In the present epoch, power quality is the major concern. The quality of power supply is necessary for fully automated industries problems with power quality are an occurrence appeared as a nonstandard voltage, current or frequency that results in a failure of end use equipments. One of the major problems dealt with here is the voltage sags. To solve this problem, custom power device is used. One of those devices is the Dynamic Voltage Restorer (DVR), is used to compensate voltage sag. The DVR generally consists of voltage source inverter (VSI) injection transformers, passive filters and energy storage (battery). The efficiency of the DVR depends on the efficiency of the control technique involved in switching the inverter. The control strategy that is used to generate the pulses by using PI & Fuzzy Logic Controller can be achieved by system studies under different operating and faulty conditions using MATLAB. This paper presents modeling, analysis and simulation of a Dynamic Voltage Restorer (DVR) with PI & Fuzzy Logic Controller using MATLAB.

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INTRODUCTION

This paper analyzes the key issues in the Power Quality (John Stones and Alan Collission, 2001) problems (Bhim Singh, Kamal et al., 1999) especially the present trend towards more distributed generations and consequent restructuring of power transmission and distribution networks. As the prominent power quality problems (Khalid & Bharti Dwivedi, 2011) are Voltage sags and harmonics. The mitigation techniques of voltage sag and harmonics problems have been discussed in detail.

The voltage sags are short duration reduction in the RMS voltage between 0.1 and 0.9 pu. Short duration variation is caused by fault conditions, the energization of large loads which requires high starting current. Important Power quality standards are defined in the IEEE, IEC, CENELEC, ANSI, and NER. The most universally accepted standards for power quality are IEC and IEEE standards.

Electrical software packages for system analysis (Edris, 2000) can be basically divided into two classes of tools:

i) Commercial software’s

ii) Educational/research-aimed software’s

Free software packages available on the internet e.g. are: SPS, PSAT, PSAP, PST, PAT, MATPOWER, EST, MATEMTP, etc.

Commercial software packages available on the market for e.g. are: PSS/E, Euro Stag, Simpow, Dig silent Power Factory, Etap, Power World, CAPE, CYME, etc.

Power Quality Problems and Issues:

A recent survey of Power Quality experts indicates that 50% of all Power Quality problems are related to grounding, ground bones, and neutral to ground voltages, ground loops, ground current or other ground associated issues. Electrically (Akagi, 1990) operated or connected equipment is affected by Power Quality. The commonly used terms those describe the parameters of electrical power that describe or measure power quality are Voltage sags, Voltage variations, Interruptions (Miller, 1992) Swells, Brownouts, Blackouts, Voltage imbalance, Distortion, Harmonics, Harmonic resonance, Inter harmonics, Notching, Noise, Impulse, Spikes (Voltage), Ground noise, Common mode noise, Critical load, Crest factor, Electromagnetic compatibility,
Dropout, Fault, Flicker, Ground, Raw power, lean ground, Ground loops, Voltage fluctuations, Transient (Haque, 2001) Dirty power, Momentary interruption, Over voltage, Under voltage, Nonlinear load, THD, Trip lens, Voltage dip, Voltage regulation, Blink, Oscillatory transient (Dixon et al., 2003) etc.

The distortion in the quality of supply power can be introduced/enhanced at various stages; however, some of the primary sources of distortion (Khalid et al., 2011) can be identified as below:

a. Power Electronic Devices
b. Information Technology and Office Equipments,
c. Arcing Devices,
d. Load Switching,
e. Large Motor Starting,
f. Embedded Generation,
g. Radiation due to Electromagnetism and Cables,
h. Environment Related Causes, etc.

While power disturbances occur on all electrical systems C. (Lin et al., 1989), the sensitivity of today’s sophisticated electronic devices makes them more susceptible to the quality of power supply (Anibal, 2003). A power voltage spike can damage valuable components. Some of the common power quality issues (Bollen, 2000) and their prominent impact are listed in the table 1 below:

<table>
<thead>
<tr>
<th>Problems</th>
<th>Causes</th>
<th>Effects</th>
</tr>
</thead>
<tbody>
<tr>
<td>Voltage Sags</td>
<td>Faults in consumer’s installation.</td>
<td>Tripping of contractors and electromechanical relays, Disconnection of</td>
</tr>
<tr>
<td></td>
<td>Connection of heavy loads, faults and</td>
<td>loss of efficiency in electric rotating machines, etc.</td>
</tr>
<tr>
<td></td>
<td>start-up of Large motors</td>
<td></td>
</tr>
<tr>
<td>Voltage Spikes</td>
<td>Lighting, Switching of lines or power</td>
<td>Destruction of components and of insulation materials, Data processing</td>
</tr>
<tr>
<td></td>
<td>Factor correction capacitors,</td>
<td>errors or data loss, Electromagnetic interference, etc.</td>
</tr>
<tr>
<td></td>
<td>Disconnection of heavy loads.</td>
<td></td>
</tr>
<tr>
<td>Voltage Swells</td>
<td>Start/stop of heavy loads, Poorly</td>
<td>Flickering of lighting and screens, Damage or stoppage or damage of</td>
</tr>
<tr>
<td></td>
<td>dimensioned power sources, Poorly</td>
<td>sensitive equipment, etc.</td>
</tr>
<tr>
<td></td>
<td>regulated transformers.</td>
<td></td>
</tr>
<tr>
<td>Voltage fluctuation</td>
<td>Arc furnaces, Frequent start/stop of</td>
<td>Most consequences are common to under voltages, Flickering of lighting</td>
</tr>
<tr>
<td></td>
<td>electric Motors (for instance elevators),</td>
<td>and screens, etc.</td>
</tr>
<tr>
<td></td>
<td>Oscillating loads.</td>
<td></td>
</tr>
<tr>
<td>Harmonic Distortion</td>
<td>Switched mode power supply, Fluorescent</td>
<td>Conductor overheating, Neutral overloads, Increased probability of</td>
</tr>
<tr>
<td></td>
<td>lighting, 3-phase rectifier, Adjustable</td>
<td>occurrence of resonance, Nuisance tripping of thermal protections,</td>
</tr>
<tr>
<td></td>
<td>speed drive</td>
<td>Loss of efficiency in electric machines, etc.</td>
</tr>
<tr>
<td>Noise</td>
<td>Electromagnetic interferences, Improper</td>
<td>Disturbances on sensitive electronic equipment, usually not</td>
</tr>
<tr>
<td></td>
<td>grounding may also be</td>
<td>destructive. May cause data loss and data processing errors.</td>
</tr>
<tr>
<td></td>
<td>a cause.</td>
<td></td>
</tr>
<tr>
<td>Micro Interruptions</td>
<td>Opening and automatic reclosure of</td>
<td>Tripping of protection devices, loss of information and</td>
</tr>
<tr>
<td></td>
<td>protection devices.</td>
<td>malfunction of data processing equipment. Stoppage of sensitive</td>
</tr>
<tr>
<td></td>
<td>Insulation failure, lightning and</td>
<td>equipment, such as ASDs, PCs, PLCs, if they're not prepared to deal</td>
</tr>
<tr>
<td></td>
<td>insulator flashover.</td>
<td>with this situation.</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Long interruptions</td>
<td>Equipment failure in the power system</td>
<td>Stoppage of all equipment.</td>
</tr>
<tr>
<td></td>
<td>network, Storms and objects (trees, etc.)</td>
<td></td>
</tr>
</tbody>
</table>

2. Power Quality Standards:

Power quality is a worldwide issue and keeping related standards current is a never-ending task. It typically takes years to push changes through the process. Most of the ongoing work of the IEEE in harmonic standards (Torseng, 1981) development has shifted to modifying Standard 519-1992.

1. IEEE 519
   i. IEEE 519 Standards for Current Harmonics.
   ii. IEEE 519 Standards for Voltage Harmonics.
2. IEC 61000-3-2 and IEC 61000-3-4 (formerly 1000-3-2 and 1000-3-4)
   i. IEC 61000-3-2 (1995-03)
   ii. IEC/TS 61000-3-4 (1998-10)
11. Standards related to Voltage Sag and Reliability.
12. Standards related to Flicker.

Standards related to Distributed Generation.

3. Solutions to Power Quality Problems:

Power quality problems (Grady et al, 1991) can basically start at four levels of the system that delivers electric power, first one, includes Power plants and the entire area transmission system. The second one is Transmission lines, major substations where as third one includes distribution substations, primary (Subjak and Mcquilkin, 1990) and secondary power lines, and distribution transformers and last and fourth one includes service equipment and building wiring. Their performance of the devices depends on the power rating and the speed of response (Chandra Sekar et al, 2012). Restructuring of the power sector and with the shifting trend towards distributed and dispersed generation, the line conditioning systems or utility side solutions will play a major part in improving the power quality (Wu and Jou, 1995); some of the active and commercial measures can be identified as listed below:

- Proper designing of the Load equipment.
- Application of passive, active and hybrid harmonic filters.
- Proper designing of the power supply system
- Application of voltage compensators.
- Use of uninterruptible power supplies (UPSs)
- Reliability of standby power
- Constant Voltage Transformers
- Grid Adequacy
- Lightening and Surge Arresters
- Electronic tap changing transformer
- Thyristor Based Static Switches

Distributed Generation (DG)
- Reciprocating engines
- Micro turbines
- Fuel Cells
- Electrochemical batteries
- Flywheels
- Super capacitors
- SMES (Superconducting Magnetic Energy Storage)
- Compressed air.

The various power quality disturbances as shown table 2 and suitable mitigating devices are tabulated below:

<table>
<thead>
<tr>
<th>Types of Disturbances</th>
<th>Transient</th>
<th>Sag</th>
<th>Swell</th>
<th>Interruption</th>
<th>Distortion (Harmonics)</th>
<th>Flicker</th>
<th>Noise</th>
<th>Frequency Deviations</th>
</tr>
</thead>
<tbody>
<tr>
<td>Surge Suppressor</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Filter</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
</tr>
<tr>
<td>Isolation Transformer</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Voltage Regulator</td>
<td>-</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>Power Conditioner</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>UPS</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>SPS</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
</tbody>
</table>

Common problems:
The most common problems in the power system are (Carnovale, 2003).
i. Voltage sags
ii. Harmonics
i. Voltage sags: By IEEE, is a reduction in voltage for a short time. The voltage reduction magnitude is between 10% and 90% of the normal root mean square voltage at 50Hz/60Hz. By the starting of a large induction motor, the most common type of power quality disturbance in the distribution system is Voltage sags. The available voltage sag mitigation devices described below.

- Reactive power compensation principle compensator.
- Shunt Compensation.
- Series Compensation
- Traditional VAR generators.
- Fixed or mechanically switched capacitors.
- Synchronous Condensers
- Thyristorized VAR Compensators
- Self Commutated VAR Compensators.
- Commutated VAR Compensators
- In Self-Commutated VAR Compensators, Semiconductor Devices are used.
- New VAR Compensator’s Technology
- Static Synchronous Compensator (STATCOM).
- Static Synchronous Series Compensator (SSSC).
- Dynamic Voltage Restorer (DVR).
- Unified Power Flow Controller (UPFC).
- Interline Power Flow Controller (IPFC).
- Superconducting Magnetic Energy Storage (SMES).
- VAR Generation Using Coupling Transformers.

4. Comparision Between Thyristorized and Self Commutated Compensators:

As compared with thyristor-controlled capacitor (Enjeti et al., 1992) and reactor banks, self-commutated VAR compensators have the accompanying merits and summarize the comparative merits of the main types of VAR compensators (Hingorani and Gyugyi, 2000). The important merits of self-commutated compensators, as listed in Table 3 make them an interesting alternative to improve compensation characteristics and also to increase the performance of AC power systems.

### Table 3: Comparison of Basic Types of Compensators

<table>
<thead>
<tr>
<th></th>
<th>Synchronous Condenser</th>
<th>TCR (with shunt Capacitors if Necessary)</th>
<th>TSC (with TCR if Necessary)</th>
<th>Self commutated Compensator</th>
</tr>
</thead>
<tbody>
<tr>
<td>Accuracy of</td>
<td>Good</td>
<td>Very Good</td>
<td>Good, very good With TCR</td>
<td>Excellent</td>
</tr>
<tr>
<td>Compensation</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control Flexibility</td>
<td>Good</td>
<td>Very Good</td>
<td>Good, very good With TCR</td>
<td>Excellent</td>
</tr>
<tr>
<td>Reactive Power</td>
<td>Leading/Lagging</td>
<td>Lagging/Lagging Indirect</td>
<td>Leading/Lagging Indirect</td>
<td>Leading/Lagging</td>
</tr>
<tr>
<td>Capability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>Continuous</td>
<td>Continuous</td>
<td>Continuous (Cont. With TCR)</td>
<td></td>
</tr>
<tr>
<td>Response Time</td>
<td>Slow</td>
<td>Fast, 0.5 to 2 cycles</td>
<td>Fast, 0.5 to 2 cycles</td>
<td>Very fast, but depends on the control system and switching frequency</td>
</tr>
<tr>
<td>Harmonics</td>
<td>Very Good</td>
<td>Very high (larger size filters are needed)</td>
<td>Good, filters are Necessary with TCR</td>
<td>Good, but depends on switching pattern</td>
</tr>
<tr>
<td>Losses</td>
<td>Moderate</td>
<td>Good, but increase in lagging mode</td>
<td>Good, but increase in leading mode</td>
<td>Very good, but Increase with Switching frequency</td>
</tr>
<tr>
<td>Phase Balancing</td>
<td>Limited</td>
<td>Good</td>
<td>Limited</td>
<td>Very good</td>
</tr>
<tr>
<td>Ability</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Cost</td>
<td>High</td>
<td>Moderate</td>
<td>Moderate</td>
<td>Low to moderate</td>
</tr>
</tbody>
</table>

ii. Harmonics: It is a sinusoidal component of a periodic wave or quantity having a frequency that is an integral multiple of the fundamental power frequency.

Available solution for harmonizing

- Passive filters
- Active filters
- Active Series
- Active Shunt
- Hybrid of Active Series and Passive Shunt
• Hybrid of Active Shunt and Active Series

The different types of filters (Uceda et al. 1983) its various applications and differentiate as per the preferable filter are tabulated below in table 4:

Table 4: Active filter's for compensation in order of preference. Active filters Configuration with higher number of “X” is more preferred.

<table>
<thead>
<tr>
<th>S.no</th>
<th>Compensation for particular Application</th>
<th>Active Series</th>
<th>Active Shunt</th>
<th>Hybrid of Active Series and Passive Shunt</th>
<th>Hybrid of Active Shunt and Active Series</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.</td>
<td>Voltage Harmonics</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>2.</td>
<td>Current Harmonics</td>
<td>XX</td>
<td>XXX</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>3.</td>
<td>Reactive Power</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>4.</td>
<td>Load Balancing</td>
<td>X</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>5.</td>
<td>Voltage Regulation</td>
<td>XXX</td>
<td>X</td>
<td>XX</td>
<td>X</td>
</tr>
<tr>
<td>6.</td>
<td>Neutral Current</td>
<td>XX</td>
<td>X</td>
<td></td>
<td></td>
</tr>
<tr>
<td>7.</td>
<td>Voltage balancing</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
<td>X</td>
</tr>
<tr>
<td>8.</td>
<td>Voltage Flicker</td>
<td>XX</td>
<td>XXX</td>
<td>X</td>
<td></td>
</tr>
<tr>
<td>9.</td>
<td>Voltage Sag &amp; Dips</td>
<td>XXX</td>
<td>X</td>
<td>XX</td>
<td>X</td>
</tr>
<tr>
<td>10.</td>
<td>Current harmonics &amp; Reactive power</td>
<td>XXX</td>
<td>XX</td>
<td>X</td>
<td></td>
</tr>
</tbody>
</table>

5. Methodology and Implementation:

The present electric power distribution system have risen of electronics, electrical devices are flattering smaller and more sensitive to power quality deviations. The load equipments of the modern generation are more sensitive than the equipment used in the past. The deficiency of power quality can initiate production loss, economic loss and environmental effect. The sags, swells and harmonics are the most important and frequently occurring power quality problems in the distribution system. The Custom Power Devices (CPDs) are used in the power distribution system to mitigate the above-mentioned power quality problems. In addition to that, the CPDs are also used to compensate reactive power, current harmonics filtering, load current balancing and power factor correction. The performance of CPDs for instance DVR in electric power distribution system to amendment the PQ is greater significance. The DVR is able to compensate load voltage from the incoming distorted source voltage.

The use of PI and fuzzy logic in power conditioning devices are the newest techniques for the fastest response. It will provide fast dynamic response in this thesis, PI controlled DVR is modeled for a PQ enhancement in a three-phase, three wire, power distribution system. A three leg VSI is used to inject or absorb the appropriate voltage through an LC filter and an injection transformer to compensate load voltage from the distorted supply voltage. In addition to that, the DVR is also used to protect the sensitive linear load. The simulation results show the effectiveness of the voltage restoration and its performance investigation of both control techniques.

The general arrangement of the DVR consists of:

i. An Injection/ Booster transformer
ii. A Harmonic filter
iii. Storage Devices
iv. A Voltage Source Converter (VSC)
v. DC charging circuit
vi. A Control and Protection system
**PI controller:**

PI controller will eliminate forced oscillations and steady state error resulting from operation of on-off controller and P controller respectively. However, introducing an integral mode has a negative effect on the speed of the response and overall stability of the system.

![Fig. 3: Line Model Closed loop with PI controller.](image)

**Fuzzy logic Controller:**

Fuzzy logic is a problem solving methodology, just like Logic control and Linear Control. “Fuzzy Logic deals with those imprecise conditions about which a true/false value cannot be determined” (Introduction to Fuzzy Logic). Pioneered the Japanese, Fuzzy Logic is currently a growing concept in the field of controller design because it provides simple and easy, yet reliable control system. Some of the current applications of Fuzzy Logic in daily devices include washing machines, camcorders, microwave ovens and dozens more electrical and electronic devices.

![Fig. 4: Line Model Closed loop with Fuzzy logic Controller.](image)
Simulation Results:

Fig. 5: Sag generated in feeder (F1) and effected supply in feeder (f2).

Fig. 6: Sag generated in feeder (F1) and effected supply in feeder (f2).

Fig. 7: Sag generated in feeder (F1) and effected supply in feeder (f2).

Fig. 8: Sag generated in feeder (F2) and effected supply in feeder (f1).

Fig. 9: Effected supply in the same feeder (F2) where fault is connected.

Fig. 10: Sag generated in feeder (F2).

Fig. 11: Compensation of sag after injecting the voltage in (f1) with PI controller.

Fig. 12: Compensation of sag after injecting the voltage in (F2) with PI controller.

Fig. 13: Compensation of sag after injecting the supply voltage in (F2) with PI.

Fig. 14: Injected voltage through DVR.

Fig. 15: Given pulse in the Bridge converter.

Fig. 16: P & Q Values during Compensation with PI.
in (F1) with Fuzzy controller.

Fig. 18: Compensation of sag after injecting the voltage in (F2) with Fuzzy controller.

6. Conclusion:
In this paper has presented the power quality problem of voltage sag and Compensation techniques of custom power electronic devices DVR were presented. The design and applications of DVR for voltage sags and comprehensive results were presented, the simulation model of a nonlinear load connected power distribution system with Dynamic voltage Restorer controlled by PI and FUZZY logic Controller has been developed using Matlab/ Simulink. The results presented in this paper show that, different levels of voltage sag caused by three phases with ground fault and other fault are effectively compensated by the proposed DVR system.

REFERENCES


