Improvement of Power Quality in Distribution System Using Artificial Neural Network Based Dynamic Voltage Restorer

G S N M Venkatesh[1] ,Chelluri manasa[2],Nuti Abhishek raj[3], Esuru Lokesh[4] ,

Vommi Vinay Kumar[5] , Atti Bhavani Shankar[6]

Asst. Professor of EEE department, Raghu Engineering College,Visakhapatnam,A.P,India.[1]

B.Tech Scholar, Raghu Engineering College, Visakhapatnam, A.P, India.[2,3,4,5,6]

Abstract- ***Power quality is a very important issue in the power system that affects both customers and services. The current electric power system has a lot of problems because of the use of power electronics equipment, smart grid systems, and renewable energy sources. Harmonics, voltage drops, and voltage rises can all damage sensitive equipment. These devices can be affected by changes in input voltage that happen when other parts of the system interfere with them. In today's world, where electronic devices are becoming more aware and expensive, power quality is very important for the safe and reliable operation of power systems. The Dynamic Voltage Restorer (DVR) is a possible Distribution Flexible AC Transmission System (D-FACTS) tool that is often used to fix problems with the distribution grid's voltage, current, or frequency that aren't always the same. Injecting voltages into the distribution line keeps the voltage profile and the load's steady voltage. Simulations in MATLAB/Simulink were done to show how well the DVR-based suggested strategy works to lower the distorted voltage caused by harmonics. An Artificial Neural Network (ANN) controller is used in this project to lower the total harmonic distortion. It has been noted that a stable indemnified load voltage was attained and that the proposed DVR-based method effectively managed voltage distortion.***

Index Terms—Dynamic voltage restorer (DVR), artificial neural networks (ANN), power quality, unit vector, voltage harmonics, voltage sag, voltage swells.

I. INTRODUCTION

There are a lot of POWER QUALITY problems in today's distribution systems because more and more sensitive and demanding equipment is being used, like communication chains, process industries, and important construction processes. Power quality issues such as transients, sags, swells, and other distortions to the sinusoidal waveform of the supply voltage can make these devices work less well. Custom power devices are one type of technology that is made to protect against problems with power quality. There are three main types of custom power devices: series-connected compensators, which are also called dynamic voltage restorers (DVRs); shunt-connected compensators, which are also called distribution static compensators; and unified power quality conditioners, which are a mix of series and shunt-connected compensators. The DVR can control the load voltage even when the supply voltages have problems like sagging, swelling, and harmonics. So, it can protect important consumer loads from tripping and the losses that follow. The custom power devices are cutting-edge and are set up at the customer's location to meet power quality standards like IEEE-519.

It is not always possible to avoid voltage sags in an electrical grid because the faults that cause them take a certain amount of time to clear and the sags are reproduced from the transmission and distribution systems to the low-voltage loads. Voltage sags are the most common reason for production plants to stop working and for defects in end-user equipment. In particular, equipment tripping on a production line can cause blackouts and big costs because production is lost. One way to fix this problem is to make the equipment more tolerant of sags, either by using intelligent control or by storing "ride-through" energy in the equipment. Instead of changing each part of a plant to make it more resistant to voltage sags, another option is to install a plant-wide incorruptible power supply system for longer power outages or a DVR on the incoming supply to reduce voltage sags for shorter periods. DVRs can get rid of most of the sags and lower the chance of load tripping for very deep sags.

Many solutions and their complications using DVRs are announced, such as the voltages in a three-phase system are stabilized and an energy-optimized control of DVR is analyzed. Industrial examples of DVRs are given in, and distinct control methods are discussed for distant types of voltage sags. An observation of different topologies and control methods is presented for a DVR. The arrangement of a capacitor-supported DVR that assure sag, swell, distortion, or unbalance in the supply voltages is concluded. The execution of a DVR with the high-frequency-link transformer is explained. In this paper, the control and act of a DVR are endorsed with a reduced-rating Voltage-Source-Converter (VSC) with ANN controller. The synchronous-Reference-Frame (SRF) theory is used for the regulation of the DVR.

II. OPERATION OF DVR

The schematic of a DVR-connected system is shown in Fig. 1(a). The voltage V_{inj} is inserted such that the load voltage V_{load} is constant in magnitude and is undistorted, although the supply voltage V_s is not constant in magnitude or is distorted.

DOI: 10.55041/IJSREM59604

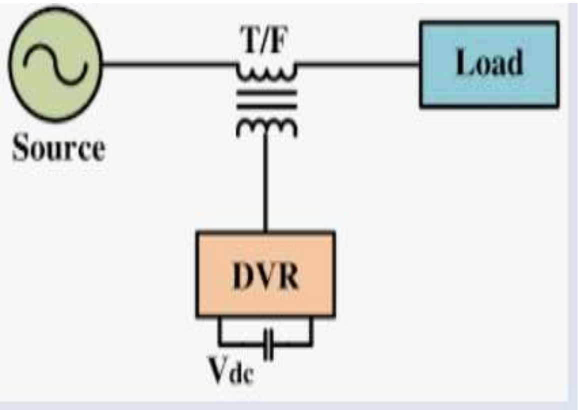
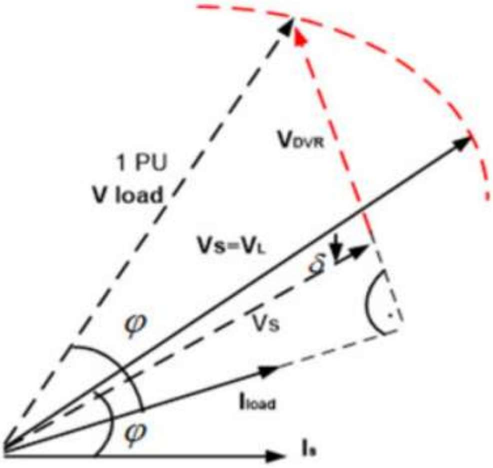


Fig. 1. (a) Basic circuit of DVR.



1(b) Phasor diagram of the DVR voltage injection schemes.

Fig. 1(b) shows the phasor diagram of different voltage injection schemes of the DVR. VL(pre−sag) is a voltage across the critical load prior to the voltage sag condition. During the voltage sag, the voltage is reduced to Vs with a phase lag angle of θ. Now, the DVR injects a voltage such that the load voltage magnitude is maintained at the pre-sag condition. According to the phase angle of the load voltage, the injection of voltages can be realized in four ways. Vinj1 represents the voltage injected in-phase with the supply voltage. With the injection of Vinj2, the load voltage magnitude remains same but it leads Vs by a small angle. In Vinj3, the load voltage retains the same phase as that of the pre-sag condition, which may be an optimum angle considering the energy source . Vinj4 is the condition where the injected voltage is in quadrature with the current, and this case is suitable for a capacitor-supported DVR as this injection involves no active power.

However, a minimum possible rating of the converter is achieved by Vinj1. The DVR is operated in this scheme with a battery energy storage system (BESS). Fig. 2 shows a schematic of a three-phase DVR connected to restore the voltage of a three-phase critical load. A three-phase supply is connected to a critical and sensitive load through a three-phase series injection transformer. The equivalent voltage of the supply of phase A v_{Ma} is connected to the point of common coupling (PCC) v_{Sa} through short-circuit impedance Z_{sa}. The voltage injected by the DVR in phase. A v_{Ca} is such that the load voltage v_{La} is of rated magnitude and undistorted. A three-phase DVR is connected to the line to inject a voltage in series using three single-phase transformers T_r. L_r and C_r represent the filter components used to filter the ripples in the injected voltage. A three-leg VSC with insulated-gate bipolar transistors (IGBTs) is used as a DVR, and a BESS is connected to its dc bus.

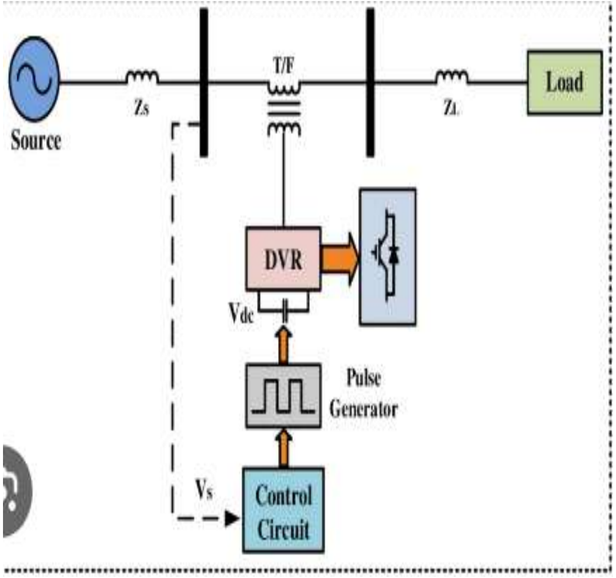


Fig2. Basic Configuration of DVR.

III. CONTROL OF DVR

The compensation for voltage sags using a DVR can be performed by injecting or absorbing the reactive power or the real power.When the injected voltage is in quadrature with the current at the fundamental frequency, the compensation is made by injecting reactive power and the DVR is with a self-supported dc bus. However, if the injected voltage is in phase with the current, DVR injects real power, and hence, a battery is required at the dc bus of the VSC. The control technique adopted should consider the limitations such as the voltage injection capability (converter and transformer rating) and optimization of the size of energy storage.

A. Control of DVR with BESS for Voltage Sag, Swell, and Harmonics Compensation

Fig. 3 shows a control block of the DVR in which the SRF theory with artificial neural networks (ANN) is used for reference signal estimation. The voltages at the PCC v_S and at the load terminal v_L are sensed for deriving the IGBTs' gate signals. The reference load voltage V^*_L is extracted using the derived unit vector. Load voltages (V_{La}, V_{Lb}, V_{Lc}) are converted to the rotating reference frame using abc−dqo conversion using Park's transformation with unit vectors (sin, θ, cos, θ) derived using a phase-locked loop as

$$\begin{bmatrix} v_{Lq} \\ v_{Ld} \\ v_{L0} \end{bmatrix} = \frac{2}{3} \begin{bmatrix} \cos\theta & \cos\left(\theta-\frac{2\pi}{3}\right) & \cos\left(\theta+\frac{2\pi}{3}\right) \\ \sin\theta & \sin\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} \begin{bmatrix} v_{Laref} \\ v_{Lbref} \\ v_{Lcref} \end{bmatrix}$$

(1)

Similarly, reference load voltages (V^*_{La}, V^*_{Lb}, V^*_{Lc}) and voltages at the PCC v_S are also converted to the rotating reference frame. Then, the DVR voltages are obtained in the rotating reference frame as

$$v_{Dd} = v_{Sd} - v_{Ld}$$

(2)

$$v_{Dq} = v_{Sq} - v_{Lq}.$$

(3)

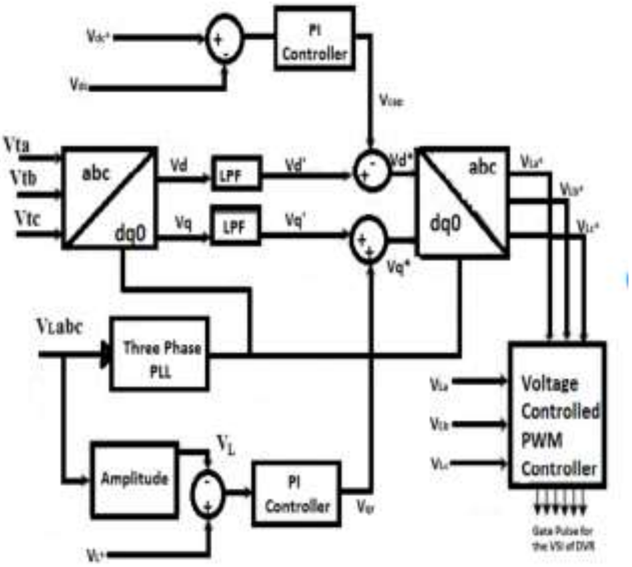


Fig. 3. Control block of the DVR that uses the Artificial neural network

The reference DVR voltages are obtained in the rotating reference frame as

$$v^*_{Dd} = v^*_{Sd} - v_{Ld}$$

(4)

$$v^*_{Dq} = v^*_{Sq} - v_{Lq}.$$

(5)

The error between the reference and actual DVR voltages in the rotating reference frame is regulated using two artificial neutral network (ANN) controllers. Reference DVR voltages in the *abc* frame are obtained from a reverse Park's transformation taking V^*_{Dd} from (4), V^*_{Dq} from (5), V^*_{D0} as zero as

$$\begin{bmatrix} v^*_{dvra} \\ v^*_{dvrb} \\ v^*_{dvrc} \end{bmatrix} = \begin{bmatrix} \cos\theta & \sin\theta & 1 \\ \cos\left(\theta-\frac{2\pi}{3}\right) & \sin\left(\theta-\frac{2\pi}{3}\right) & 1 \\ \cos\left(\theta+\frac{2\pi}{3}\right) & \sin\left(\theta+\frac{2\pi}{3}\right) & 1 \end{bmatrix} \begin{bmatrix} v^*_{Dq} \\ v^*_{Dd} \\ v^*_{D0} \end{bmatrix}.$$

(6)

Reference DVR voltages (v^*_{dvra}, v^*_{dvrb}, v^*_{dvrc}) and actual DVR voltages (v_{dvra}, v_{dvrb}, v_{dvrc}) are used in a pulse width modulated (PWM) controller to generate gating pulses to a VSC of the DVR. The PWM controller is operated with a switching frequency of 10 kHz.

B. Control of Self-Supported DVR for Voltage Sag, Swell, and Harmonics Compensation

Fig. 4(a) shows a schematic of a capacitor-supported DVR connected to three-phase critical loads, and Fig. 4(b) shows a control block of the DVR in which the SRF theory is used for the control of self-supported DVR. Voltages at the PCC v_S are converted to the rotating reference frame using *abc−dqo* conversion using Park's transformation. The harmonics and the oscillatory components of the voltage are eliminated using low pass filters (LPFs). The components of voltages in the *d*- and *q*-axes are

$$v_d = v_{ddc} + v_{dac}$$

(7)

$$v_q = v_{qdc} + v_{qac}.$$

(8)

The compensating strategy for compensation of voltage quality problems considers that the load terminal voltage should be of rated magnitude and undistorted.

IV. Artificial neural networks (ANN)

Neural networks consist of a large class of different architectures. In many cases, the issue is approximating a static nonlinear, mapping *f* **x**with a neural network *f NN* (**x**) , where **x€R**^{K} .

The most useful neural networks in function approximation are Multilayer Layer Perceptron (MLP) and Radial Basis Function (RBF) networks. Here we concentrate on MLP networks. A MLP consists of an input layer, several hidden layers, and an output layer. Node i, also called a neuron, in a MLP network is shown in Fig. 5. It includes a summer and a nonlinear activation function g.

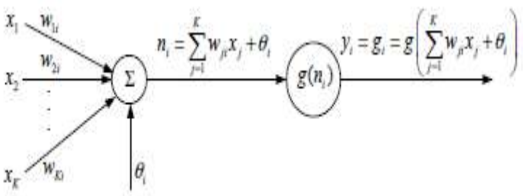


Fig.4. Single node in a MLP network.

The inputs , 1,..., *k x k K* to the neuron are multiplied by weights *wki* and summed up together with the constant bias term θ*i*. The resulting *i n* is the input to the activation function *g*. The activation function was originally chosen to be a relay function, but for mathematical convenience a hyperbolic tangent (*tanh*) or a sigmoid function are most commonly used. Hyperbolic tangent is defined as

$$\tanh(x) = \frac{1-e^{-x}}{1+e^{-x}} \tag{9}$$

The output of node *i* becomes

$$y_i = g_i = g\left(\sum_{j=1}^{K} w_{ji}x_j + \theta_i\right) \tag{10}$$

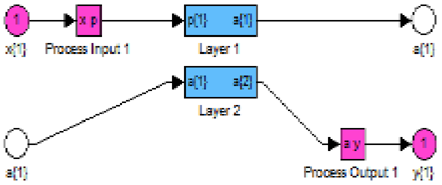


Fig. 6. Simulink structure of artificial neutral network controller

V.SIMULATION RESULTS

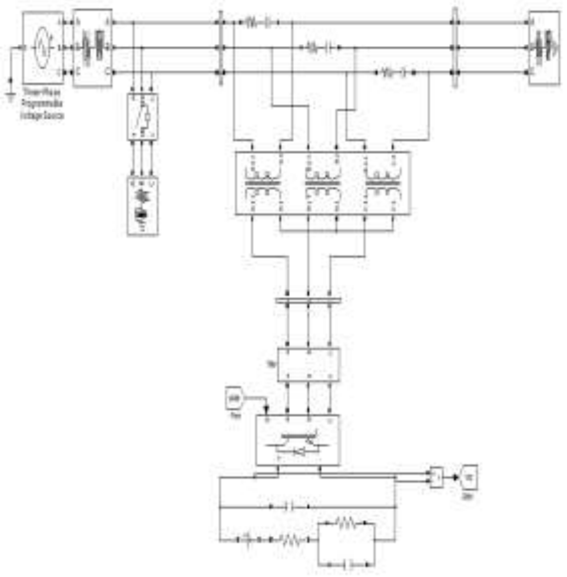


Fig7Simulation Diagram

A. PERFORMANCE OF THE DVR SYSTEM

The performance of the DVR is demonstrated for different supply voltage disturbances such as voltage sag and swell. Fig. 8 shows the transient performance of the system under voltage sag and voltage swell conditions. At 0.2 s, a sag in supply voltage is created for five cycles, and at 0.4 s, a swell in the supply voltages is created for five cycles. It is observed that the load voltage is regulated to constant amplitude under both sag and swell conditions. PCC voltages *vS*, load voltages *vL*, DVR voltages *vC*, amplitude of load voltage *VL* and PCC voltage *Vs*, source currents *iS*, reference load voltages *vL*ref , and dc bus voltage *v*dc are also depicted in Fig.7.

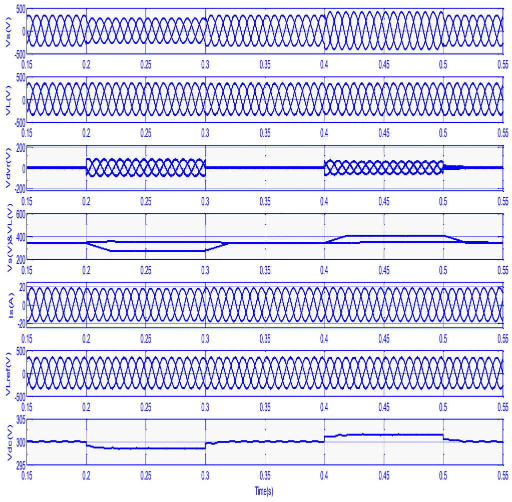


Fig.8. Dynamic performance of DVR with in-phase injection during voltage sag and swell applied to critical load.

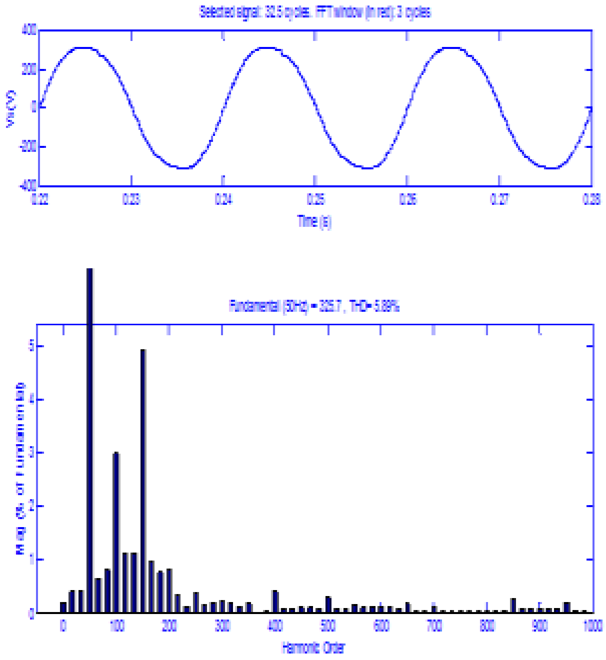


Fig.9 PCC voltage and harmonic spectrum during the disturbance using ANN Controller.

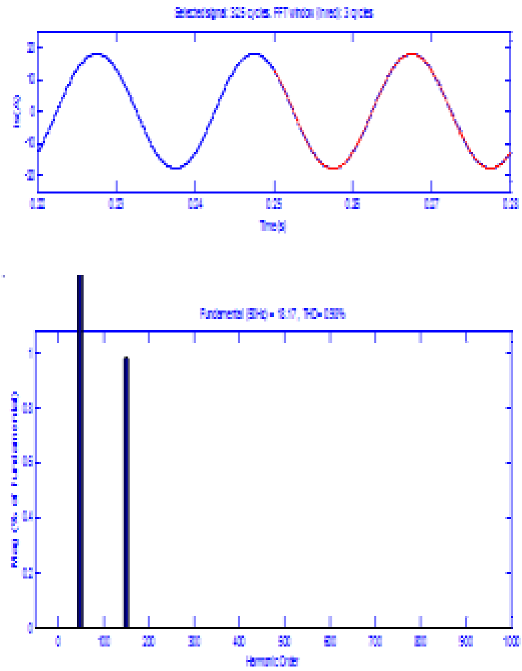


Fig.10 Supply current and harmonic spectrum during the disturbance in ANN Controller

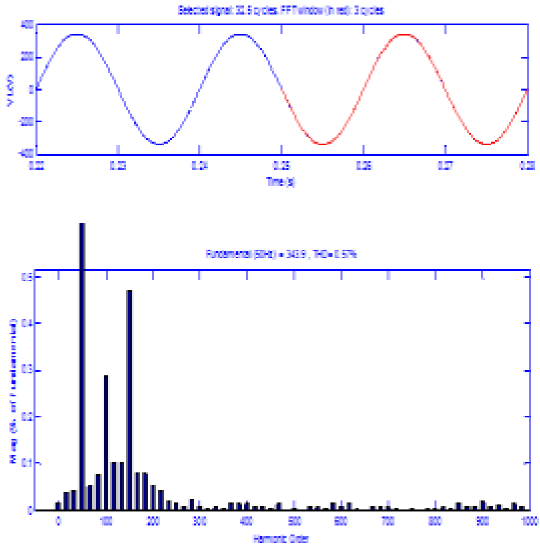


Fig.11 Load voltage and harmonic spectrum during the disturbance in ANN Controller.

Table1: Comparison of Total Harmonic Distortion with PI and ANN controllers

	PI Controller THD	ANN Controller THD
Source Voltage	6.5%	5.9%
Source Current	1.1%	0.9%
Load Voltage	0.8%	0.6%

VI. CONCLUSION

The operation of a DVR has been demonstrated with an improved control technique using various voltage injection schemes. A comparison of the DVR's performance with different schemes has been performed. An ANN controller based VSC, including in this DVR. The reference load voltage has been predicted using the method of unit vectors, and control of DVR has been achieved, which minimizes voltage injection error. SRF theory is employed for estimating reference DVR voltages. It is concluded that voltage injection in phase with the PCC voltage. This power quality improvement and reduction in the THD in load voltage explain the effectiveness of the DVR based ANN control strategy used in this work.

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