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ENHANCEMENT OF POWER QUALITY USING ARTIFICIAL NEURAL NETWORKS TO IMPLEMENT A DYNAMIC VOLTAGE RESTORER

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Abstract: Once Dynamic Voltage Restorer knows the precise voltage quality level that the customer needs, they has the ability to offer the least expensive method of reducing voltage dips. The distribution feeder and the DVR are connected in series at medium voltage. One typical method of controlling DVRs is via the PI controller. The traditional controller relies on fixed gains, namely the THD, to lower the THD, which is a restriction of the controller. It is possible to operate a DVR using an ANN. Based on PI and ANN Controller, this work investigates the compensation notion and various DVR control methods. A constant load voltage may be achieved by injecting voltage into the DVR, as shown in comprehensive studies and MATLAB/Simulink simulations.

IndexTerms **- Dynamic Voltage Restorer, PI Controller, Neural Network Controller.**

I. INTRODUCTION

After investing so much in fixing electricity quality issues, industries are understandably concerned about the future. Power quality issues including voltage sag, harmonic, and flicker are less common when there is a constant need for dependable power [1]. Voltage sag is a serious problem with power quality that occurs often. According to data from Tenaga Nasional Berhad (TNB) [2], voltage sag was linked to 80% of power quality complaints in Malaysia. Common reasons of voltage loss include short circuits, improper wiring, initiating heavy loads, and system malfunctions [3]. As a result, companies might anticipate lower output and financial setbacks. The primary priority should be to minimize voltage sag. Nowadays, voltage dips are among the most important power quality issues impacting power distribution networks. A voltage sag occurs when the power frequency momentarily falls below a certain level, often ranging from 0.1 to 0.9 p.u. of the normal voltage. This temporary dip could be fleeting, lasting just a few cycles or a few seconds at most. Voltage drops are usually caused by a three-phase failure, a single line-to-ground problem, or a double line-to-ground issue. [2] After investing so much in fixing electricity quality issues, industries are understandably concerned about the future. Because of the potential for voltage dip, harmonic distortion, flicker, interruptions, and blackouts, it is critical to have dependable power at all times. The growing reliance on extensive automation in almost all sectors of industrial operations has intensified the need to avert such tragedies. Because issues caused by intermittent outages could affect production costs, a dependable power source is essential. There are several methods for dealing with voltage drops. Dynamic Voltage Restorers is another option to consider. Power loss detection, voltage compensation calculations, and reference voltage creation are all responsibilities of the digital video recorder's (DVR) central processing unit (CPU). The PWM generator then uses this reference voltage to activate the PWM inverter. The DC0-transformation, PI/FL/ANN, and PLL controllers are only a few of the components of the control system. When it comes to controlling plants, artificial neural networks (ANNs) learn control using activation functions and back propagation methods, while PI controllers (feedback controllers) use a weighted sum of the error and the integral of that value.

II. LITERATURE SURVEY

[1] " R. E. Nambiar, M. Darshan, B. Lavanya, A. J. Pavan Kumar, and V. Priyadarshini wrote the paper "Comparative Study Between Different Controllers of DVR For Power Quality Improvement" that was presented at the 2021 International Conference on Design Innovations for 3Cs Compute Communicate Control (ICDI3C) in Bangalore, India, June 2021. You may find the document between pages 84 and 87.

Because of their sensitivity to fluctuations in power quality, modern consumer and commercial electronics are especially at risk when crucial load protection is inadequate. One approach to lowering One solution to problems with power quality is to install bespoke power devices that link to the grid. Essential loads must be protected from voltage-related power quality issues by use of a "dynamic voltage restorer" (DVR). In order to protect the whole group from power supply reliability difficulties, DVR can detect and compensate for continuous decreases in the applied AC voltage. This study evaluates and analyzes two DVR control strategies: the ANN and the proportional integral controller (PI).

[2] "A Comprehensive Study to Mitigate Voltage Sags and Phase Jumps Using a Dynamic Voltage Restorer" was written by C. Tu, Q. Guo, F. Jiang, H. Wang, and Z. Shuai and was published in the June 2020 issue of the IEEE Journal of Emerging and Selected Topics in Power Electronics. This excerpt is taken from that article.

An innovative method for improving the voltage quality of sensitive loads by making optimal use of a dynamic voltage restorer (DVR) is presented in this paper. In the past, control strategies aimed at reducing the energy storage device's or DVR's voltage rating mostly targeted the voltage compensation phase. More and more people are opting to have the phase jump correction performed at the beginning of the compensation procedure. There is a lack of information on the safe exit procedure for a DVR after the vulnerability has been fixed, despite the fact that it is crucial to avoid compensation process phase leaps. These jumps might occur at any moment. By using energy-optimized compensation techniques, this study demonstrates how to improve the total sag compensation time while minimizing the phase leap in the load side voltage. By minimizing phase jump and enhancing overall sag compensation, we can shorten the total sag compensation time and provide a seamless transition between the transient process's voltage compensation and recovery phases. The two main points covered are these. 2) In order to prevent the system from overheating, we compare and identify the constraints of the operating modes in both stages. We inject a fresh reference voltage to activate the better approach.

[3] " This article "Recent Trends in Power Quality Improvement Using Custom Power Devices and Its Performance Analysis" delves into the years 2020–2021, and it was published in the Turkish Journal of Computer and Mathematics Education (doi: 10.17762/turcomat.v12i7.3052), pages 1686–1695.

Disturbances from the nominal frequency and standard voltage levels are indicators of power quality. Voltage, current, or frequency variations caused by power outages or by consumer devices being used incorrectly are considered power quality problems in the viewpoint of the customer. Each custom power device is described in depth, along with how to set it up and what it mostly does, in this page. Due of the abundance of devices that have the potential to address power quality concerns, researchers are concentrating on power electronics-based novel solutions. By using power electronics, "custom power" means modifying the power distribution system to meet the unique requirements of an individual or several clients. Some of the specialized power devices covered in this research are Distributed Static Compensator (DSTATCOM), Dynamic Voltage Restorer (DVR), and Unique Power Quality Conditioner (UPQC). The MATLAB Simulink studies that we conducted to determine each device's potential as a tailored power solution are outlined here.

[4] "Performance analysis of various soft computing controller-based dynamic voltage restorer," published in the 2019 edition of the International Journal of System Control and Communications, by Kohila, Kannan, and Muthu Kumar (vol. 10, no. 3, pp. 265-280).

Important current user power devices (CUPDs) for addressing power quality issues in the present day include the unified power quality conditioner (UPQC), distribution static compensator (DSTATCOM), and dynamic voltage restorer (DVR). The use of DVR allows for the rapid restoration of the load voltage and the correction of voltage sag issues. The control mechanism and algorithm determine the DVR's performance. An ANFIS controller based on synchronous reference frame theory (SRFT) is suggested in this work. We use MATLAB/Simulink to evaluate the suggested control approach in several failure situations, such as line-to-ground, double-line-to-ground, and three-phase failures. The simulation results show that the DVR based on ANFIS is beneficial for reducing harmonics and voltage sag.

[5] A novel decentralized control scheme for a dynamic voltage restorer based on elliptical trajectory compensation was proposed by Li, Xie, Han, Pang, and Li, 2016 (Li et al.). Journal of Industrial Electronics and Systems, 2017.

The objective of this research is to find a way to free loads by improving their voltage quality. A new method of distributed control for dynamic voltage restorers is suggested to accomplish this. The suggested method employs elliptical correction and instantaneous voltage and current computations to achieve low-voltage ride-through by adjusting the injected voltage's amplitude and phase angle. Using two parameters in a system of extended equations with symmetric-sequence components, the active and reactive powers may be discretely controlled. The technique may also provide a theoretical methodology with clarity and a multitude of choices by adjusting the status factors. Both of these components add an external voltage to the system in an effort to inject powers in a positive and negative sequence; one raises the phase voltage and the other equalizes it. Reference generators with variable voltage support and ride-through capabilities are also suggested with a control approach. In MATLAB simulations, the suggested control strategies are able to quickly restore voltage after a drop.

III. PROPOSED SYSTEM

Distributed voltage regulators (DVRs) are devices that control voltage by injecting the necessary voltage by switching its power electronics. They are designed to be linked in series with the distribution line. Figure 1 shows the grid connection and the generalized DVR model. A DVR is a control system that also serves as an energy storage device. A boosting injection transformer is used to connect a VSC in series with the grid.

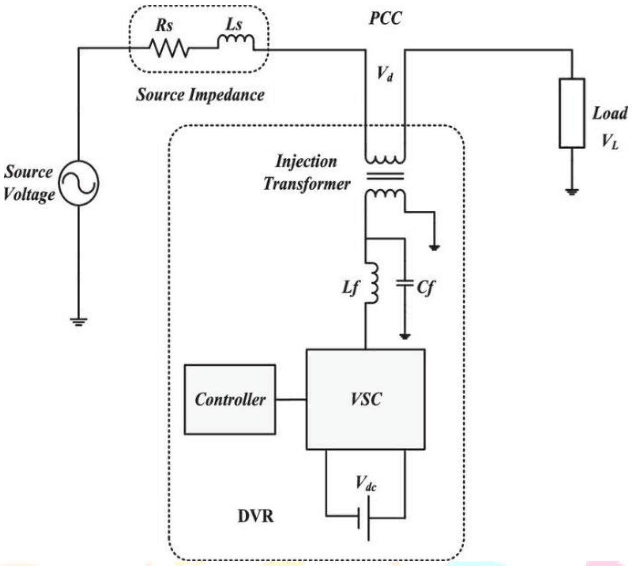

Figure 1 Generalized single line model of DVR in the distribution network.

To generate the required voltage rating, the voltage source converter typically uses a network of converters connected in series. The DVR may inject the required magnitude and phase into each phase as a voltage at the fundamental frequency. The DVR may be used in two ways. One mode is standby, which goes by a several names: SCO mode, zero-volt injection, and so on.

Boost: In order to rectify the load bus voltage, the DVR applies a voltage with the correct magnitude and phase to its pre-fault level throughout this operation. The four parts shown in Figure.1 constitute the DVR's power circuit, which are detailed below.

3.1 Voltage Source Converter (VSC)

There are two options for three-phase VSCs here: one with three wires and one with four. The second one makes it possible to implement voltages with zero sequence. On the other hand, you may utilize a three-level converter or the more common two-level converter (Graetz Bridge).

3.2 Boost or Injection Transformers

By connecting the distribution feeder in series with three single-phase transformers, the voltage drop between the VSC and distribution voltage may be bridged. This setup is compatible with all three varieties of single-phase transformers: star, open star, and delta. The latter cannot be used to inject the zero-sequence voltage. Which injection transformer winding is utilized is determined by the connections of the load-supplying step-down transformer.

3.3 Passive Filters

Both the converter side and the high voltage side are viable options for where to locate the boost transformers' passive filters. One benefit of using converter side filters is that they lower the voltage ratings of the components. Another advantage is that they prevent the higher-order harmonic currents produced by the VSC from entering the transformer windings. One drawback is that the injected voltage loses voltage and has a phase shift due to the filter inductor. The schematic of the DVR's command and control system is shown here. One way to get around the problems and get better ratings is to put the filter on the transformer's high voltage side. In this way, high-frequency currents may flow through the windings, and the transformer's leakage reactance can serve as a filter inductor.

3.4 Energy Storage

To maintain power to the load in the case of a sharp voltage drop, this is required. Lead acid batteries! A second possibility is to provide the VSC with the DC power it needs by means of an auxiliary bridge converter, which may take power from an additional AC source.

3.5 By-Pass switch

A set of devices are linked to record footage. If there's an issue farther down the line, you may create a fault current by sending current via the inverter. To prevent damage to the inverter, use the bypass switch. To avoid the inverter circuit, a crowbar switch is often used. Lastly, the crowbar would be used to disable the inverter whenever the current reached a certain threshold. On the other hand, a strong current can potentially bypass the inverter's components.

IV. CONTROL TECHNIQUES OF DVR

The load voltage is raised to a pre-sag level while the supply voltage is constantly monitored. However, a higher DVR rating is often necessary for this approach to supply (almost) constant load voltage. Thus, VS = VL = Vo just before a sag. When the voltage drops, the supply voltage to VS1 also drops. Refer to Figure 5.2 for a graphical depiction of the possible shift in the phase angle of the supply. The DVR injects VC1 to maintain phase relationship between VS1 and Vo, which is proportional to the sum of VS1 and VC1, the load voltage. It is critical to address both of these concerns because certain loads may be very phase-jump sensitive.

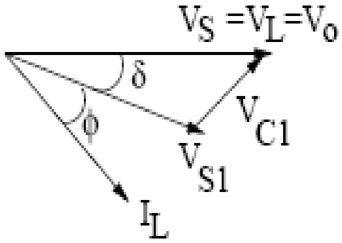

Figure 2 Pre sag phaser diagram.

4.1 In-phase Compensation

Regardless of the load current or the pre-sag voltage (Vo), the DVR maintains voltage phase with the supply voltage at all times. Minimizing the injected voltage amplitude is the goal of this control strategy. However, the phase of the load voltage is an important consideration. This control style makes use of voltage rating of the DVR for loads that are not phase jump sensitive. Neither of these methods will cause the DVR to use zero power.

4.2 DVR control system

In Figure 1, we can see a DVR control block that uses SRF theory to estimate the reference signal. The IGBT gate signals are determined by comparing the voltages at the PCC Vs and the load terminal V_{Lare}. Using the calculated unit vector is one approach to get the reference load voltage V*L [23]. A process similar to the abc−dqo conversion is used to transfer the voltages at the load points (V_{La}, V_{Lb}, V_{Lc}) into the reference frame for rotation utilizing unit vectors (sin, θ, cos, θ) that are generated from a phase-locked loop.

$$\begin{bmatrix} V_{Lq} \\ V_{Ld} \\ V_{Lo} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \cos\left(\theta + \frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta - \frac{2\pi}{3}\right) & \sin\left(\theta + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} V_{Laref} \\ V_{Lbref} \\ V_{Lcref} \end{bmatrix} \qquad (1)$$

Also, voltages used as a reference for the load

Additionally, the reference frame of rotation is used to convert the PCC Vs voltages. Next, the reference frame, which is in a perpetual state of motion, is used to compute the DVR voltages.

$$V_{Dd} = V_{Sd} - V_{Ld} \qquad (2)$$

$$V_{Dq} = V_{Sq} - V_{Lq} \qquad (3)$$

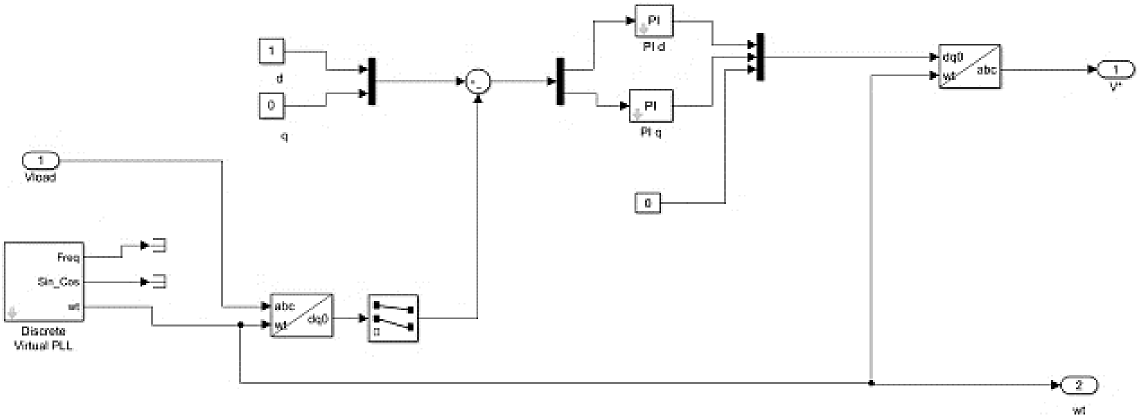

Figure 3 Control block of the DVR that uses the SRF method of control.

4.3 Proportional-Integral Controller

As shown in Figure 4, the PI Controller is a kind of feedback controller that manages the plant by combining the integral of the error with a weighted total. One way to change the proportional response is to multiply the error by a constant KP, which is also called proportional gain.[9] The worse the inaccuracy and the longer it lasts, the more important the integral term is. To get the corrected offset, multiply the initial error by the integral Gain, Ki, and then integrate the result.

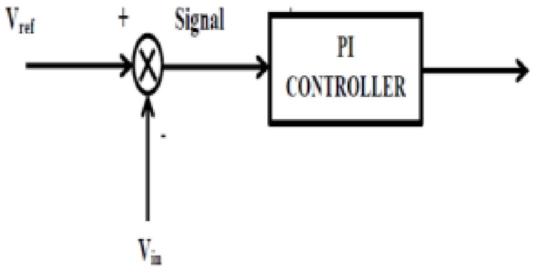

Figure 4 Typical Structure of PI control.

4.4 ANN Controller

The compensatory device's performance is enhanced with the help of a multilayer back propagation ANN controller. Students learn ANN with the help of a MATLAB toolbox. The ANN controller makes use of a training technique known as Levenberg Marquardt. Compared to gradient descent and the Gauss-Newton technique, back propagation is superior. Among the several benefits of the Levenberg-Marquardt back propagation approach are faster convergence, lower memory needs, and competent learning [9]. Every one of the ANN's training variables are taken straight from the traditional PI controller. The three-layer artificial neural network controller was built with two input levels, ten hidden layers, and one output layer. The ANN controller takes as inputs everything that changes in the error signals from the d and q coordinate systems, as well as the difference between the actual and reference values. The main goal of an ANN controller is to minimize error. The procedure of converting dqo into abc components is rendered as an output by the ANN controller. Figure 5 displays the mean square error, a performance measure for the ANN controller. The difference between the intended and actual values is symbolized by this.

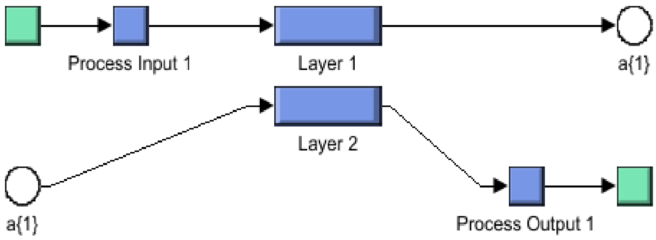

Figure 5 Typical Structure of ANN control.

V. SIMULATION RESULTS

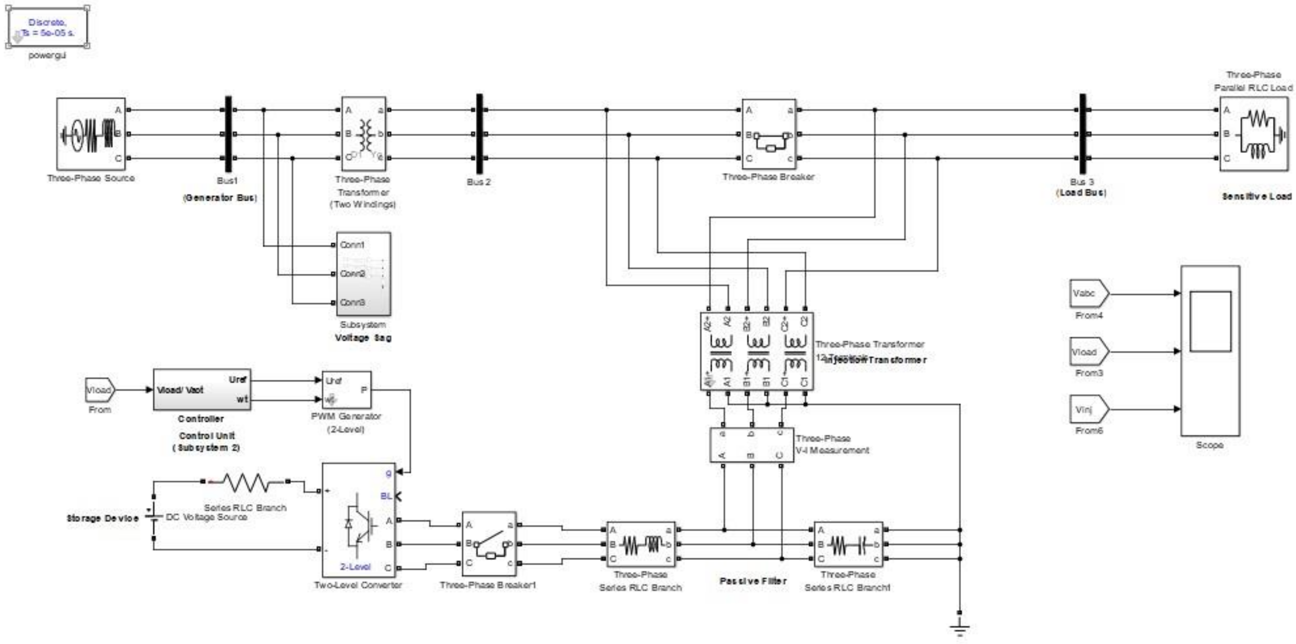

Figure 6 MATLAB/SIMULINK circuit diagram of the proposed system.

5.1 Proportional-Integral Controller

The error signal is sent to the PI controller after the load voltage is transformed into a dq term and compared with the reference values. Separate PI controller blocks handle error signal-d and error signal-q, as seen in Figure 7 [9].

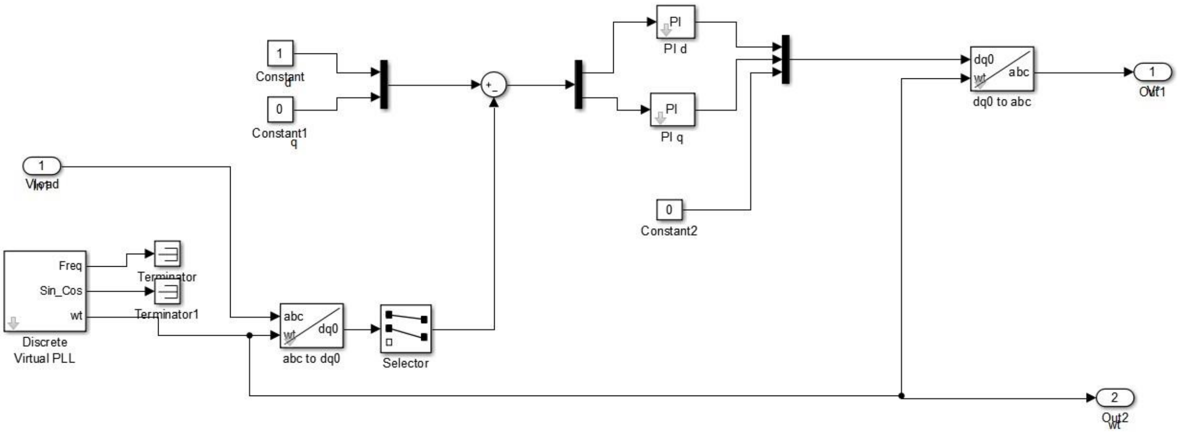

Figure 7 Schematic for a PI Controller Simulation

Below Figures 8, 10, 12, 9, 11, and 13, you can see the waveforms of the PI controller's output, together with the source voltage, load voltage, and injected voltage of the DVR. These are shown with sag, swell, and Three Phase Fault.

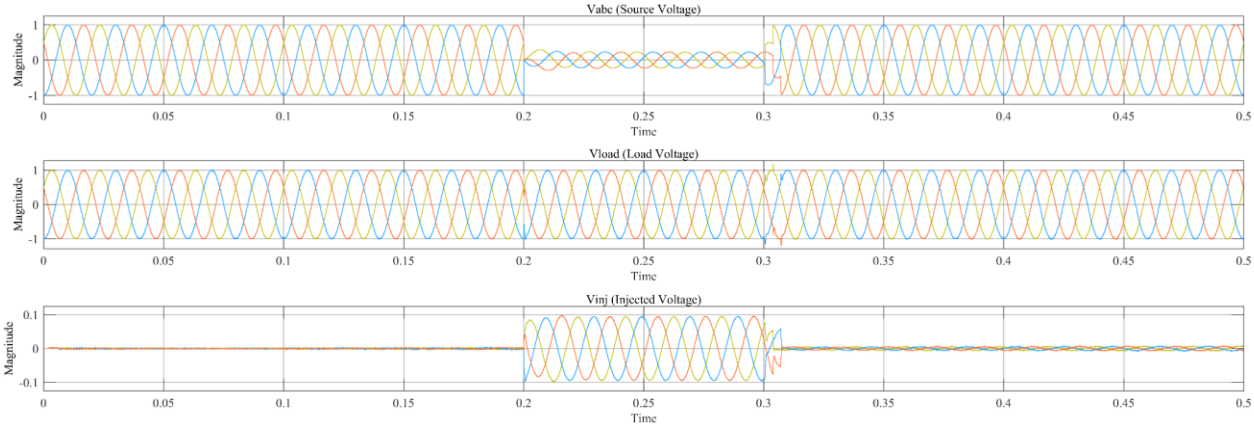

Figure 8 In the event of voltage sag the source voltage, load voltage and injected voltage.

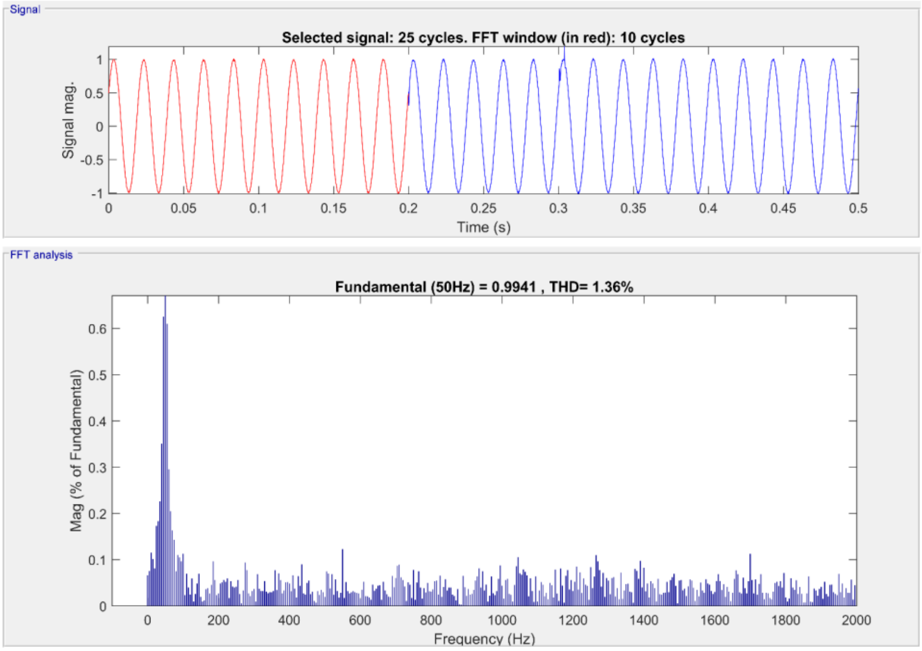

Figure 9 The THD value, as measured with the PI controller, is 1.36%.

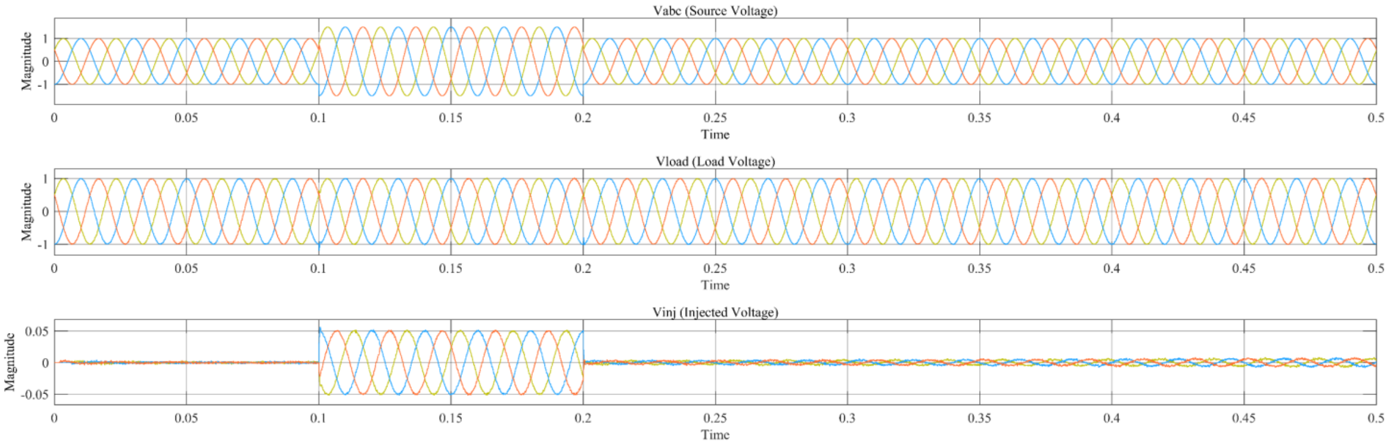

Figure 10 In the event of a swell the source voltage, load voltage and injected voltage.

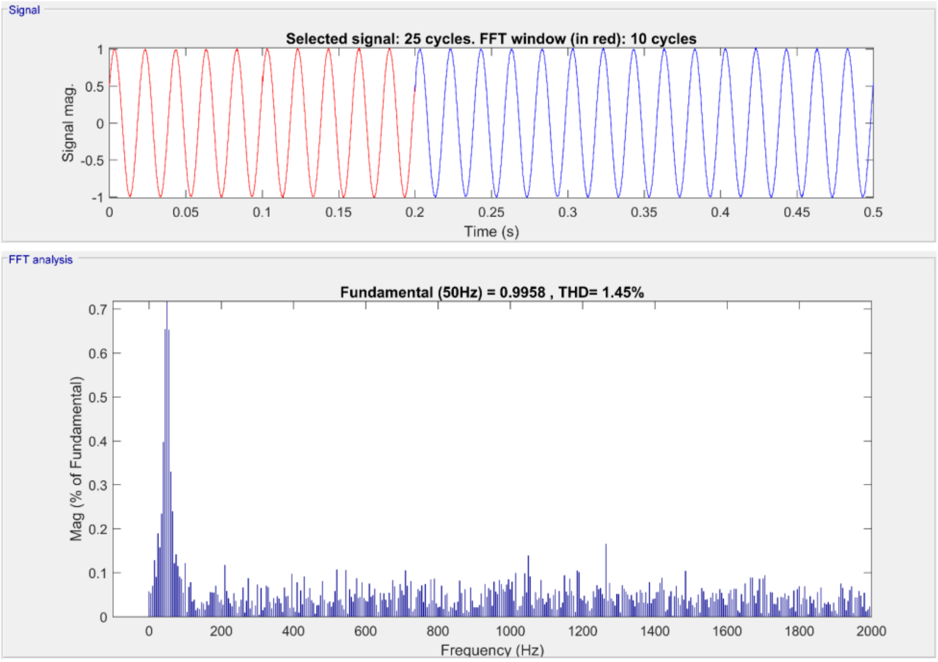

Figure 11 The calculated THD with the PI controller is 1.45%.

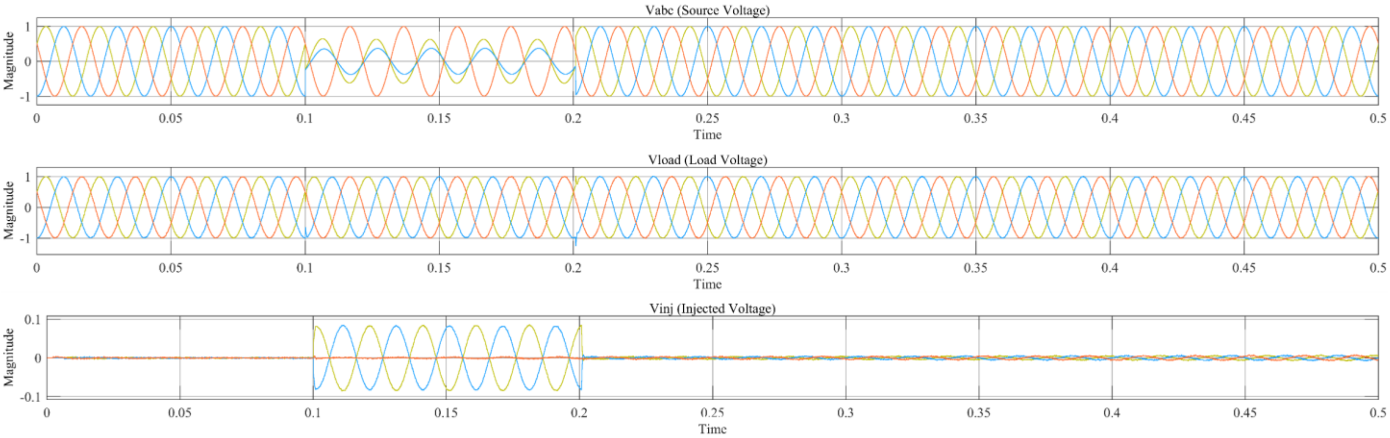

Figure 12 Under Fault condition the source voltage, load voltage and injected voltage.

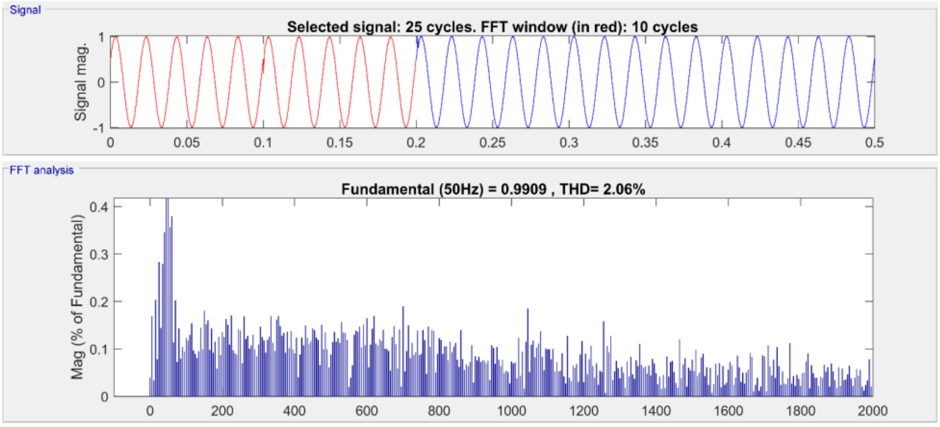

Figure 13 THD value is 2.06% is obtained with PI controller.

5.2 With Neural Network Controller

The controller of a neural network is shown in the simulation diagram (Fig. 14). The voltages at the DVR's source, load, and injection points for sag, swell, and the Three Phase Fault Figures 15, 17, 19, 18, and 20 below show the ANN controller's output waveforms and total harmonic distortion (THD) of the load voltages.

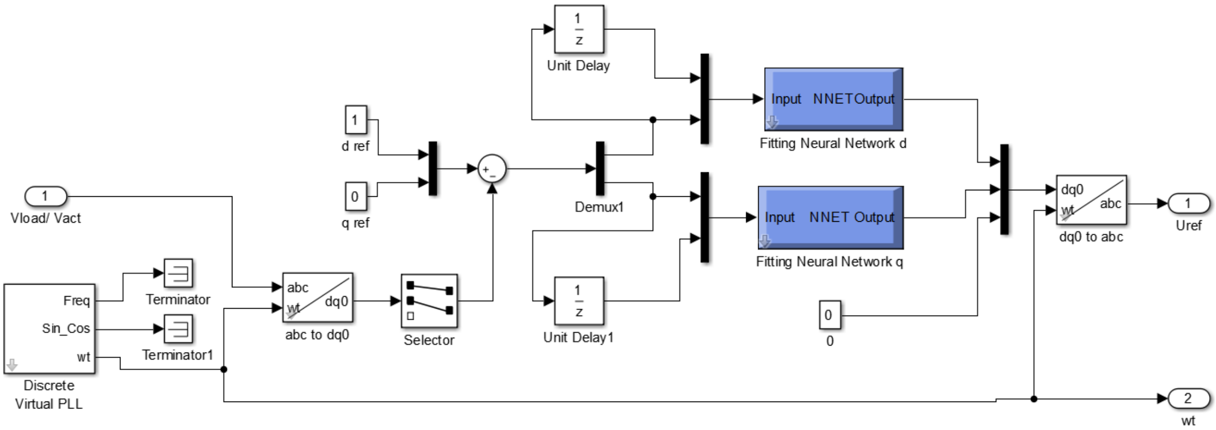

Figure 14 Simulation Diagram of an ANN Controller.

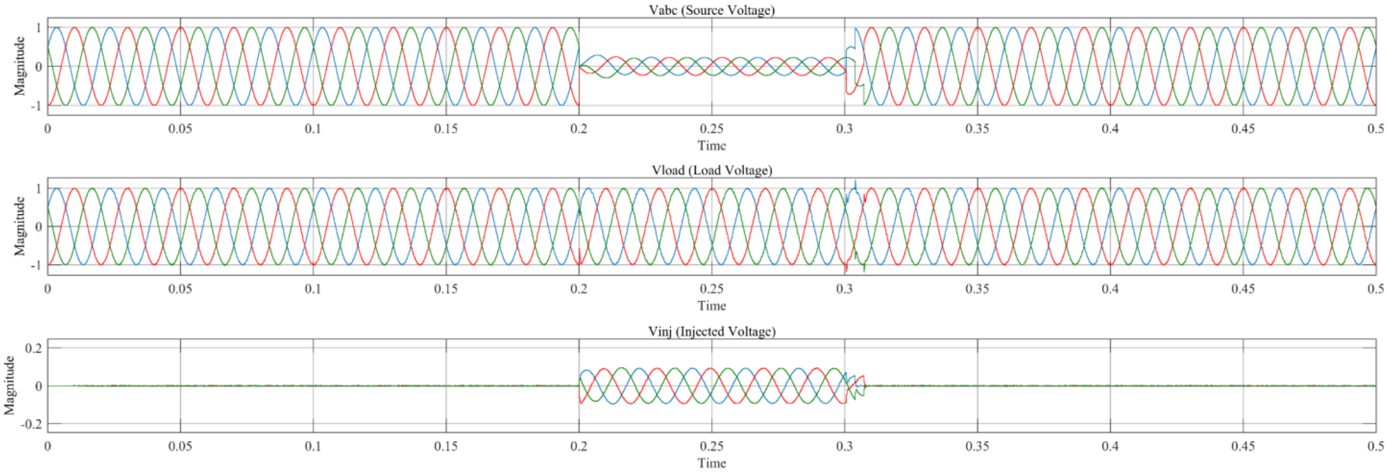

Figure 15 Under Sag condition the source voltage, load voltage and injected voltage.

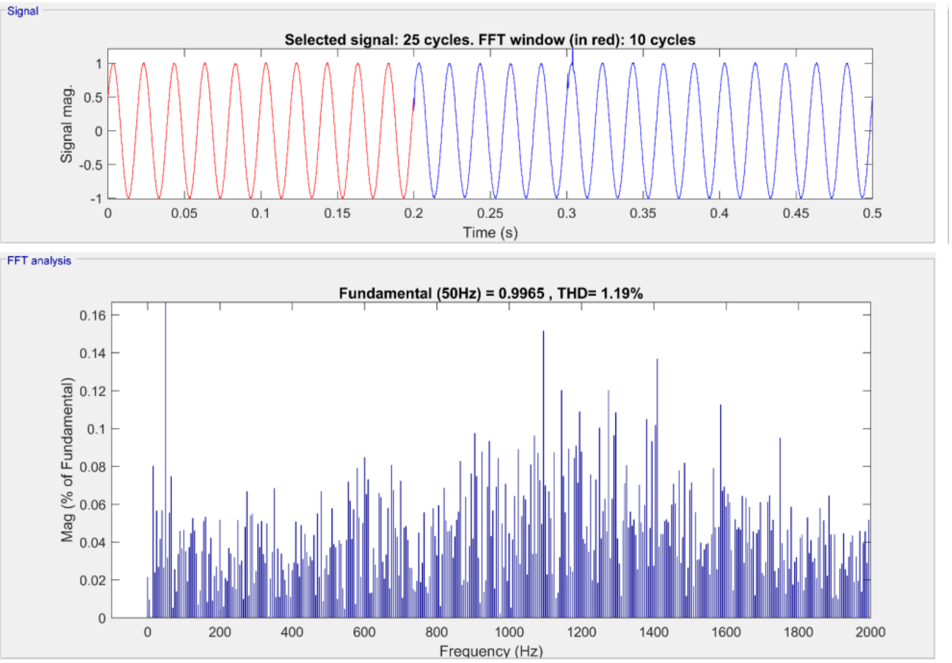

Figure 16 THD value is 1.19% is obtained with ANN controller.

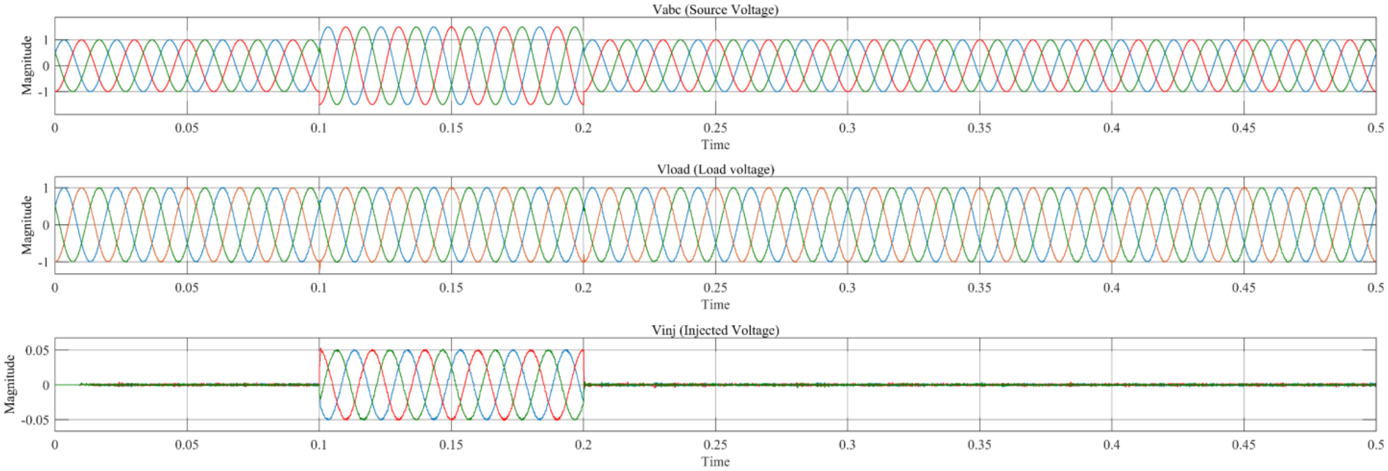

Figure 17 Under Swell condition the source voltage, load voltage and injected voltage.

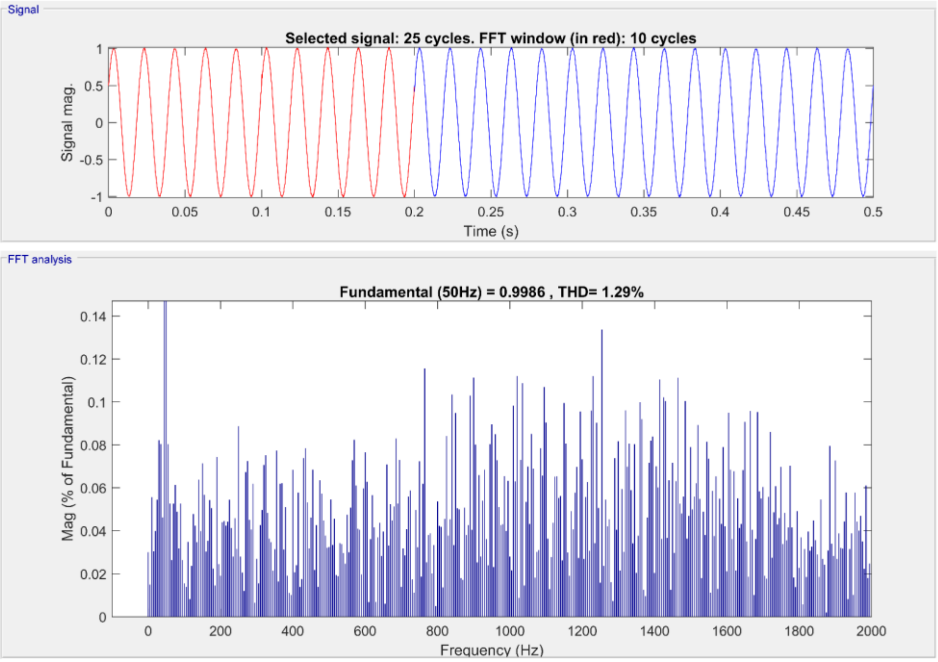

Figure 18 THD value is 1.29% is obtained with ANN controller.

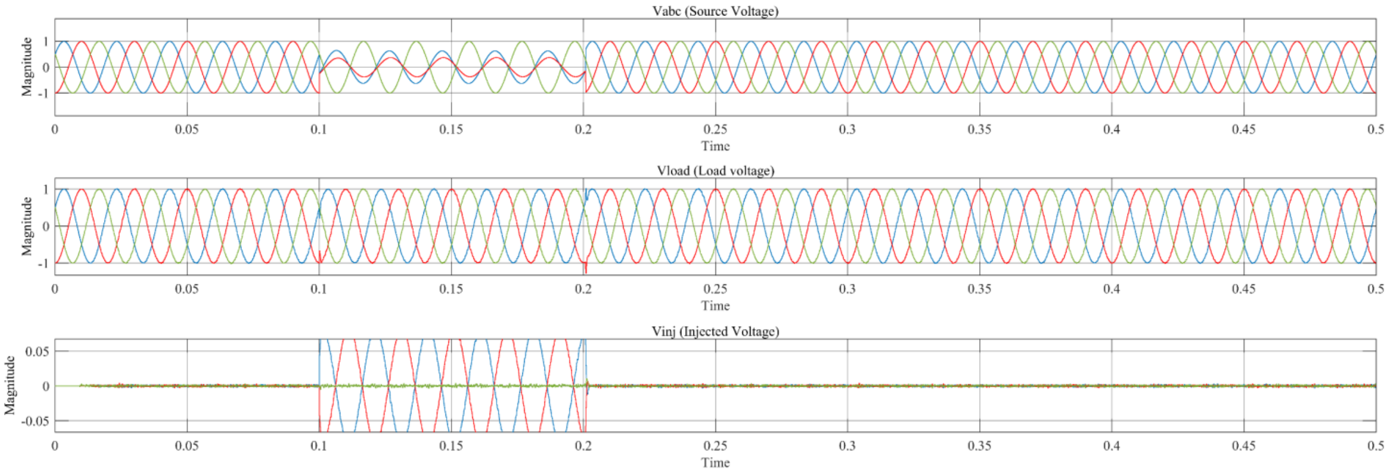

Figure 19 Under Fault condition the source voltage, load voltage and injected voltage.

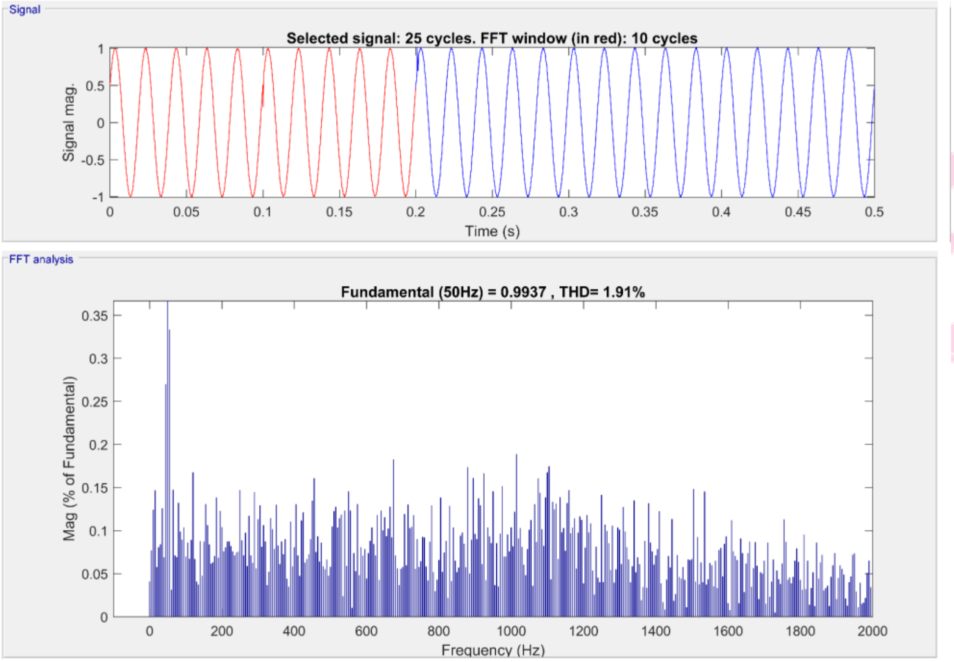

Figure 20 THD value is 1.91% is obtained with ANN controller.

5.3 Comparison Table

Table 1 comparative analysis of PI controller and ANN controller

	PI Controller	**ANN Controller**
Load Voltage THD% under sag condition	1.36%	1.19%
Load Voltage THD% under swell condition	1.45%	1.29%
Load Voltage THD% under fault	2.06%	1.91%

VI. CONCLUSION

In this work, we provide a simple and inexpensive dynamic voltage restorer (DVR) to fix voltage dips, sags, and other fault situations in industrial distribution systems, especially for systems that carry critical and sensitive loads. Research on various load cases was carried out at this site. According to the results, DVR enhances the power quality of the system with sensitive and critical loads by reducing total harmonic distortion (THD) and the amount of voltage imbalance in the load. Not only do we prove that the DVR using PI and the Neural Network controller operate well under linear static load, but we also find that the Neural Network controller performs better than the others in a number of failure situations.

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DECLARATION OF CONFLICTING INTERESTS

The authors declare no potential conflicts of interest with respect to the research and publication of this article.

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