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Power Quality Improvement Using ANN Controlled Dynamic Voltage Restorer

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ABSTRACT:The power electronics-based converters provide smooth and easy controlling features. So their uses is increased speedily in various fields day by day. As many power electronics converters are the non-linear types of nature, it introduces harmonics and certain non-linearities in the supply system. Due to such harmonics and non-linearities, power quality of supplied electrical waves like voltage and current is get affected. If such distorted electrical waves are provided to a certain application, it causes heating and mal-functioning of a certain application. Because of the increased number of modern sensitive and sophisticated loads connected to the distribution system, power quality has become a major matter of concern in the modern era. Voltage sag, swell, transient, and disturbances are some of the power quality issues which occur in a system. Thus, it becomes necessary to implement a device in a system which has capability to overcome or compensate the certain non-linearities. These power quality issues concerned with the voltage wave can be overcome with the help of one of the most effective custom power devices named Dynamic Voltage Restorer. In this paper, a simulink model of Dynamic Voltage Restorer for overcoming the power quality issues related to voltage wave is proposed. Here in this paper, the operation of Dynamic Voltage Restorer is controlled using ANN controller, and all the results are validated on Matlab/Simulink platform and comparative analysis with PI-controlled Dynamic Voltage Restorer is carried out.

KEYWORDS: Power Quality, Dynamic Voltage Restorer (DVR), ANN, Active Power Filter.

I.INTRODUCTION

Over many years ago, power systems evolved into one of the complex networks found in human history. With increasing consumer demand, modern power grids are now growing in huge structures with various interconnected regional grids owned and operated by Power Corporation of all height and layers. Because of the close attention towards to the management and operation between the various power companies, regular interregional transmission is complicated and the long-time leads to insufficient coordination, which makes the power supply inefficient. Therefore, today's world's existing power grids face some future challenges [1][2].

As the categories of demand and consumption increase, a wide variety of modern technologies, including electrical components, charging systems, decentralized renewable energy generation, smart meters, etc. Increasing reliance on power every day puts higher demands on power quality, requiring flexible pricing, especially better power delivery than faster power recovery. The demand for electrical energy is increasing rapidly, so the quality of energy available to consumers has become a major issue. With the development of semiconductor device technology, the use of high-tech equipment/loads at the level of transmission and distribution is increasing significantly in recent years [3][4][5].

A clean power supply is required for the equipment to work properly. At the same time, the switching operation of these devices produces harmonics of current and pollutes the distribution system. Power electronics-based devices are used to overcome major power quality issues. Power electronics-based converters provide smooth and easy control functions. Therefore, every day the applications in various fields are increasing rapidly. Many power electronics converters are of the natural non-linear type which causes harmonics and certain non-linearities in the supply system. These harmonics and non-linearity affect the power quality of the supplied energy waves, such as voltage and current [6]. When these distorted waves are provided to a specific application, it causes heat generation and malfunction of the specific application. As the modern sensitive and sophisticated loads connected to distribution systems have increased, power quality has become a major concern of our time [7][8].

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Normally, the use of a custom power supply is effective as there are several ways to mitigate power quality issues regarding voltage drops and rises. The term custom power specifically means the use of power electronics controllers in distribution systems to handle a variety of power quality issues. There are different types of custom power device techniques that can be used to mitigate voltage quality issues. This includes APF (Active Power Filter), BESS (Battery Energy Storage System), DSTATCOM (Distribution Static Synchronous Compensator), DSC (Distribution Series Capacitor),Dynamic Voltage Restorer (DVR), Surge Protector (SA), Superconducting Magnetic Energy System (SMES), Static Electronic Tab Changer (SETC), Solid State Changeover Switch (SSTS), Solid State Error Current Limiters (SSFCL) are Static Var Compensators (SVC), Thyristor Switch Capacitors (TSC) and Uninterruptible Power Supplies (UPS). Out of the above mitigation methods Dynamic Voltage Restorer (DVR) is considered to be the most effective due to its small size and low capital/maintenance costs[9][10].

DVR is connected between the supply grid mains and load in series configuration through a series-connected linear transformer. DVR comprises of DC energization source, bridge inverter, filter circuit, and series-connected linear transformers. It senses the power quality issues subjected in the voltage wave of supplied power. When certain non-linearities are occurs in supplied voltage, DVR injects voltage into the line so that, uniform rated distortion less voltage is provided to load. The phasor diagram for operation of DVR is as shown in Fig.1. For under voltage/ voltage sag condition injection of voltage is in phase with the supplied voltage. So that, this voltage is getting added into supplied voltage nominal rated voltage level can be maintained. For the overvoltage conditions, injection of voltage is in opposite phase with the supplied voltage, so that excess voltage level get cancels out and voltage level brings up to nominal level [11].

In this paper, a novel topology/structure of ANN controller-based Dynamic Voltage Restorer (DVR) provided for power quality (PQ) compensation is proposed. This topology/structure provides a 3-phase system with a series transformer in each phase where the power supplied from the utility is a three-phase three wire (3P3W) and it is also used for energization of a compensating device DVR.

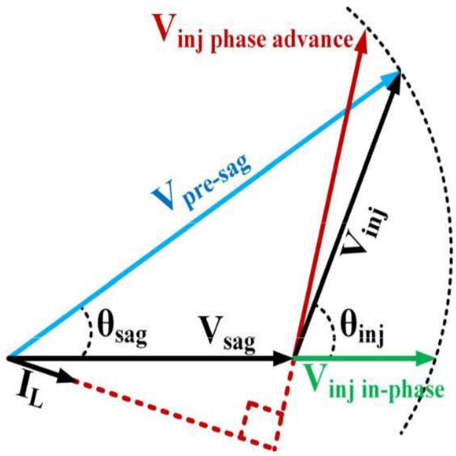

Fig.1 Phasor diagram for voltage sag compensation

$$|V_{inj}| = |V_{pre-sag}| - |V_{sag}| \quad (1)$$

$$\angle V_{inj} = \theta_{inj} = \theta_{sag} \quad (2)$$

II. SYSTEM DEVELOPMENT

The block diagram for a proposed system simulink model of ANN controlled DVR is as shown inFig. 2.

The system is designed for three-phase systems. The system consists of a series-connected Dynamic Voltage Restorer circuitry connected to a common DC bus. Series injecting transformers are used here to inject the voltage generated by the ANN-controlled Dynamic Voltage Restorer into the grid under various abnormal Power Quality issues such as voltage sag and voltage swell. Ripple filters are used to filter the harmonics produced by the switching

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operation of the converter. The load used is a non-linear load consisting of a supply voltage, a bridge rectifier with a load.

A. Series Connected Transformer

The primary function of the series voltage transformer used in the secondary distribution system is to increase the supply voltage from the output of the AC line filter to the desired nominal voltage level required for the customer load and in the event of a quick disconnection of the DVR from the mains failure to protect the DVR system from damage. For the DVR to fully compensate for the deficit, the secondary of the series transformer must be equal to the mains voltage and must be properly connected to the utility grid.

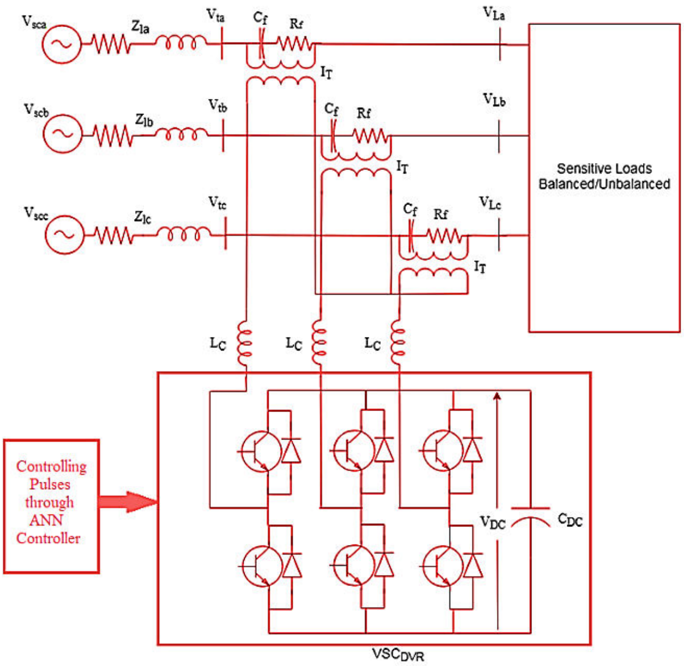

Fig.2 Block diagram for proposed system

B.AC Filter

Filters are mainly used to reduce or eliminate switched harmonics generated by a series voltage inverter system. This is to maintain the standard harmonic distortion of the sinusoidal voltage signal applied to the series voltage transformer.

C.DC Supply Unit

It supplies the energy source after voltage fluctuation and fluctuation reward events and also keeps the DC link voltage at the nominal DC link voltage, providing a discharge circuit and grounding device for purpose of maintenance.

D.Pass Switch

The pass switch is mainly used in the secondary distribution system to protect the entire DVR system from the fault current caused by the failure of the secondary distribution system.

E.Voltage Source Inverter (VSI)

The VSI consists of six pulsed power electronic switches, the AC output of which is connected to the secondary of a transformer that supplies voltage in series through an AC line filter. The VSI circuit generates an applied voltage to compensate for voltage noise. VSI rating is relatively low for voltage and high current. This is due to the serial voltage input step-up transformer used in the design of the DVR system.

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III.CONTROL STRUCTURE

An artificial neural network (ANN) is a mathematical or computational model inspired by the structure and functional aspects of biological neural networks that are used to evaluate or approximate functions, they can depend on a large amount of inputs that are usually unknown. It is suggested to use it to compute the output gradient. Training process flowchart of the ANN controller for DVR is as shown in below Fig.3.

Hidden Layer Node Output:

$$y_j = f\left(\sum_i w_{ji}x_i - \theta_j\right) - f\left(net_j\right) \tag{3}$$

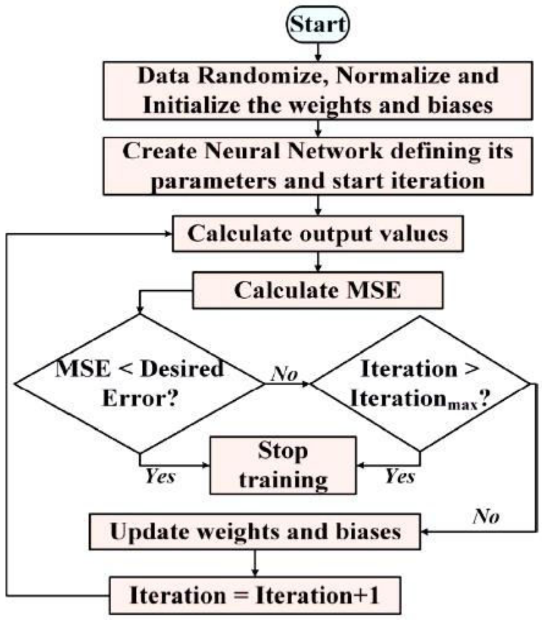

Fig.3 Training process flowchart of the ANN controller for DVR

The calculated network output of ANNcan be explained as follows.

Where,

$$net_j = \sum_i w_{ji}x_i - \theta_j \tag{4}$$

The result of calculating the output node:

$$z_l = f\left(\sum_i v_{lj}y_j - \theta_l\right) = f(net_l) \tag{5}$$

Where,

$$net_l = \sum_i w_{lj}y_j - \theta_l \tag{6}$$

The error of the Output Node:

$$E = \frac{1}{2}\sum_l (t_l - z_l)^2 = \frac{1}{2}\sum_l \left(t_l - f\left(\sum_i v_{lj}y_j - \theta_l\right)\right)^2 \tag{7}$$

Hypothesis:

$$h_\theta(x) = \theta^T x = \sum_{i=0}^{n} \theta_i x_i \tag{8}$$

Upgradation of Gradient:

$$\theta_j = \theta_j - \alpha \frac{1}{m}\sum_{i=1}^{m}\left(h_\theta\left(x^{(i)}\right) - y^{(i)}\right)x_j^{(i)} \tag{9}$$

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Where, x_i= input node, y_j= node of the hidden layer, z_l = node of the output layer, w = weight value of network between the input node and node of the hidden layer, v_{lj} =weight value of network between the nodes of hidden layer, and output layer, t_l =expected value of the output node, α =learning rate, m = total sample, θ = weight.

The ANN training process flow is shown in Fig.3. Although, establishing a universal group of parameters which are best suited for each system is difficult, the training process can be optimized to obtain results that are close to correct results for each case. The time required for training process can also be changed by taking into account the relative effect between accuracy of system and the nodes number in the ANN, as fewer layers and nodes reduce training time also reduces accuracy simultaneously.

IV.SIMULATION RESULTS

A three-phase power system with a supply source, a step-down transformer on one end, a transmission lines and a non-linear load was designed in Matlab/simulink platform to test the proposed compensation method.

Fig. 4 shows the simulation model, and Fig. 5 and Fig. 6 illustrates the waveform of the proposed three-phase power supply voltage of the ANN-driven DVR, the sag state, the voltage required to compensate for this, and the voltage after restoration. The restored waveform is the same as the original waveform, indicating that stability has been ensured. The sag simulated here is a thing that the actual system generally does not change as suddenly as it does.

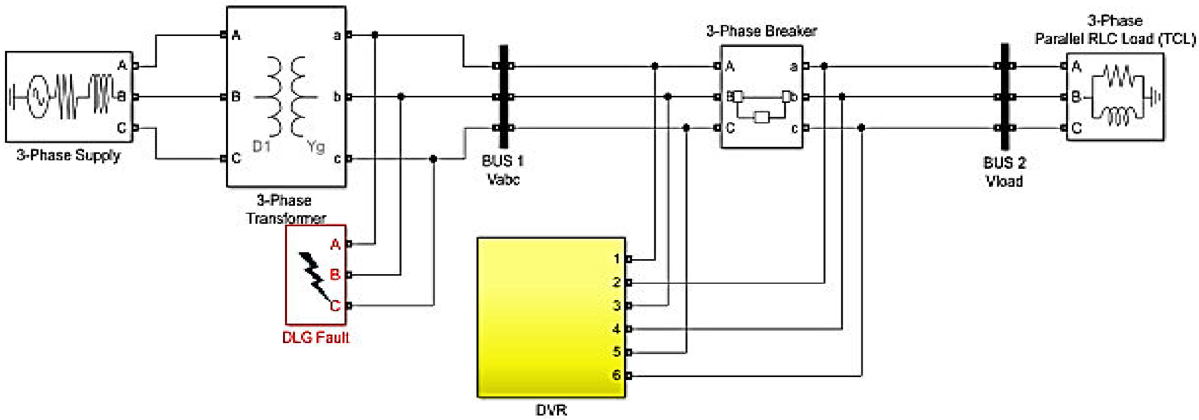

Fig.4 Simulink model of proposed DVR scheme

A.Performance during voltage sag condition

The output from both PI-controlled and ANN-controlled DVR systems under voltage sag conditions are as shown in Fig. 5 and Fig. 6.

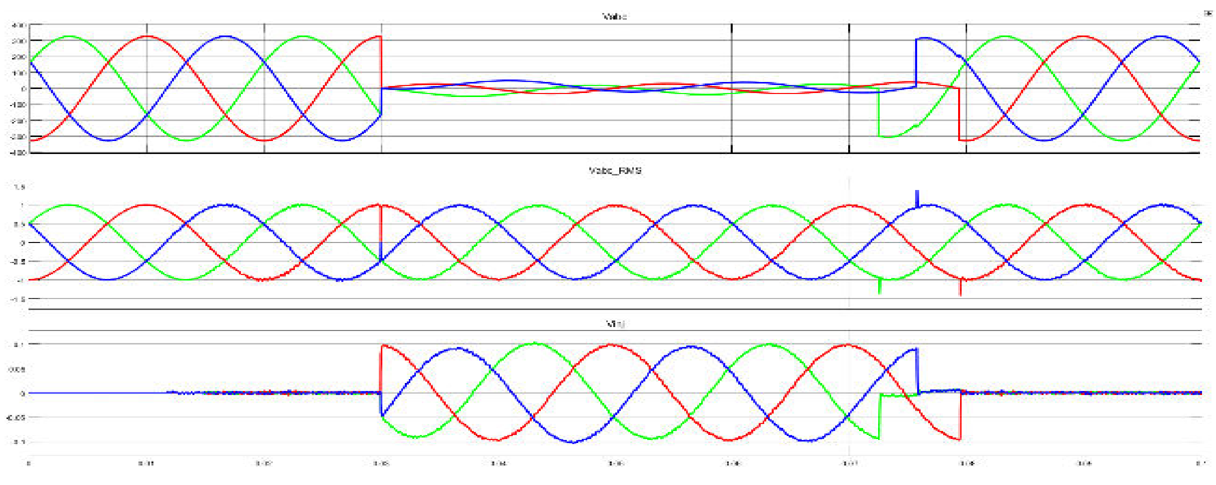

Fig.5 Performance of ANN controlled DVR under voltage sag condition

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Both systems are simulated for 0.1 sec. for the period time 0 to 0.03 sec, system voltage at nominal state. They do have not any nonlinearity up to 0.03 sec. At 0.03 sec, fault is introduced in a system. Due to this the voltage level drops.

If such lower voltage is provided to the motor load, the motor will runs at low speed. As a result, this will affect the performance of the motor. The proposed DVR schemes detect voltage drops and supplies compensation voltage to the transmission line through series-connected transformers in such a manner that this voltage is added with the fallen level voltage and makes it equal to the nominal rated voltage and then this uniform rated level voltage is applied to the load. When the load is driven by such sag-free voltage, the load performance is not affected. Thus, the electrical power quality of the voltage wave is maintained during the load energization process.

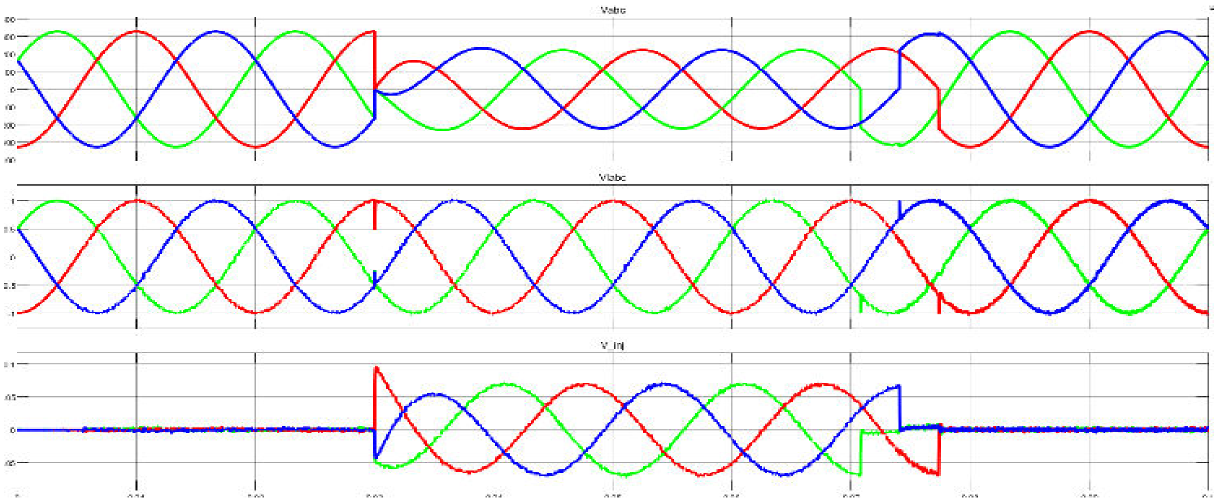

Fig.6 Performance of PI controlled DVR under voltage sag condition

B. Performance during voltage swell condition

The output received from both PI-controlled and ANN-controlled DVR System in the scenario of swelling situations are as depicted in above Fig. 7 and Fig. 8.

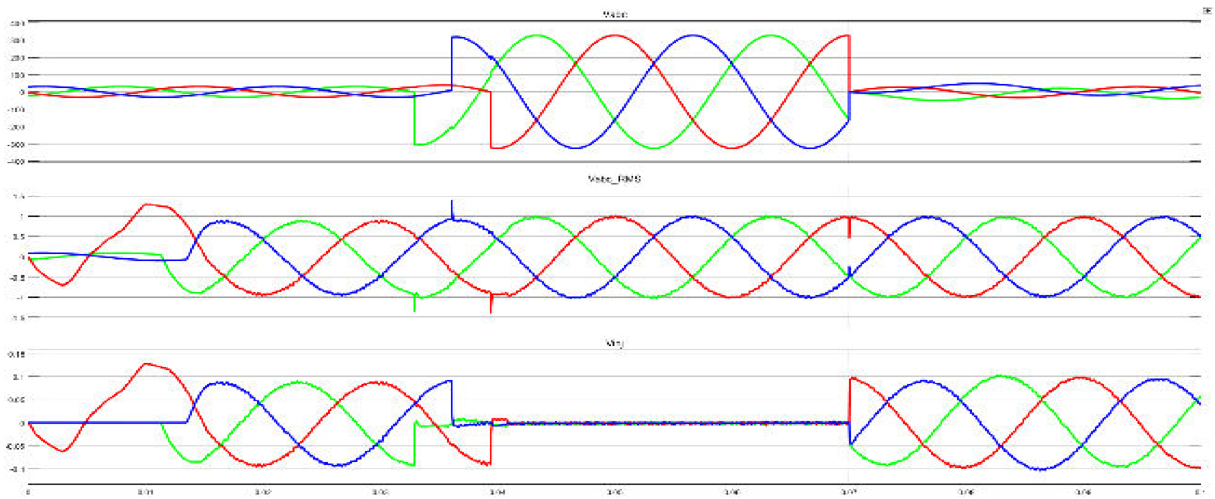

Fig.7 Performance of ANN controlled DVR under voltage swell condition

For observing the overall performance of both PI-controlled and ANN-controlled DVR schemes in the case of voltageswell situation, the simulation is carried out for 0.1sec. From the beginning zero sec, the device voltage is at a nominal stage upto 0.03 sec. After 0.03 sec, the fault is introduced in a system. Due to whichswelling in supplied voltage is brought.

During this period, the device voltage is getting risen in a level above the nominal stage. If such raised voltage is given to motoring Load, motor runs at a dangerously excessive speed. Due to this, the motor starts heated. This

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heating reasons to the burning of insulation which can damage motor winding and different components and, in the end, motor receives completely damage.

The swell in voltage is getting sensed by a proposed DVR. When the voltage level gets risen, the proposed DVR scheme injects compensating voltage into the transmission line via series connected transformer. The injected voltage is in a contrary way with raised voltage. Thus, injected voltage is get subtracted from swelled supplied voltage. Due to this, the voltage supplies to load is maintained at a nominal rated value, so that the swelling-free nominal rated voltage is given to load and it operates in good situation. In such a way, the proposed DVR scheme works for the voltage swell situation.

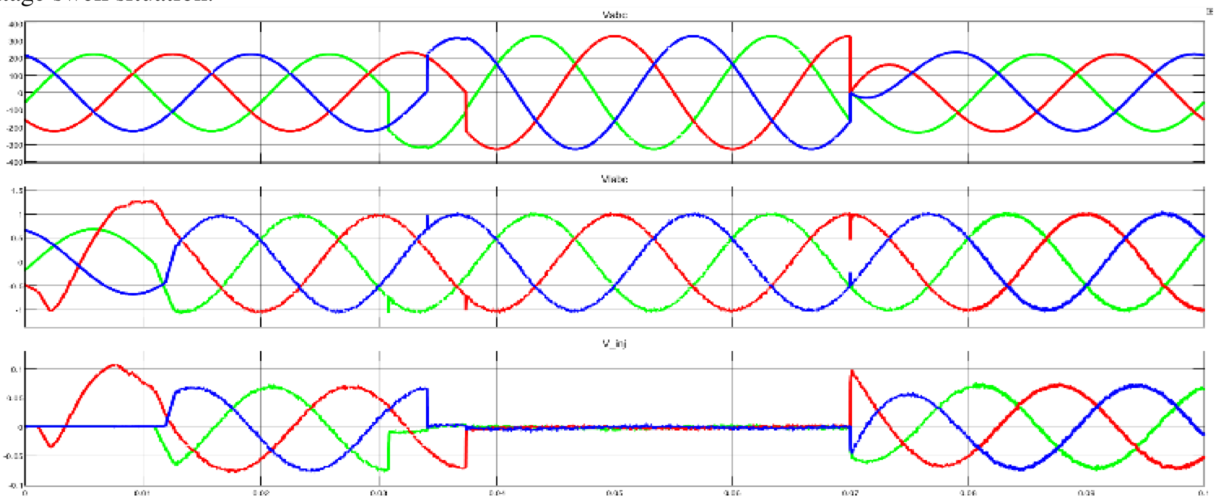

Fig.8 Performance of PI controlled DVR under voltage swell condition

The observed parameters of both PI-controlled and ANN-controlled DVR schemes are shown in Table 1

.Table 1. Observed values for voltage

Parameter	Without DVR	With PI- DVR	With ANN-DVR
Load Voltage	100	330	336
Injected Voltage	-	176	326

Fig. 10 shows the THD level of voltage supplied to the load. For calculation of THD level in percentage, FFT analysis tool is used. From the observation of the result of the FFT analysis, the voltage is given to the load after compensation has2.45% THD level which is lesser than the 5% as in specified IEEE standard for harmonic content IEEE 519.

C. Load Current

The output waveform for Load current is as shown in Fig. 9

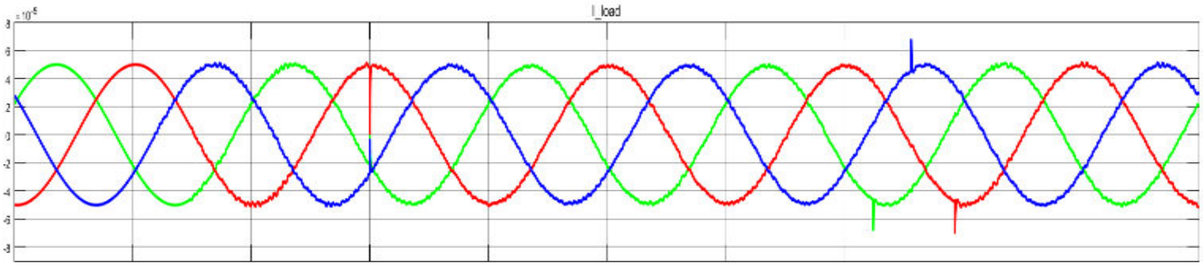

Fig.9 Load current waveform

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This waveform has a uniform level for all the power quality issues that occurred in voltage signals. It has a sinusoidal shape and its power quality is also maintained.

V.CONCLUSION

A novel design and performance analysis of Dynamic Voltage Restorer controlled using Artificial Neural Network (ANN) is presented in this paper and its response is compared with PI controlled DVR. Compared to conventional PI controlled DVR, the ANN-controlled DVR provides a good and faster response. ANN-controlled DVR gives compensation for power quality issues regarding voltage waves like voltage sag, voltage swell and also maintains load current at uniform and rated levels for such issues. ANN-controlled DVR injects voltage in phase for voltage sag issue and opposite phase for voltage swelling condition. It maintains percentage voltage THD level below 5% as specified by IEEE standard for power quality IEEE 519. From observing overall performance, it can conclude that the ANN-controlled DVR scheme can be a better option for mitigating power quality issues and maintaining THD level within a level. It can be used for smart grid applications as it provides a very good and faster response.

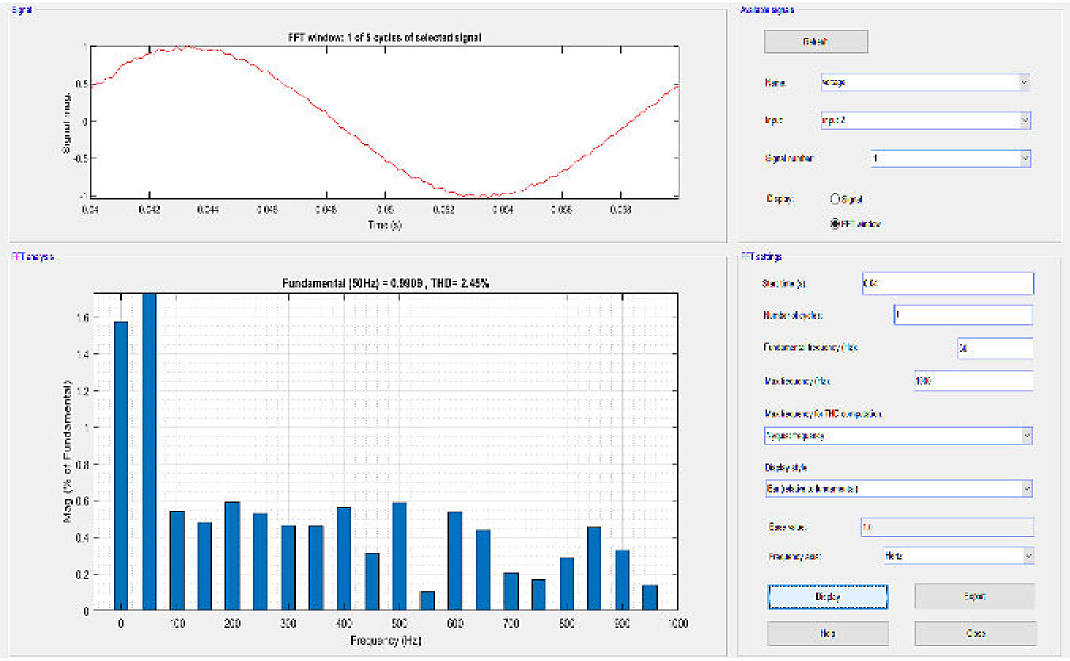

Fig.9 THD level of load voltage

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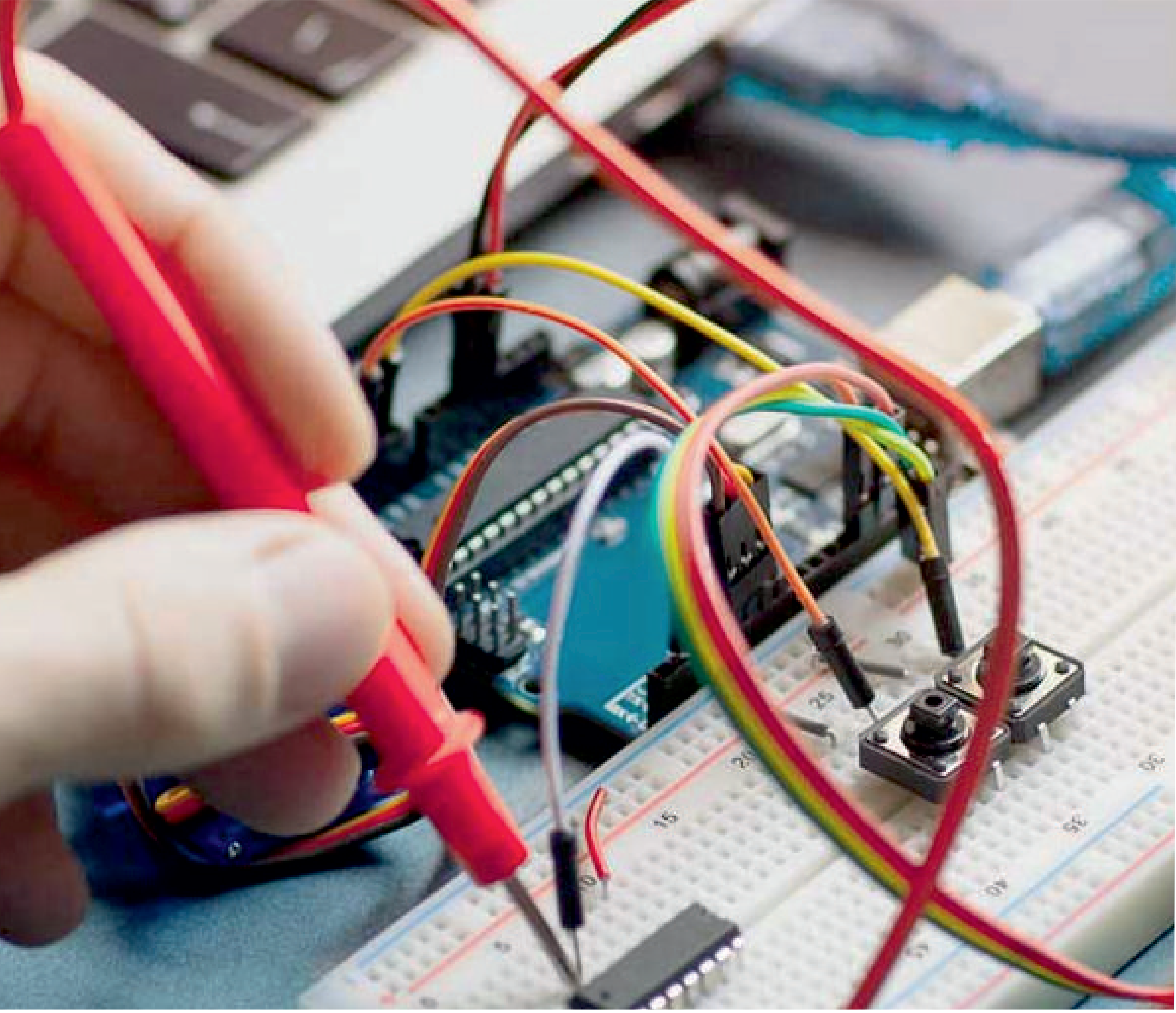

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