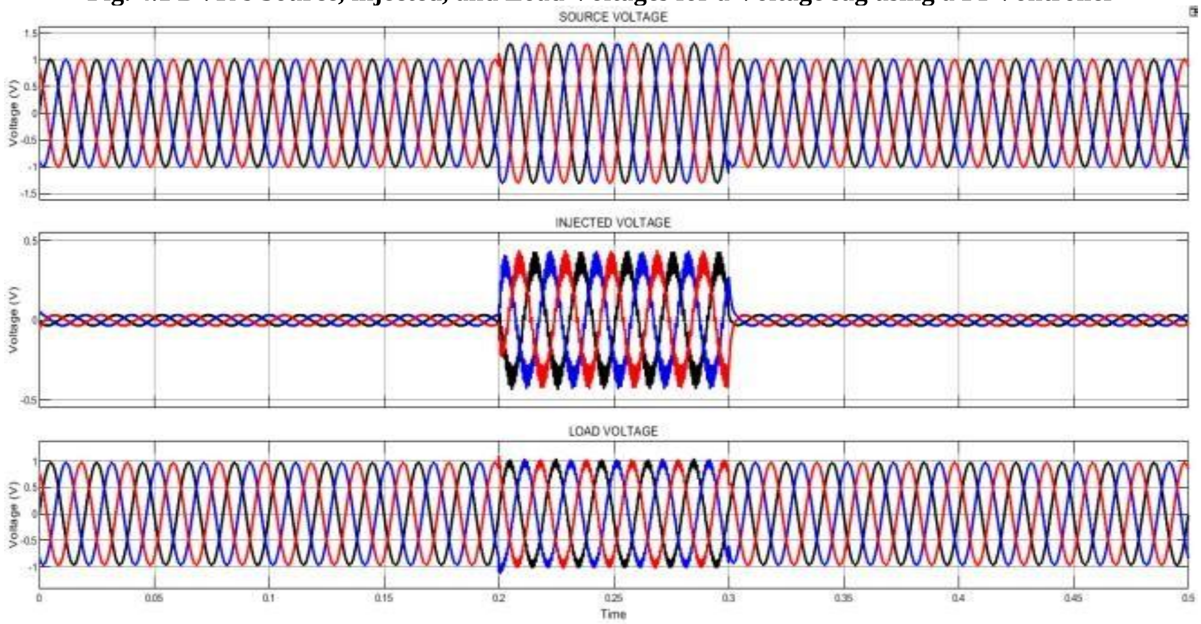

Fig. 4.2 DVR's Source, injected, and Load Voltages for Voltage swelling with PI Controller

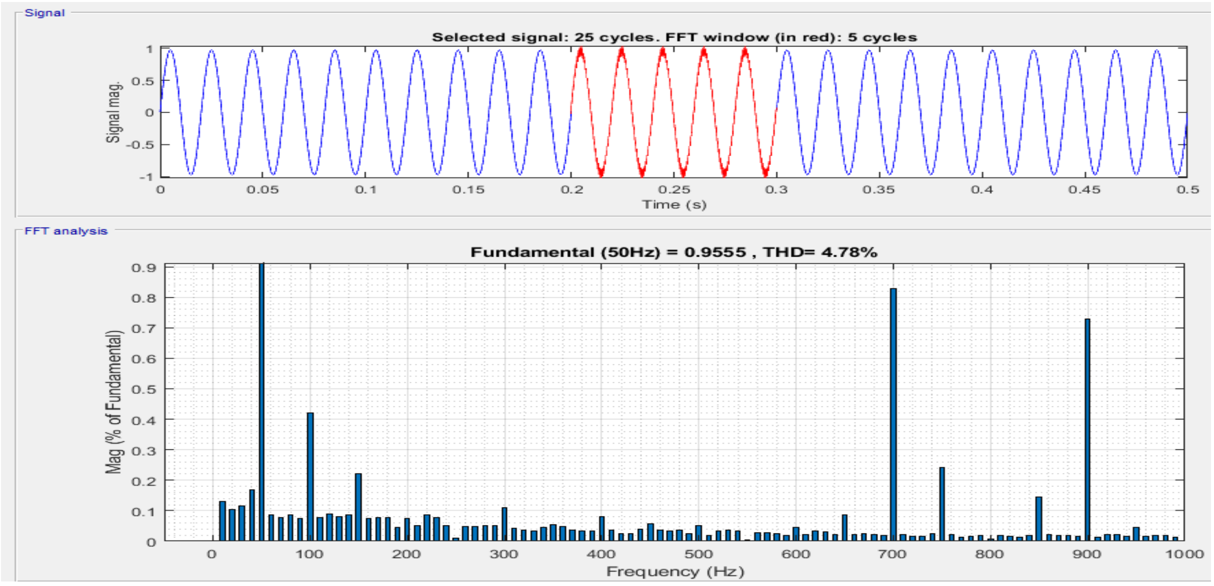

Fig. 4.3 The Load Voltage's THD% is 4.78%

In a similar vein, the simulated outcomes of an ANN control strategy-based DVR for voltage swell and voltage sag are shown in Figures 4.4 and 4.5. Figures 4.3 and 4.6 depict the Total Harmonic Distortion (THD) analysis of the DVR utilizing the PI and ANN control approaches, respectively.

The source, injected, and load voltages of the traditional PI controller-based DVR for voltage sag are displayed in Fig. 4.3. The necessary injected voltage via DVR employing PI controller compensates for the sag, which happens in the range of 0.2 to 0.3 seconds. The source voltage, injected voltage, and load voltage of the PI-based DVR for voltage swell are shown in Fig. 4.4. In this case, a voltage injection compensates for the observed voltage swell, which lasts from 0.2 to 0.3 seconds. Fig. 4.3 describes the THD% of the load voltage using the PI controller approach.

The source, injected, and load voltages of the ANN controller-based DVR for voltage sag are displayed in Fig. 4.4. The sag, which happens between 0.2 and 0.3 seconds, is made up for by injecting the necessary voltage in line via DVR and an ANN controller.

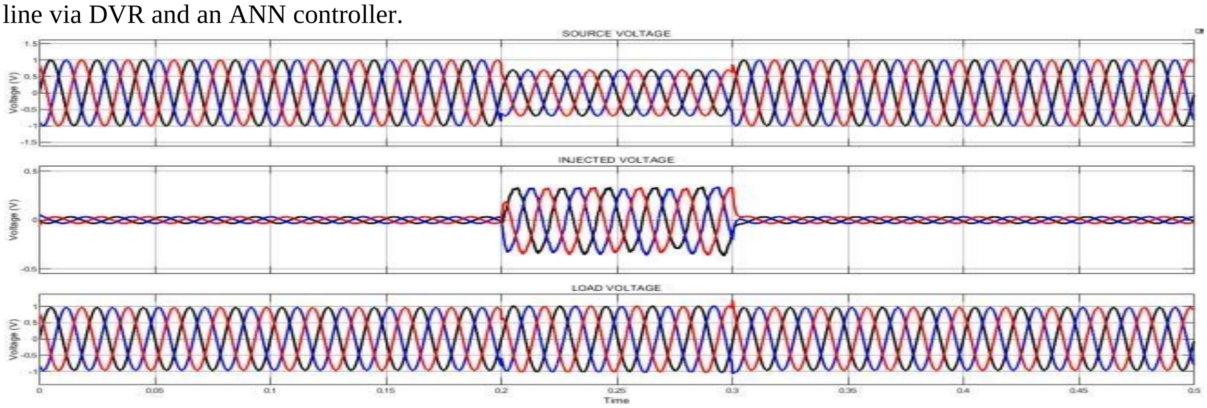

Fig. 4.4 DVR's Source, injected, and Load Voltages for a Voltage Sag using a ANN Controller

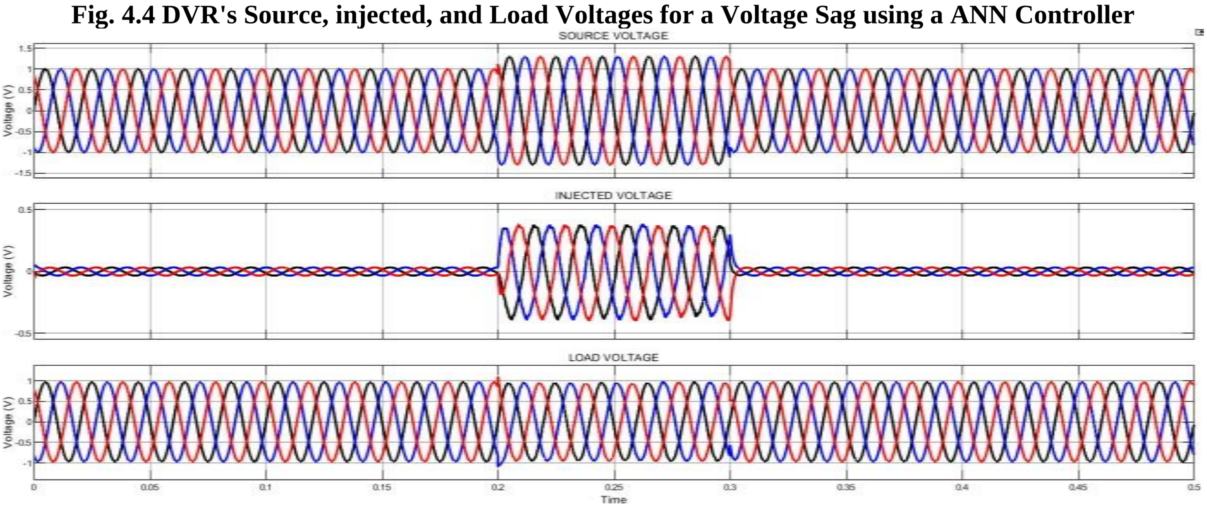

Fig. 4.5 DVR's Source, injected, and Load Voltages for Voltage swelling with ANN Controller

The source, injected, and load voltages of the ANN-based DVR for voltage swell are shown in Fig. 4.5. In this case, a voltage injection compensates for the observed voltage swell, which lasts from 0.2 to 0.3 seconds.
Figure 4.5 shows the THD% of the load voltage using the PI controller method, and Figure 4.6 shows the THD% of the load voltage using the ANN controller. The results of the simulation enable us to examine how well the ANN control scheme performs in contrast to the traditional PI control method.

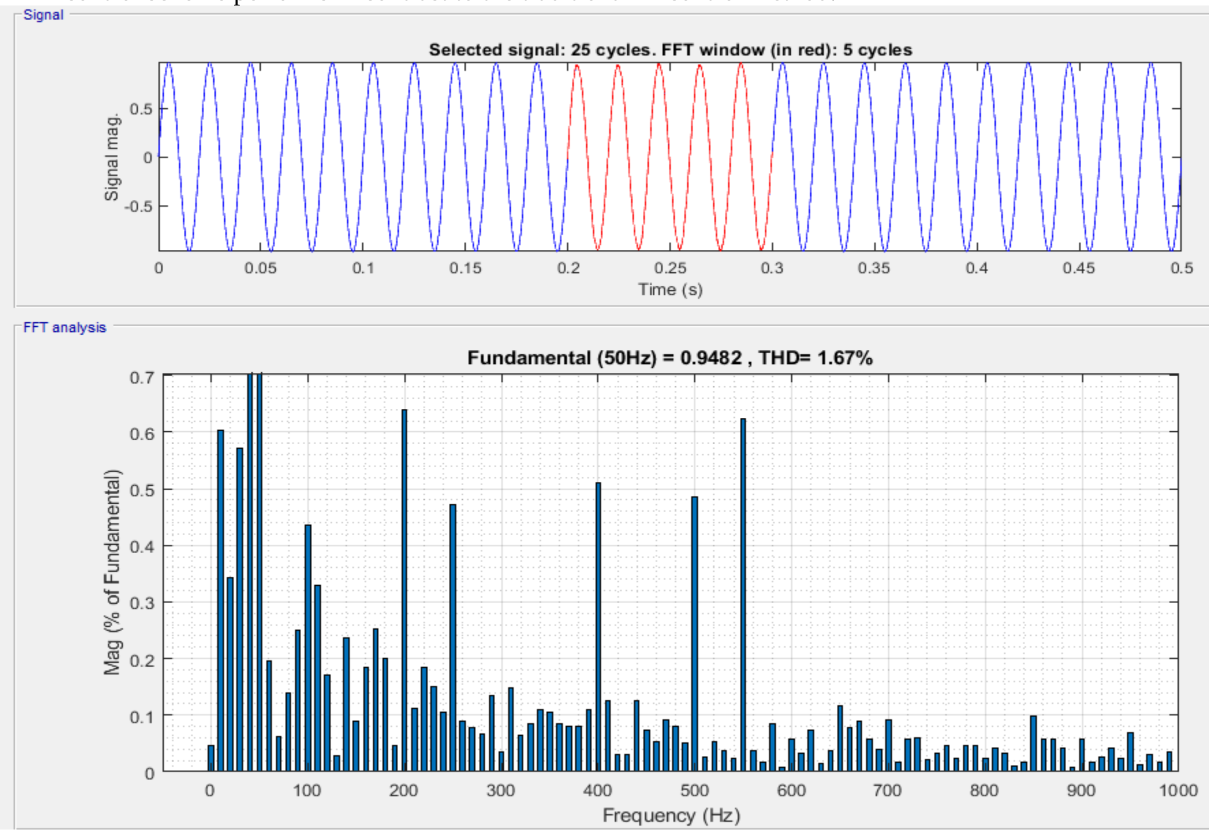

Fig. 4.6 The Load Voltage's THD% is 1.67%

CONCLUSIONS

DVR has shown to be a practical and effective tool for enhancing power quality. The DVR's design and functionality were described. This study shown that the ANN controller's THD is lower than the PI controller's. In contrast to the conventional controller, the ANN application to DVR was proposed in this paper for better performance in minimizing voltage sag and swell. The reference DVR voltages were estimated using the SRF theory. MATLAB/Simulink software is used to simulate the suggested system with a sensitive load. The simulation results during voltage disturbances demonstrate DVR performance. When the suggested approach was contrasted with the widely used PI controller, it was shown to be the most effective way to restore system voltage while largely lowering THD.

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