Power Quality Improvement Using DVR Control Designed With Ann-Fuzzy In MATLAB

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ABSTRACT: Industrial loads are particularly vulnerable to disruptions in the power supply and must be carefully managed to prevent disruptions in production. Semiconductor devices are often responsible for providing the majority of the power required by an industrial load. That is why you need a dynamic voltage restorer, which can detect voltage drops and restore the proper voltage level quickly and precisely. In this paper, the simulation of dynamic voltage restorer (DVR) was made by using an artificial neural network. DVR injects the voltage in the system when voltage sag or swell occurred due to fault. The ANN is trained online by data generated by the uncompensated model. The problem of voltage sags and its severe impact on sensitive loads is well known. To solve this problem, the DVR is a modern and important custom power device for compensation voltage sags in power distribution systems. The Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to voltage sag problem. The DVR is a series compensator used to mitigate voltage sags and to restore load voltage to its rated value. In this paper, an overview of the DVR, its functions, configurations, components, operating modes, voltage injection methods and closed loop control of the DVR output voltage are reviewed along with the device capabilities and limitations. A power system model with a programmable power source is used to include 3rd and 5th harmonics. The systems’ response for load voltage is evaluated for with and without DVR scenarios. It has been noted that the proposed DVR based strategy has effectively managed the voltage distortion, and a smooth compensated load voltage was achieved. The load voltage THD percentage was approximately 18% and 23% with insertion 3rd and 5th harmonics in the supply voltage, respectively. The inclusion of the proposed DVR has reduced THD around less than 4% in both cases.

Key words: DVR, Sag, Facts, ANN, Harmonics. Fuzzy.

1.0 INTRODUCTION

Because of this, electricity quality has become paramount in the grid's distribution infrastructure. Voltage and power quality have deteriorated due to increasing reliance on nonlinear loads such as
microcontrollers and power electronics. Therefore, it should determine the source of the issue and
the amount of compensation required. In addition, for electronic devices to work correctly, the
voltage coming from the supply system must remain somewhat stable. Sags, harmonic distortions,
surges, spikes, and brief interruptions are all characteristics of voltage variations that can
negatively impact power quality. The electrical power grid frequently experiences voltage dips
and increases. [1]. The common causes of voltage sag are short circuit or faults in power system,
at starting of large loads and faulty conductor Voltage sag is not a complete interruption of power;
it is a temporary drop below 90 percent of the nominal voltage level. The maximum voltage sags
do not go below 50 percent of the nominal voltage and they normally last from 3 to 10 cycles or
50 to 170 milliseconds. The Voltage swell is defined as an increase in rms voltage or current at the
power frequency for durations from 0.5 cycles to 1 min [2] A series connected converter-based
mitigation device, the Dynamic Voltage Restorer (DVR) is the most economical and technically
advanced mitigation device proposed to protect sensitive loads from voltage sags. The power
system is divided into the following parts as generation, transmission, distribution, and by using
other transmission line power systems is fed to different loads on the distribution side. Power
quality plays a vital role in the power system when variable power is supplied to the load.
Subsequently, the domestic and industrial customers with delicate loads are affected by the poor
quality of power. Even there is various type of load on the distribution side, but poor power quality
affects the sensitive loads more than others.

**Principles Of DVR Operation**
A DVR is consisting of GTO or IGBT based Voltage Source Inverter (VSI), an energy storage
instrument, a capacitor bank, and an injection transformer. The DVR is also called solid-state
power electronic switching device. A DVR connected to a distribution bus is illustrated in Figure
3. The practical guideline of the DVR as it works by methods for an injecting transformer; a control
voltage is created by a forced commutated converter, which is in arrangement to the bus voltage

**2.0 LITERATURE REVIEW**
In a few regions, issues with transmission and distribution were fixed with the use of FACTS and
D-FACTS equipment. AC transmission systems with static and power electronics-based
controllers to increase power transfer capability and more measurable controllability' Today,
electricity demand has risen significantly while the development of generation and transmission
systems is not adequate due to limited resources, economic issues, and some environmental
limitations. Due to limited resources, the current transmission infrastructure cannot be expanded.
Accordingly, increasing transmission capacity is a workable option [4]. For various reasons,
transmission cables are not being loaded to their maximum capacity. This is thought to be the case
due to the temperature limit, dielectric, and stability. Power may be regulated and current lines'
usable capacity increased with the help of FACTS controllers. Power could flow through a line,
even when it's being subjected to faults, thanks to the FACTS controllers, which also allow a line
to transmit power near to its thermal ratings. [5] Distribution voltage regulators (DVRs) are
installed on distribution feeders to prevent failures caused by voltage dips and voltage sags. DVR is installed in series with the load, and a transformer and inverter are linked to it to compensate the active and reactive power need for the decrease in voltage sags and voltage swells [6,7]. DVR injects power into the distribution system, connecting the DVR to the system through a transformer in order to maintain consistent voltages throughout the building. DVR is a FACTS device that corrects for voltage fluctuations and harmonics applied loads [8]. The FACTS controllers allow a line to transfer electricity near its thermal ratings under normal and fault situations. [9] In order to prevent power outages caused by voltage dips and spikes, DVR is installed on the distribution feeder. The dynamic voltage regulator (DVR) is installed in series with the load, and a battery energy storage system (BESS) is connected with a transformer and inverter to compensate the active and reactive power requirement for the reduction in voltage sags and voltage swells [10,11]. To maintain consistent voltage throughout the network, a DVR injects power into the distribution system via a transformer. Disturbances such as voltage dips, voltage spikes, and voltage harmonics caused by loads are regulated by the FACTS device known as a digital voltage regulator (DVR). Electrical Energy is invisible; a universal commodity that is immediately available in most of the world, and it has now been recognized as everyday consumer need [12]. Renewable Energy Systems (RESs) is used to aid the primary energy demand in solar, solar thermal, wind energy, etc. The intermittent nature of RESs, harmonics, and reactive power problems halt the power system’s performance by originating stability concerns in the power system [13-14]. The Flexible AC Transmission Systems (FACTS) devices are widely adapted for reactive power compensation, voltage stability, and power quality in distribution grids around the world [15-16]. However, FACT devices also alter different parameters on the transmission and distribution system [17]. This work presents a study of the power quality and aims at identifying the causes of poor power quality and provides the solutions to these power quality problems. Some equipment like computers, laptops, relays, solid-state devices, adjustable speed drives, and optical devices are known as sensitive equipment. These devices are susceptible to input voltage variations created by interference with other parts of the system. The power system is divided into the following parts as generation, transmission, distribution, and by using other transmission line power systems is fed to different loads on the distribution side. Power quality plays a vital role in the power system when variable power is supplied to the load. Subsequently, the domestic and industrial customers with delicate loads are affected by the poor quality of power. Even there is various type of load on the distribution side, but poor power quality affects the sensitive loads more than others.

3.0 CONTROL SCHEME OF DVR
The power factor on the source side (at PCC) can be improved by connecting a DVR in series with the linear load to smooth out harmonics and unbalanced voltages from the power supply [10]. It is the primary goal of the control technique to maintain stable, sinusoidal voltages across the load buses at all times (positive sequence). Load currents are required to be sinusoidal and balanced (positive sequence) if the load is linear. The source current should also be in phase with the PCC voltage's fundamental frequency component. Therefore, the DVR must be capable of handling the
load's reactive power. As an added perk, DVR may be set up to provide a certain amount of the reactive power needed by the load, which might be a microprocessor.

### 3.1 PROPOSED DYNAMIC VOLTAGE RESTORER

The frequency of the supplied voltage can determine the power supply quality that is a significant indicator of power quality. The voltage sag is interpreted as a drop in the Root Mean Square (RMS) value of the voltage that can happen from 10 ms to 60 seconds with the depth of the falling voltage of 0.9 per unit (p.u) 0.1 p.u of a nominal p.u based on the IEEE standards [18-[24]. Regular voltage sags are usually checked for the load at the distribution level due to different reasons. The voltage sags are highly unbearable for a few delicate loads in high technology sectors. The load voltage requirements could be maintained by the complicated tasks with a specific frequency and exact value of voltage sag while distortion and oscillation. Usually, the destruction of the production sector and its downtime is the result of voltage sag that is costly and leads to harsh problems among consumers. A specific amount of energy and voltage is supplied to the distribution system by using electric devices that are also named consumer power devices. The complex problem could be mitigated. As compared to the conventional methods of voltage sags problem solving, the DVR is supposed to be an efficient method to control the voltage sag and distortion. In this work, the power system’s performance is evaluated by removing voltage sag through a DVR at the distribution level.

![DVR series connected topology](http://www.webology.org)

**Figure: 1 DVR series connected topology**
3.2 Internal Control of DVR

For control purposes, the different parameters and internal control of DVR, as shown in Figure 9, are simulated in the MATLAB/Simulink. At the normal level of the supply voltage, to provide the lower number of losses in the conversion circuits, the DVR should be controlled in the transformer and the filtering circuits. When the voltage unbalance, or distorted voltage is detected in the system, then the required injected voltages are supplied to the test system through the installed DVR. Depend upon the voltage \( V_{\text{ref}} \), the instantaneous value of the supply voltage \( V_{\text{supply}} \), the whole process is accomplished by the feedback control technique. The reference voltages \( V_{\text{ref}} \) are extracted by the control algorithm from the supply and the load voltages when the gate pulses provide the VSI to regulate the load voltage at the control algorithm’s reference voltage. In this step, the detection of the voltage distortion, including voltage sag and voltage swell, can be done by calculating the problems among the dq-frame voltages of the load voltage \( V_{\text{Load}} \) and the reference voltage \( V_{\text{ref}} \). The abc frame is converted into the \( \alpha\beta \)-frames by connecting of the
load voltage to a transformation block. The reference voltage will generate the gate pulses by equating the reference voltage (Vref) with that of the load voltage (VLoad) in the case of any detection of the voltage swelling or sag and these pulses received by the VSI and by using the pulse width modulation (PWM), the preferred voltage will be formed in a way to maintain the load voltage at the (Vref) or reference voltage, i.e., 330V.

1) Mathematical Model For Operating Principle Of Proposed Dynamic Voltage Restorer

The power (active) that load absorbed is as follows:

\[ P_L = V_L I_L \cos \theta \ldots (1) \]

While if the active power of the DVR is given, When DVR gives active power,

\[ P_{DVR} > 0 \ldots (2) \]

When active power is taken by DVR

\[ P_{DVR} < 0 \]

When the active power is not exchanged

\[ P_{DVR} = 0 \]

\[ \theta_r = \theta_i + \theta_s - \cos^{-1} \left( \frac{V_L \cos \theta_L}{V_S} \right) \ldots (3) \]

3.3 CONTROL TECHNIQUES FOR DVR:

The controller's primary function in a DVR is to monitor the system voltage, determine the necessary compensating voltage, and then use that number as the trigger for the PWM inverter's trigger pulses. If you want a quick and reliable answer, don't use the RMS value computation of the voltage to evaluate the sags. To determine voltage, the authors of this study employed either the dqo or parks transformations. Coordinates in the three-phase stationary system can be transformed into those in the dq rotating system via the dqo transformation. This dqo technique reports the beginning and ending times together with the voltage drop's depth (d) and phase shift (q).

**Proportional-Integral Controller:**

The PI Controller is a form of feedback control that uses a weighted integral of error to regulate a given plant. For a proportional reaction, the error is multiplied by a constant KP to provide a gain of proportionality Both the size and length of a mistake have a direct bearing on the integral term's contribution. Accumulated offsets that have already been compensated for will be calculated by multiplying the initial mistake by the integral Gain, Ki.
Fuzzy Logic Controller:
The foundation of fuzzy set theory is the concept of the fuzzy logic (FL) controller, which differs from traditional control systems in that it relies on linguistic variables rather than numerical ones. This kind of regulation is rooted in quality control principles and depends on human ability to comprehend system behaviour. With the help of Fuzzy Logic, one may quickly and easily draw a firm conclusion in the face of incomplete, inconsistent, or otherwise problematic data.

Figure 4: Basic structure of FL controller

4.0 SIMULATION AND DISCUSSION

Figure 5. Compensated signal (VLoad) in test system With DVR (Scenario 1).
Figure 6. Injected voltage (Vinj) by DVR in all three phases (Scenario 2).

where, \( V_S > V_L \cos \theta_L \), this condition should be satisfied. By ignoring the limitations of the voltage, the exchange of active power for the voltage swell is zero. But in the circumstance of the voltage sag, the active power is supplied by the equipment, and if the voltage sag has a magnitude that is very deep that it could not satisfy the condition, thus injection voltage is as follows. Able

\[
V_{INJ} > \sqrt{V_s^2 + V_L^2 - 2V_sV_L \cos(\theta_s - \theta_L)} \quad (4)
\]

The three-phase injection transformer is used to connect the DVR system to that of the test system’s transmission line. The control circuit of the DVR is used for the amplification of the pulses and produced by the PWM. Then through the transformer, the injected of the voltage in the transmission line occurs.

B. Scenario 1: Injection of 3rd Harmonic

In scenario 1, the 3rd harmonic voltage is inserted into the supply voltage programmable source.
The 3-phase sensitive loads are connected with this distorted supply and examined with this distortion in all three phases. Figure 5 shows that the insertion causes a distortion in voltage profile, and load voltage has observed a distorted voltage (VLoad) with a disturbing waveform, and some swell in it. The VRMS phase to phase peaks reaches to near 460 V magnitude in voltage profile. The disturbance in the voltage profile may lead to failure or malfunctioning of sensitive equipment. The THD distortion is calculated for all the three phases and shown in Figure 6 (a), (b), and (c). The impact of THD is lessening the quality of power as phase A (18.49%), phase B (18.49%), and phase C (18.50%) having a high THD because of distortion of load voltage (VLoad). The THD graphs show that the signal has almost 11.5% of 3rd harmonic content in it. As the same magnitude of 3rd harmonics is inserted in the system; therefore, all the phases have shown almost similar THD with almost similar harmonics in it. Such systems are not accepted because they are not according to the IEEE standards. Referring to the IEEE standard 519 to 1992, the THD rate must be 5% less than the fundamental frequency. The value of THD is way over IEEE Standards. Thus, the disturbance in the voltage source is mitigated by the inclusion of DVR. To maintain the THD distortion under the IEEE limit and improve the power quality, DVR with a control system is implemented. The load voltage with DVR, along with the control system, is shown in Figure 7. The compensation in the load voltage (VLoad) can be seen in all three phases of voltage. This is accomplished with the automatic connection, and the injection of the voltage occurs when the breakers of the circuit open in the presence of the DVR. A significant reduction is seen from $t = 0.1$ to $0.3$ sec for the voltage swell as well as the high magnitude of harmonics is removed, and voltage profile is back to normal in all the three cases with a slight flicker at 0.1 sec or 0.3 sec only. A smaller spike has been observed at 0.1 and 0.3 sec. To maintain the power quality, DVR has injected the voltage into the distribution line, the injected voltage for all three phases are shown in Figure 13. The DVR used the electronic device, transistor, and diodes to protect from the error, convert voltage from AC to DC, correct the voltage in load, and control the flow of the power. Then during operating, the generation of the harmonics takes place through the inverter that is PWM. Then the small amount of effect will occur on the load the supply of the utility, reduction
in the harmonics occur. Later in the power system, the filters of the harmonics are used to resolves the above issues.

\[
\text{THD} = \sum_{k=2}^{\infty} \frac{C_{2k}}{C_1} \times 100\%
\]  
...(7)

The above equation shows that the \( C_1 \) is considered the essential component magnitude, where the harmonic component magnitude is the \( C_k \) (where \( k = 2, 3, 4, \ldots \)). Then, for the sensitive loads, the THD’s value must be put just below the 5 percent in the power system; to produce the low frequency in the harmonics’ constant frequency, the passive filters like the LC filters are used. If the harmonics’ frequency is inconsistent and frequencies are different, then the active filters are used to compensate for this. Figure 7 (a), (b), and (c) shows the THD of the compensated voltage by DVR; the percentage THD has reduced to 2.69%, 2.40%, and 2.49%. This shows a significant improvement in the voltage profile and a reduction in harmonic content in the load voltages.

C. Case: 2 Injection of 5th Harmonic

In scenario 2, the parameters of the programmable voltage source are changed with 5th harmonics insertion.

![Graph showing distorted voltages](http://www.webology.org)

**Figure 8. Distorted voltages (VLoad) profile without DVR (Scenario 2).**

The duration of change in supply voltage was set to 0.1 sec to 0.4 sec in this scenario. It has also resulted in a distorted voltage waveform with almost identical shapes for all three phases, as shown in Figure 8. The distortion in the wave shape is more in this scenario; however, voltage peaks are less as compared to the previous case. The THD percentage is shown in Figure 16 (a), (b), and (c), which was around 22.56%, 22.56%, and 22.57% for phases a, b and c, respectively. The THD profiles show that the load voltage waveform has 17% of 5th harmonic content in it. Therefore, it has resulted in more than 22% of THD. Most of the world has done work on DVR, and mostly it is for power plants and grid stations. Authors have worked on low voltage distribution lines for controlling voltage fluctuations (sag and swell and harmonics), which is a significant issue in the textile, surgical, and paper industry in Pakistan. All the requisite conditions of DVR are applied according to the requirements of different sectors in Pakistan. Without DVR, THD is almost constant as the significant portion of THD as the input magnitude of inserted harmonics is kept the
same for all the phases. When DVR applied, the distorted voltage is minimized, and as the DVR is involved at different phases having different angles with a 120-degree phase shift so the values will differ in THD due to this change of angle, which is prominent after applying DVR.

![Graphs showing THD in different phases](image1.png)

Figure 9. Without DVR (Scenario 2): (a) THD in Phase A (b) THD in Phase B (c) THD in Phase C.

Installation of FACTS on existing HVAC lines will definitely increase the capability of these lines. Pakistan cannot only rely on increasing the installed capacity of power systems with the same old
power transmission and distribution infrastructure. The transmission capacity should also be improved by adding FACTS devices on the transmission network. This is how electrical utilities can tackle power loss and reactive power compensation in a better way. The installation of FACTS devices requires two types of basic costs; equipment cost and necessary infrastructure costs. The equipment costs significantly rely upon the device’s installation rating.
just as it additionally relies upon other specific necessities like; excess of control and assurance hardware, surrounding conditions, seismic conditions, and correspondence with the substation control framework. The foundation cost relies upon the area at which FACTS should be installed. It comprises of land securing, change in the current substation, development of working for indoor control hardware (insurance thermistor valve, other equipment, and battery banks, and so on.), civil works, and associating the correspondence framework.

5.0 Implementation of DVR for Gepco Subdivision

Due to these advantages of DVR, a proposal for three DVR systems for the Distribution side at Gujranwala Electric Power Company (GEPCO) subdivision at Sialkot is submitted. This scheme can overcome the undesired voltage sags, swell and harmonic distortion at Sambrial, GEPCO sub.
divisions Sialkot, to mitigate these problems output. These problems mostly occur due to extensive use of low-power factor equipment like motors at industrial zones of Sambrial and Sialkot, which sometimes causes significant voltage sag, swell, and harmonics problems and could not be directly checked without particular types of equipment.

The DVR's effectiveness in minimizing voltage drops and spikes is demonstrated through a MATLAB simulation of a basic distribution system. By temporarily connecting various impedances at the supply side bus, voltage dips and spikes may be simulated. In order to connect a DVR to the system, a series transformer is used, which has the capacity to insert a voltage up to half of the phase-to-ground system voltage. In addition, the high-frequency components of the power supply are filtered out using a series filter. The IPC (In-Phase Compensation) technique is employed in this simulation. During the research, a 5.5 MVA capacity load with 0.92 p. f. lagging was used.

![Figure 13: Single-phase voltage sag: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage](http://www.webology.org)
Figure 14: Three-phase voltages sag: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

Figure 15: Three-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage
Figure 16: Two-phase voltages swell: (a)-Source voltage, (b)-Injected voltage, (c)-Load voltage

Figure 17: Voltage waveform

Figure 18: Current waveform
power system with a sensitive load. The DVR is implemented with the test system and investigated with and without DVR. A programmable voltage source is used to supply a distorted voltage with first with 3rd harmonic content and then with 5 th harmonic insertion in the supply voltage. The proposed DVR based control strategy was effective in compensation of the distorted load voltage and maintained a better steady and smooth voltage profile with very less harmonic content in it. To maintain the load voltage normal and steady at the optimal range, the correction of any problem in voltage supply is possible when the DVR injects the suitable voltage component into it. While maintaining the compensation of voltage profile, the THD was reduced to around 4%. Like for scenario 1, the observed THD with DVR case was 2.69%, 2.40%, and 2.69%, and for scenario 2, there were 3.74%, 4.04%, and 3.60% THD in the voltage profile. This improvement and reduction in the THD in load voltage explain the effectiveness of the DVR based control strategy used in this work.

6.0 CONCLUSION
To improve the power quality for sensitive consumers and loads at a lower cost, an unique DVR based on PET has been developed. It has been demonstrated that the proposed PET may effectively improve DC voltage supply and reduce DC-link voltage distortion. Because of HFT's incorporation into the design, neither an injection transformer nor the DC sources themselves need to be severed. A smaller, more accessible DVR is the result of the presence of the proposed PET. Because of the placement of the power electronic transformer (PET) between the DC source and the main line interrupter (MLI), the DVR is able to supply the necessary sinusoidal voltage during fault duration, improving the power quality for accurate. DVR handles all types, balanced and unbalanced fault without any difficulties and injects the appropriate voltage component to correct any fault situation occurred in the supply voltage to keep the load voltage balanced and constant at the nominal value. The simulation based FFT results are shows, the fuzzy logic controller gave a better performance than the PI controller in improving the load voltage to normal conditions.

Future recommendation: The application of control strategy based on soft computing like adaptive Neruo Fuzz controllers for power quality improvement is a promising future perspective of this research. Authors have already implemented Type-2 NeuroFuzzy controls for enhancement of power system stability using STATCOM.

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http://www.webology.org


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