Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 344-352

AENSI Journals

Australian Journal of Basic and Applied Sciences

ISSN:1991-8178

Journal home page: www.ajbasweb.com

Intelligent Controller Based Custom Power Device In Transmission Line

[1]A. Kannan, [2]B. Justus Rabi and [3]T. Chandrasekar

[1]*Research Scholar, Dr.M.G.R .Educational and Research Institute - Department of Electrical and Electronics, Chennai. India, 600095*
[2]*Principal, Shri Andal Alagar College of Engineering, Chennai, India*
[3]*Research Scholar, St Peter's University- Department of Electrical and Electronics, Chennai, Tamil Nadu, India - 600054.*

ARTICLE INFO

Article history:
Received 19 August 2014
Received in revised form
19 September 2014
Accepted 29 September 2014
Available online 3 November 2014

Keywords:
Power quality, voltage sag, intelligent controller, voltage source inverter, dynamic voltage restorer

ABSTRACT

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.

To Cite This Article: A.Kannan, B. Justus Rabi, T. Chandrasekar., Intelligent Controller Based Custom Power Device In Transmission Line. ***Aust. J. Basic & Appl. Sci.,*** *8(17): 344-352, 2014*

INTRODUCTION

This paper analyzes the key issues in the Power Quality (John Stones and Alan Collinsion, 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,

Corresponding Author: A. Kannan, Research Scholar, Dr. M.G.R. Educational and Research institute - Department of Electrical and Electronics Engineering, Chennai. India -600095.

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 1: Various power quality problems, causes and their effects.

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

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
3. IEEE Standard 141-1993, Recommended Practice for Electric Power Distribution for Industrial Plants.
4. IEEE Standard 142-1991, Recommended Practice for Grounding of Industrial and Commercial Power Systems.
5. IEEE Standard 446-1987, Recommended Practice for Emergency and Standby Power Systems for Industrial and Commercial Applications.
6. IEEE Standard 493-1997, Recommended Practice for Design of Reliable Industrial and Commercial Power Systems.

7. IEEE Standard 1100-1999, Recommended Practice for Powering and Grounding Sensitive Electronic Equipment.
8. IEEE Standard 1159-1995, Recommended Practice for Monitoring Electric Power Quality.
9. IEEE Standard 1250-1995, Guide for Service to Equipment Sensitive to Momentary Voltage Disturbances.
10. IEEE Standard 1346-1998 Recommended Practice for Evaluating Electric Power System Compatibility with Electronic Process Equipment.
11. Standards related to Voltage Sag and Reliability.
12. Standards related to Flicker.
13. Standards related to Custom Power.

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 2: PQ disturbances with mitigating equipments.

Type of Equipments	Types of Disturbances							
	Transient	Sag	Swell	Interruption	Distortion (Harmonics)	Flicker	Noise	Frequency Deviations
Surge Suppressor	Yes	-	-	-	-	-	-	-
Filter	-	-	-	-	Yes	-	Yes	-
Isolation Transformer	Yes	-	-	-	-	-	Yes	-
Voltage Regulator	-	Yes	Yes	-	-	-	-	-
Power Conditioner	Yes	Yes	Yes	-	-	-	Yes	-
UPS	Yes	Yes	Yes	Yes	Yes	Yes	Yes	Yes
SPS	-	-	-	Yes	-	-	-	-

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 Commuted VAR Compensators.
- Commuted 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 Commuted 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.

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

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.

S.no	Compensation for particular Application	Active Filters			
		Active Series	Active Shunt	Hybrid of Active Series and Passive Shunt	Hybrid of Active Shunt and Active Series
1.	Voltage Harmonics	XXX		XX	X
2.	Current Harmonics		XX	XXX	X
3.	Reactive Power		XXX	XX	X
4.	Load Balancing		X		
5.	Voltage Regulation	XXX	X	XX	X
6.	Neutral Current		XX	X	
7.	Voltage balancing	XXX		XX	X
8.	Voltage Flicker	XX	XXX		X
9.	Voltage Sag & Dips	XXX	X	XX	X
10.	Current harmonics & Reactive power		XXX	XX	X

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.

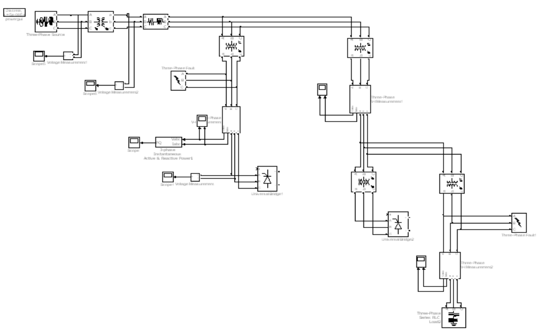

Fig. 1: Line Model Open Loop Simulation.

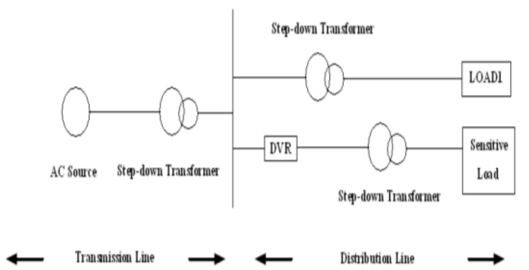

Fig. 2: Location of DVR.

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

Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 344-352

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.

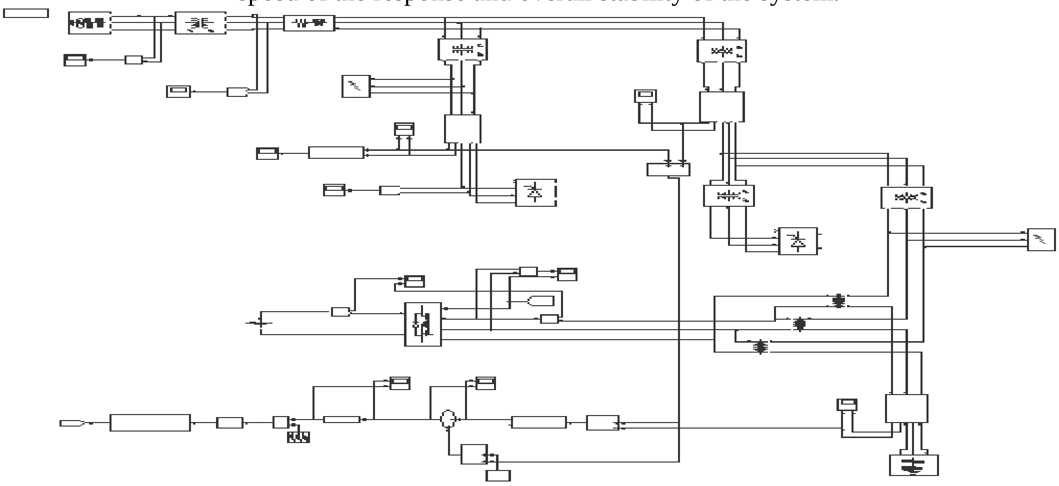

Fig. 3: Line Model Closed loop with PI controller.

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.

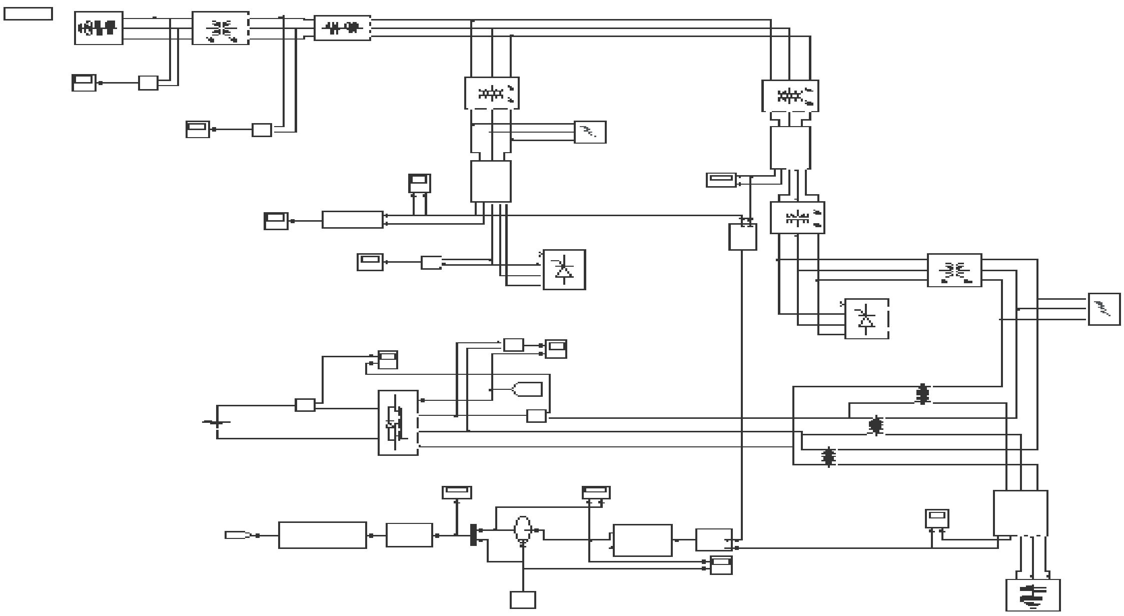

Fig. 4: Line Model Closed loop with Fuzzy logic Controller.

Australian Journal of Basic and Applied Sciences, 8(17) November 2014, Pages: 344-352

Simulation Results:

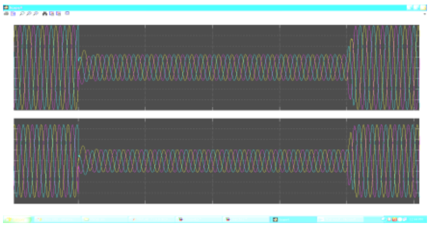
Fig. 5: Sag generated in feeder (F1) and effected supply in feeder (f2).

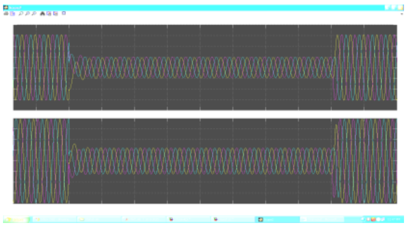
Fig. 6: Sag generated in feeder (F1) and effected supply in feeder (f2).

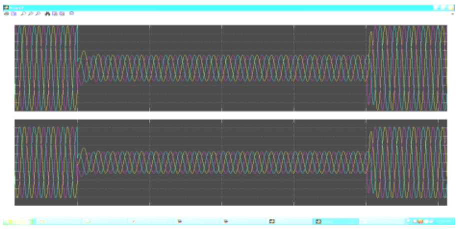
Fig. 7: Sag generated in feeder (F1) and effected supply in feeder (f2).

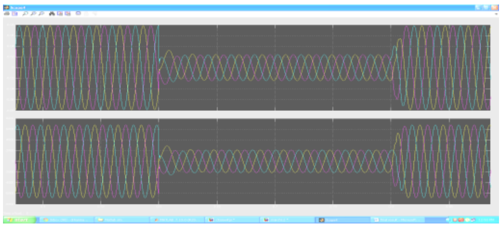
Fig. 8: Sag generated in feeder (F2) and effected supply in feeder (f1).

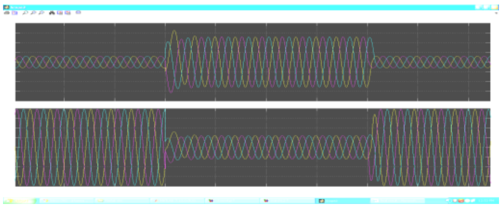
Fig. 9: Effected supply in the same feeder (F2) where fault is connected.

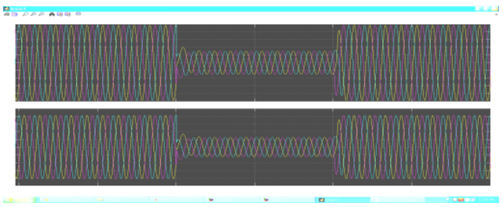
Fig 10: Sag generated in feeder (F2).

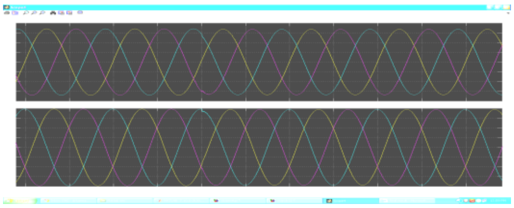
Fig. 11: Compensation of sag after injecting the voltage in (f1) with PI controller.

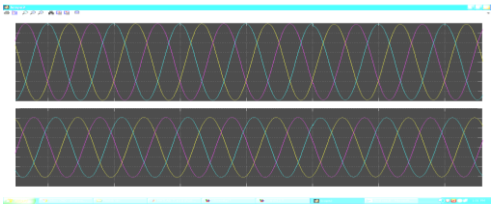
Fig. 12: Compensation of sag after injecting the voltage in (F2) with PI controller.

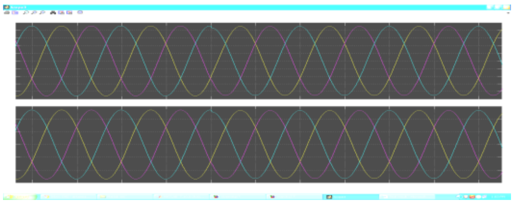
Fig. 13: Compensation of sag after injecting the supply voltage in ($F2_1$) with PI.

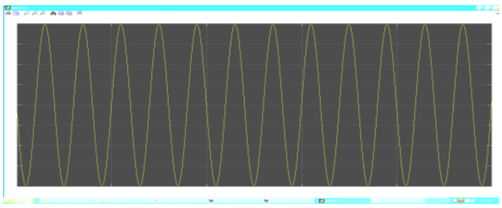
Fig 14 : Injected voltage through DVR.

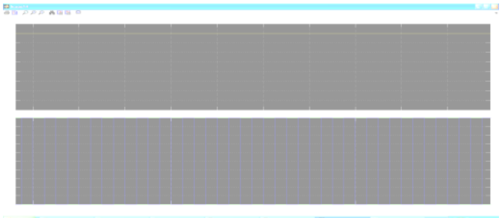
Fig. 15: Given pulse in the Bridge converter.


Fig. 16: P & Q Values during Compensation with PI.

Fig. 17: Compensation of sag after injecting the Voltage in (F1) with Fuzzy controller.

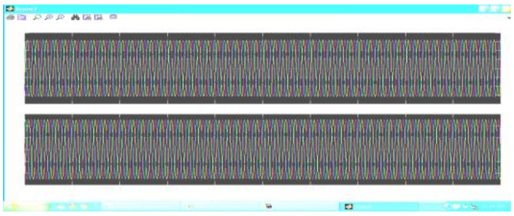

Fig 18: Compensation of sag after injecting the voltage in (F2) with Fuzzy controller.

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

Akagi, H., Y. Tsukamoto and A. Nabae, 1990. *"Analysis, design of an active power filter using quad-series voltage source PWM converters," IEEE Trans. Ind. Applicat.*, 26: 93-98.

Anibal, T. de Almeida, 2003. ”*Power Quality Problems and New Solutions*”, Universidade de Coimbra, Vigo, 9-11.

Bhim Singh, Kamal Al-Haddad, Ambrish Chandra, 1999. ”*A Review of Active Filters for Power Quality Improvement*” *IEEE Transactions On Industrial Electronics*, 46(5).

Bollen, M.H.J., 2000.*“Understanding Power Quality Problems—Voltage Sags and Interruptions”* Piscataway, New York: IEEE Press.

Bhattacharya, S., B. Fardenesh, B. Shperling, S. Zelingher, 2005.*“Convertible Static Compensator: Voltage Source Converter Based FACTS Application in the New York 345 kV Transmission System”,* International Power Electronics Conference, IPEC 2005, Niigata, Japan, pp: 2286-2294.

Chuco, B.P., ”*Electrical software tools overview*” Centro de Investigations Electrical Electronics del Peru – CIEEP, SINATEC-IEEE, Telf. 51-1- -240 0407.

Choi, J.H., G.W. Park and S.B. Dewan, 1995. *"Standby power supply with active power filter ability using digital controller,"* in *Proc. IEEE APEC'95,* pp: 783-789.

Carnovale, Daniel J., 2003. *“Price and Performance Considerations for Harmonic Solutions.”* Power Quality Conference, Chicago, IL.

Chandra Sekar, T., B.Justus Rabi and A. Kannan, 2014. “Harmonics Reduction In Front End Rectifier of Uninterruptible Power Supplies with Active Current Injection” -*American Journal of Applied Sciences,* 11(4): 564-569.

Chandra Sekar, T., B. Justus Rabi, 2012. “Review and Study of Harmonic Mitigation Techniques” in *Proc. IEEE ICETEEEM*, pp: 93-97.

Dixon, J.W., Y. del Valle, M. Orchard, M. Ortúzar, L. Morán and C. Maffrand, 2003. *“A Full Compensating System for General Loads, Based on a Combination of Thyristor Binary Compensator, and a PWM-IGBT Active Power Filter”,* IEEE Transactions on Industrial Electronics, 50(5): 982-989.

Edris, A., 2000. *“FACTS Technology Development: An Update,”* in IEEE Power Engineering Review, pp: 4-9.

Enjeti, P., W. Shireen and I. Pitel, 1992. *"Analysis, design of an active power filter to cancel harmonic currents in low voltage electric power distribution systems,"* in *Proc. IEEE IECON'92,* pp: 368-373.

Haque, M.H., 2001. *Compensation of distribution system voltage sag by DVR and DSTATCOM”* Power Tech Proceedings, 2001 IEEE Porto, 1: 1-5.

Hingorani, N.G. and L. Gyugyi, 2000. *“Understanding FACTS: Concepts and Technology of Flexible AC Transmission Systems”,* 1st edition, The Institute of Electrical and Electronics Engineers.

John Stones and Alan Collinsion, 2001. “*Introduction to Power Quality”* power engineering journal, pp: 58-6.

Khalid, S., Bharti Dwivedi, 2011.”*Power qualities issues, problems, standard & there effects in industry with corrective means*” IJAET, ISSN: 2231-1963.

Larsson, M., 2004. ObjectStab *An Educational Tool for Power System Stability Studies"*, *IEEE Trans. Power Syst.*, 19(1): 56-63.

Lin, C.E., T.C. Chen and C.L. Huang, 1989. "*A real time calculation method for optimal reactive power compensator*," *IEEE Trans. Power Syst.*, 4: 643-652.

Miller, T.J.E., 1982. "*Reactive Power Control in Electric Systems.* Toronto, Canada: Wiley, pp: 328.

Peng, F.Z., H. Akagi and A. Nabae, 1990. *"A study of active power filters using quad-series voltage-source PWM converters for harmonic compensation," IEEE Trans. Power Electron,* 5: 9-15.

Peng, F.Z., H. Akagi and A. Nabae, 1993.*"Compensation characteristics of the combined system of shunt passive and series active filters,"* IEEE Trans. Ind. Applicat., 29: 144-151.

Sen, K. and A.E. Emanuel, 1987. *"Unity power-factor single-phase power conditioning,"* in *Proc. IEEE PESC'87,* pp: 516-524.

Subjak, J.S. Jr. and J.S. Mcquilkin, 1990. *"Harmonics-causes, effects, measurements, analysis: An update," IEEE Trans. Ind. Applicat,* 26: 1034-1042.

Shuter, T.C., H.T. Vollkommer, Jr. and J.L. Kirkpatrick, 1989. *"Survey of harmonic levels on the American electric power distribution system," IEEE Trans. Power Delivery,* 4: 2204-2213.

Takahashi, I., 1983. *"A flywheel energy storage system having distorted power compensation,"* in *Proc. IPEC-Tokyo,* pp: 1072-1083.

Torseng, S., 1981.*"Shunt-Connected Reactors and Capacitors Controlled by Thyristors,"* IEE Proc. Part C, 128(6): 366-373.

Uceda, J., F. Aldana and P. Martinez, 1983. *"Active filters for static power converters," Proc. Inst. Elect. Eng.,* 130(5): 347-354.

Wu, J.C. and H.L. Jou, 1995. *"A new UPS scheme provides harmonic suppression, input power factor correction," IEEE Trans. Ind. Electron.,* 42: 629-635.

Williams, S.M. and R.G. Hoft, 1988. *"Discrete controlled harmonic, reactive power compensator,"* in *Conf. Rec. IEEE-IAS Annu. Meeting,* pp: 881-887.

Walker, L., 1986.*"Force-Commutated Reactive Power Compensator,"* IEEE Trans. Industry Application, IA-22(6): 1091-1104.