IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE)
e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 14, Issue 6 Ser. II (Nov. – Dec. 2019), PP 34-44
www.iosrjournals.org

Control Strategies for Power Quality Improvement Using Dynamic Voltage Restorer

M.Sharanya[1], Dr. Basavaraja Banakara[2], Dr. M.Sasikala[3]
[1] *Department of Electrical & Electronics Engineering, MRCET, Hyderabad, Telangana, India*
[2] *Davangere University. Davangere, Karnataka.*
[3] *Department of Electrical Engineering, GECW, Gulbarga, Karnataka, India.*

Abstract: *Power quality(PQ) is important topic of concern in power sector now. Increasing use of technology in industrial as well as domestic loads has led to various PQproblems. Harmonics, Voltage swell and sag are some common PQproblems caused due to the extensive use of semiconductor devices in the loads. In present paper it is proposed that by use of Custom Power Devices(CPD's) these PQproblems can be reduced. The CPD considered in this paper is Dynamic Voltage Restorer(DVR). Proportional and Integral (PI) controller and Repetitive Controller are the controllers used to generate the pulses for the active filter used in the CPD's. DVR and controllers are designed using MATLAB/SIMULINK. Results obtained by controllers are presented and compared.*

Keywords: *Power Quality, Custom Power Devices, Dynamic Voltage Restorer, Hybrid Active Power Filter, Repetitive Controller MATLAB/SIMULINK.*

Date of Submission: 31-12-2019 Date of Acceptance: 15-01-2020

I. Introduction

Power quality has become important in the distribution industry. Every power consumer is clear of what type of voltage and current is required by them so that the loads are not damaged or effected [11]. With the use of various nonlinear loads, the power distributed to the consumers is having various power quality problems like voltage sag, voltage swell, harmonics, flickers etc. Voltage sag occur due to turning on of large motors, adjustable speed drives and some equipment's like arc furnaces, welders, smelters etc. [3]. Dynamic Voltage Restorer(DVR) is one of the Custom Power Devices(CPD) which is used to improve the voltage quality [1]. If the voltage sag prevails for longer time, then it may damage the equipment. To protect the equipment's, DVR should be able to inject the required voltage as quickly as possible [4].

In this paper the working of DVR is considered with the control methods like Proportional Integral (PI) controller and Repetitive controller. From the results it is shown that repetitive controller is better method compared to PI controller as outputs obtained by this method is much superior. The three control methods are explained in detail and then the simulation results are presented for each method.

II. Dynamic Voltage Restorer(DVR)

DVR is a CPD used to improve the voltage quality in the distribution system. DVR can effectively reduce voltage sag, voltage swell and voltage unbalance. A DVR basically consists of an injection transformer, energy storage device, filters, inverter and its control circuit [2]. Fig.1. shows the block diagram of a DVR.

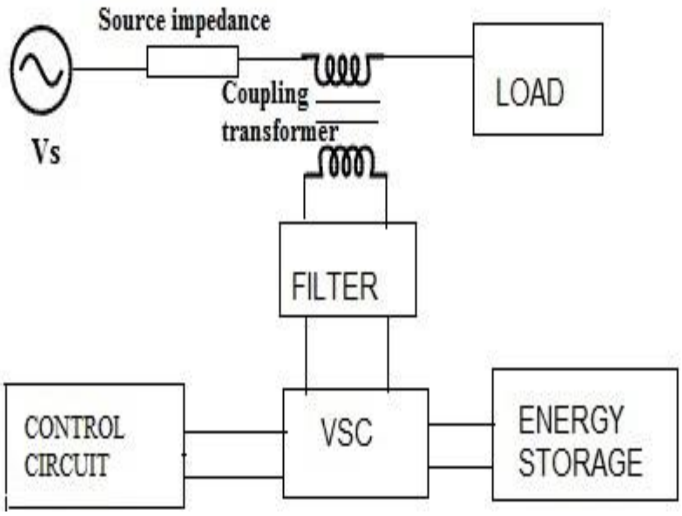

Figure 1 Block diagram of a DVR

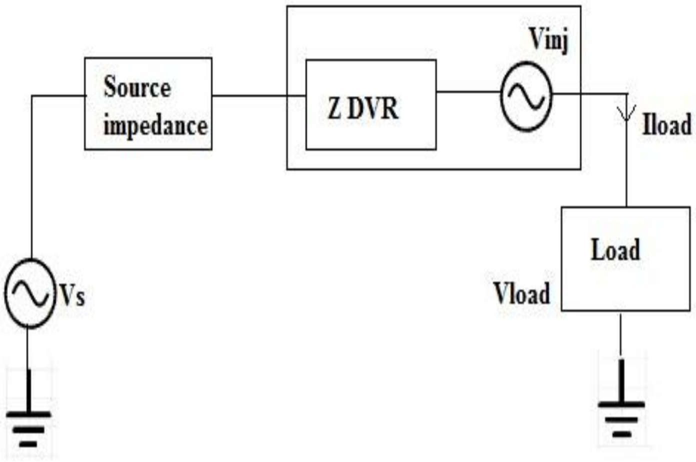

Figure 2 Equivalent circuit of DVR

When system voltage drops from a specific value due to any fault, series volt,V_{DVR} is injected by DVR through an injection transformer such load voltage, Vload is maintained at the desired value [5].

$$V_{DVR} = V_{load} + Z_s * I_{load} - V_s \qquad (1)$$

Where
V_{load} = Load voltage, Z_s = Source impedance, I_{load} = Load Current, V_s = Source voltage
Considering I_{load} as I_L, V_{load} as V_L, Zs as Z_{Th} and Vs as V_{Th}.
The load current I_L is given as

$$I_L = \frac{[P_L + j\,Q_L]}{V} \qquad (2)$$

The equation (2) can be rewritten by considering V_L as reference [6]

$$V_{DVR}\angle \propto = V_L\angle 0 + Z_{Th}\angle(\beta - \theta) - V_{Th}\angle\delta \qquad (3)$$

Where ∝, β and δ are the angles of V_{DVR}, Z_{Th} and V_{Th} respectively. Θ is the power angle.

$$\theta = \tan^{-1}\frac{Q_L}{P_L} \qquad (4)$$

The complex injection of DVR is given as

$$S_{DVR} = V_{DVR}\, I_L^{*} \qquad (5)$$

III. P-I Controller

Using necessary assumptions, mathematical model is built with various quantities on dynamics of system. Control strategy can be derived mathematically if objective is defined in precise mathematical terms [7]. Figure 3shows block diagram of closed loop system.

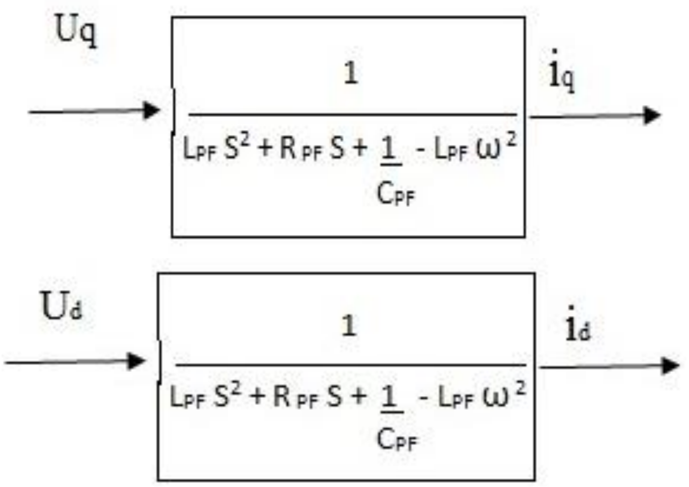

Figure3 Block diagram for closed loop system

The control law is applied to dynamic model equations (6) and (7).

$$L_p\frac{d2}{dt2}i_d + R_p\frac{d}{dt}i_d + \left(-\omega^2L_p + \frac{1}{Cp}\right)i_d = 2\omega L_p\frac{d}{dt}i_q + \omega R_p i_q + \frac{dVd}{dt} - \omega V_q \tag{6}$$

$$L_p\frac{d2}{dt2}i_q + R_p\frac{d}{dt}i_q + \left(-\omega^2L_p + \frac{1}{Cp}\right)i_q = 2\omega L_p\frac{d}{dt}i_d + \omega R_p i_d + \frac{dVq}{dt} - \omega V_d \tag{7}$$

For making system equations (6) and (7) linear, two input variables U_d and U_q are to be substituted such that

$$U_d = 2\omega L_p\frac{d}{dt}i_q + \omega R_p i_q + \frac{dVd}{dt} - \omega V_q \tag{8}$$

$$U_q = 2\omega L_p\frac{d}{dt}i_d + \omega R_p i_d + \frac{dVq}{dt} - \omega V_d \tag{9}$$

Hence equations (8) and (9) become linear. The corresponding transfer functions are

$$\frac{i_d}{U_d} = \frac{1}{\left(L_pS^2 + R_p S + \frac{1}{Cp} - \omega^2 L_p\right)} \tag{10}$$

By using the error signals

$\widetilde{i_d} = i_d^* - i_d$ & $\widetilde{i_q} = i_q^* - i_q$

Figure 4shows the block diagram of closed loop system in q-axis. Figure 5 gives the block diagram of closed loop system in d-axis.

Then applying PI compensation U_d & U_q are chosen such that

$$U_d = K_p\widetilde{i_d} + K_i \int \widetilde{i_d}\,dt \tag{11}$$

$$U_q = K_p\widetilde{i_q} + K_i \int \widetilde{i_q}\,dt \tag{12}$$

The transfer function of P-I controller is given as

$$G(s) = \frac{U_q(s)}{\widetilde{i_q}(s)} = \frac{U_d(s)}{\widetilde{i_d}(s)} = K_p + \frac{K_i}{s} \tag{13}$$

Closed loop transfer function of current loop is

$$\frac{i_q(s)}{\widetilde{i_q}(s)} = \frac{i_d(s)}{\widetilde{i_d}(s)} = \frac{K_p}{L_p}\left[\frac{s + \frac{K_i}{K_p}}{s^3 + \frac{K_p}{L_p}s^2 + \left(\frac{1}{CpL_p} - \omega^2 + \frac{K_p}{L_p}\right)s + \frac{K_p}{L_p}}\right] \tag{14}$$

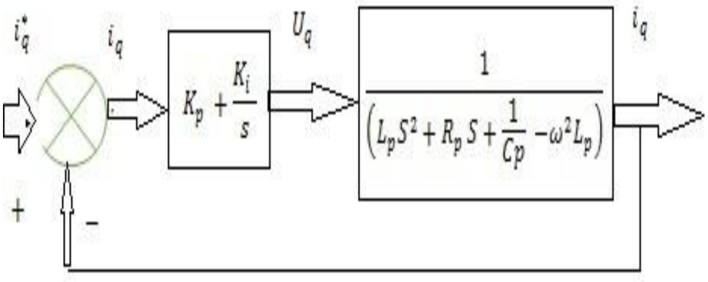

Figure4 Block diagram of closed loop system in q-axis

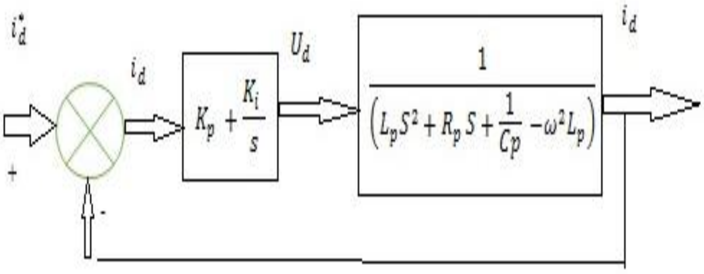

Figure5 Block diagram of closed loop system in d-axis

IV. Repetitive Controller

Control method regulates load voltage or current in presence of various disturbances. Control structure is based on use of feedforward term of voltage or current at PCC to obtain fast transient response and feedback term of load voltage or current to ensure zero error in steady state.
Load voltage is

$$V(S) = e^{\frac{(-2\pi)s}{(w1)}} V^*(S) + \left[1 - e^{\frac{(-2\pi)s}{(w1)}}\right] e^{-t_0 s} +$$
$$\left[1 - e^{\frac{(-2\pi)s}{(w1)}}\right] [(1 - e^{-t0s}) V_{pcc}(S) - P_2(S) I(S) \tag{15}$$

But by using this controller delay,t_0 is not exactly known and closed loop system will not be stable. To tackle this problem, a modified controller C(S) is proposed as

$$C(S) = \frac{Q(s)\, e^{-(\tau - to)s}}{1 - Q(s) e^{-Ts}} \tag{16}$$

Where Q(S) is the transfer function of a low pass filter to is the estimated value of the time delay for DVR with $T = \frac{(2\pi)}{(w1)} - \beta$

The transfer functions F(S), $F_w(S)$, $F_i(S)$ with the new modified controller C(S) are:

$$F(S) = \frac{[e^{-t_0 s} + Q(s) e^{-Ts}(e^{-\delta s} - e^{-t_0 s})}{1 + Q(s) e^{-Ts}(e^{-\delta s} - 1)} \tag{17}$$

$$Fw(S) = \frac{[1 - e^{-t_0 s}][1 - Q(s) e^{-Ts}]}{1 + Q(s) e^{-Ts}(e^{-\delta s} - 1)} \tag{18}$$

$$F_i(S) = \frac{[1 - Q(s) e^{-Ts}] P_2(s)}{1 + Q(s) e^{-Ts}(e^{-\delta s} - 1)} \tag{19}$$

With $\delta = t_0 - t_0$^
The characteristic equation of the resulting closed loop system is

$$1 + Q(S) e^{-Ts}(e^{-\delta s} - 1) = 0 \tag{20}$$

Where $G(s) = Q(S) e^{-Ts}(e^{-\delta s} - 1)$

In order to guarantee stability term G(s) in equation(20) must comply with Nyquist criterion: if no. of unstable poles of open loop system G(s) is equal to zero (p=0), then no. of counter clock wise encirclements of the pt (-1,0) of term G(jω) must be zero (N=0) with $-\infty < \omega < \infty$.
Since all poles of Q(S) are stable, which implies that P=0, then N must be zero to guarantee stability and a

sufficient condition for Q(S) can be obtained by making

$$G(s) = \left| Q(S)e^{-Ts}\left(e^{-\delta s} - 1\right)\right| < 1\forall\omega \qquad (21)$$

Which is fulfilled if

$$2\left|\sin\left(\frac{\partial}{2}\omega\right)\right| \left|Q(j\,\omega)\right| < 1\forall\omega$$

V. Simulation Results

The DVR test system consists of 3phase, 415V, 50Hz supply. Output of the supply feeds the 3windings of transformer. 2parallel feeders are drawn. One feeder is kept as it is. DVR is connected in series with other feeder.

The circuit parameters are as below.
Supply 3phase,
Voltage 415V,
Frequency 50Hz.
Inverter 6pulse, 3 arm, IGBT based,
Carrier frequency 1080Hz
Sample time 5µsecs.

A. Results with P-I Controller

Fig.6 shows that there is drop in source voltage from 0.2s to 0.6s. The RMS Sag voltage supply waveform is shown in Fig. 8. With the use of DVR required voltage is injected and hence the load voltage profile is improved which can be seen in fig.7. The RMS load voltage is shown in Fig. 9.

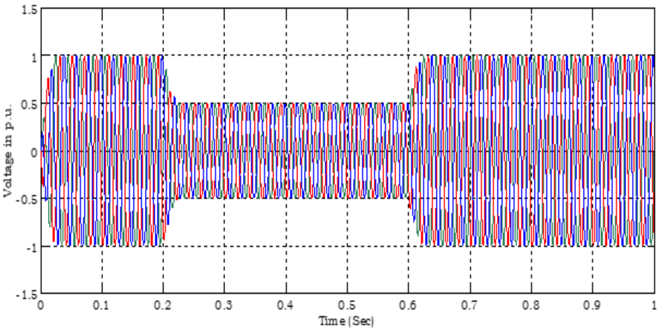

Figure 6 Source voltage with sag

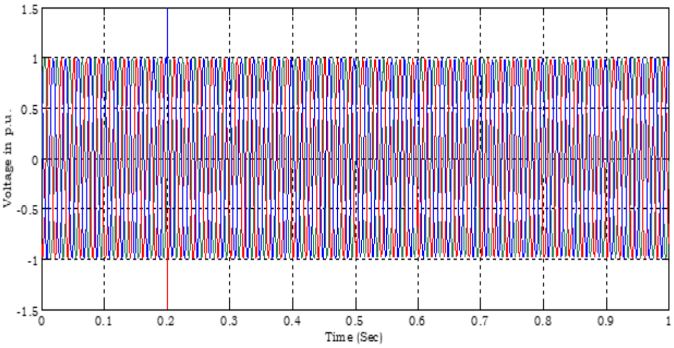

Figure 7 Load voltage with DVR

Fig.10 shows that the supply voltage has a swell during the period from 0.2s to 0.6s. The RMS supply voltage wave is shown in Fig.12. The load voltage profile is improved by the use of DVR with PI controller which can be seen in fig.11. The corresponding RMS waveform is shown in fig.13.

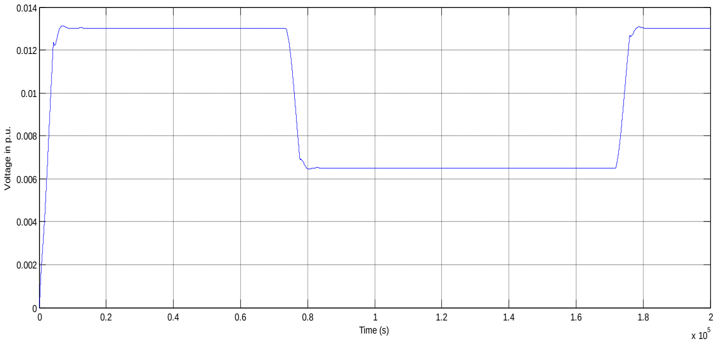

Figure 8 RMS Source voltage

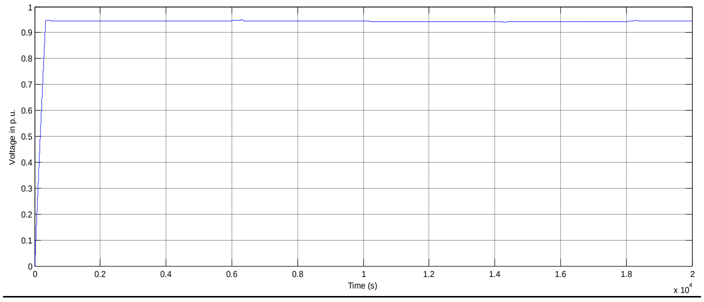

Figure 9 RMS Load Voltage

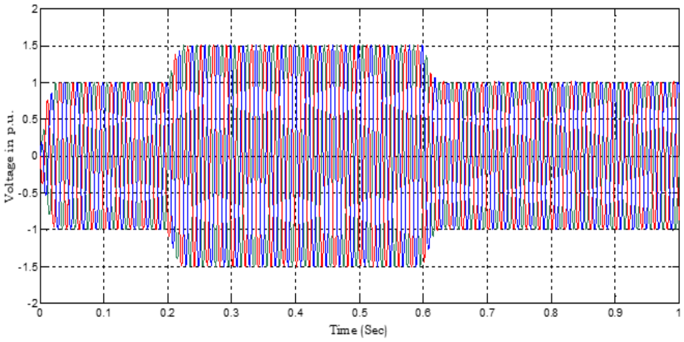

Figure 10 Supply voltage with swell

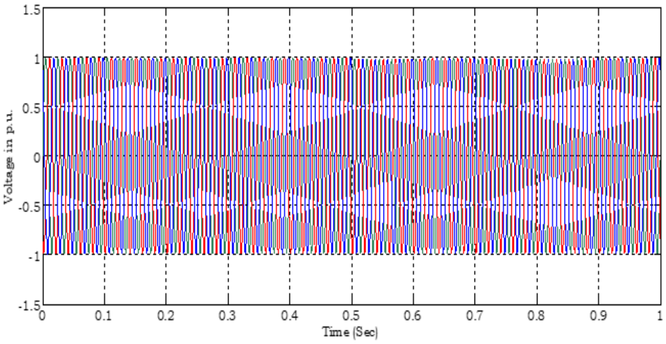

Figure 11 Load voltage with DVR

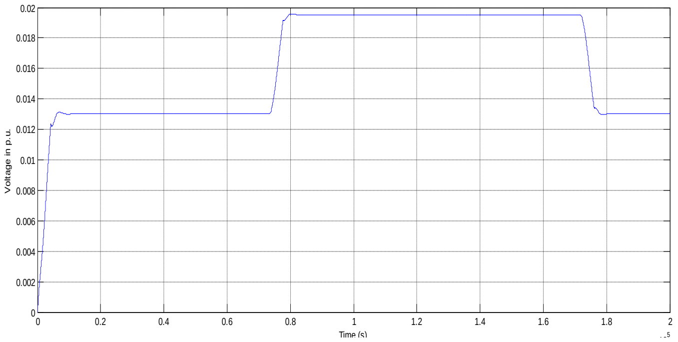

Figure 12 RMS supply voltage with swell

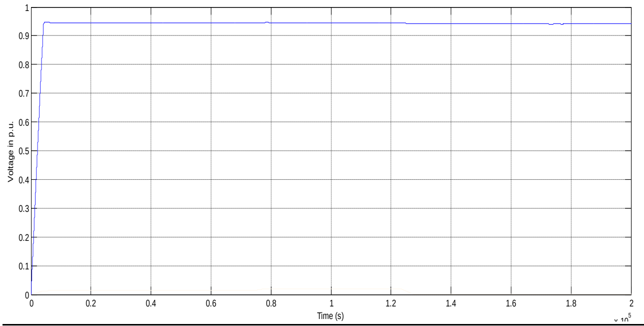

Figure 13 RMS Load voltage

Fig.14. shows the source voltage with sag and swell conditions. Fig. 16. Shows the RMS source voltage. Voltage sag is between the duration 0.1s to 0.3s and voltage swell is between the duration 0.5s to 0.7s. The improved voltage profile can be seen in the fig.15 and fig.17. The table I shows the Total Harmonic Distortion(THD) of source and load voltage with sag, swell and sag-swell conditions with PI controller.

Table I

	Source voltage %THD	Load Voltage %THD
Voltage Sag	19.76%	4.77%
Voltage Swell	17.07%	4.5%
Voltage Sag & Swell	17.23%	4.82%

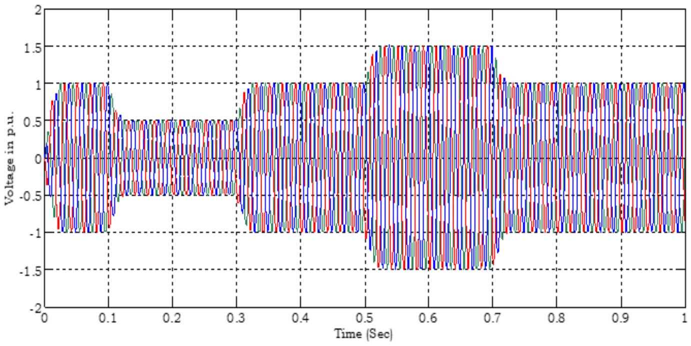

Figure 14 Source voltage with sag and swell

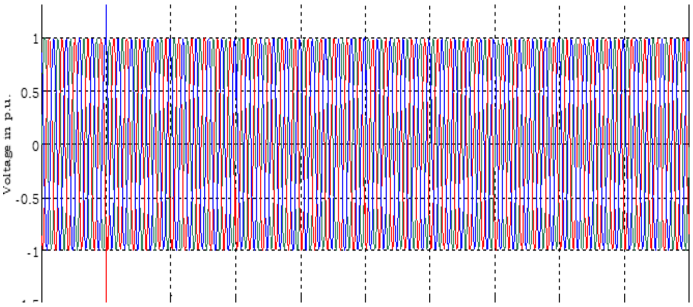

Figure 15 Load voltage

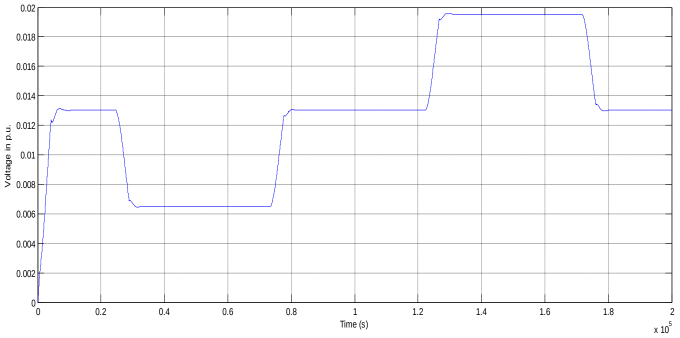

Figure 16 RMS source voltage

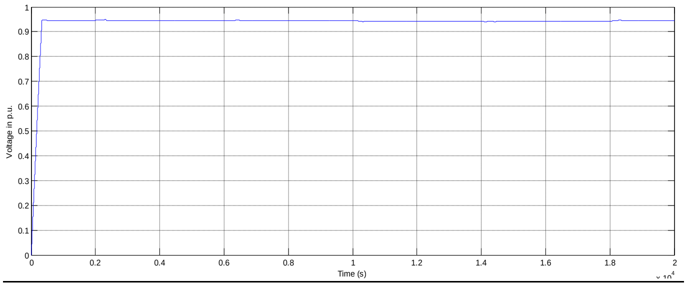

Figure 17 RMS Load Voltage

B.Results with Repetitive Controller

The source voltage waveform is shown in fig.18. Voltage Sag can be seen form 0.4ms to 0.6ms. With repetitive controller of DVR, voltage is injected during this interval of 0.4ms to 0.6ms which can be seen in fig.19. After the injected voltage the load voltage is improved and this can be seen in fig.20 The RMS voltage for sag condition can be seen in fig.21.

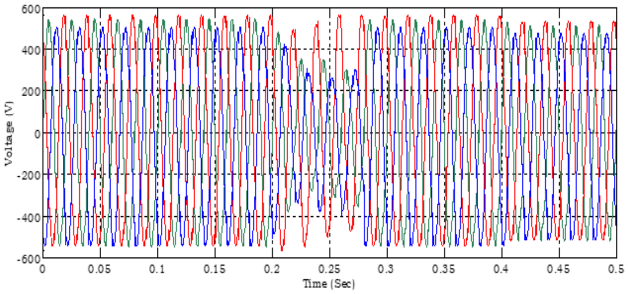

Figure 18 Source voltage

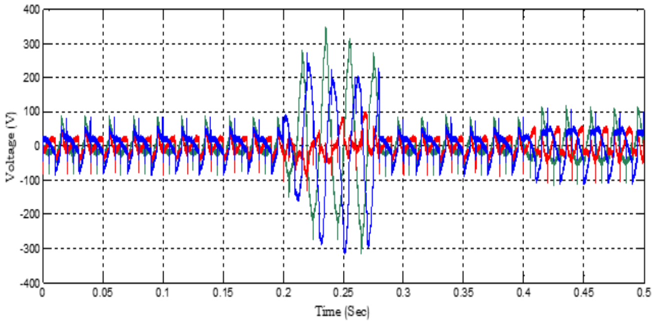

Figure 19 DVR injected voltage

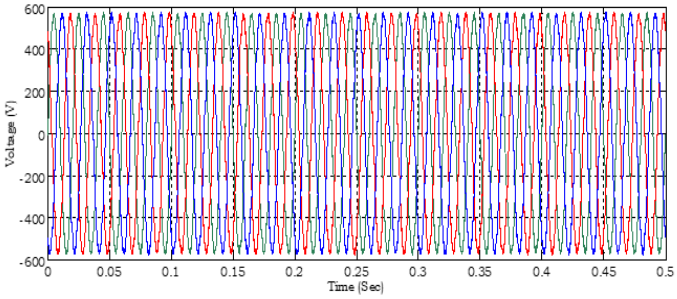

Figure 20 Load voltage

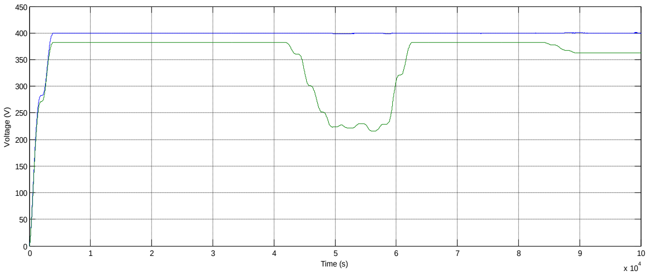

Figure 21 RMS source and Load voltages

Fig.22 shows the voltage sag condition in source voltage in individual phases. The per phase injected voltage can be seen in fig.23. The improved load voltage per phase is seen in fig.24.

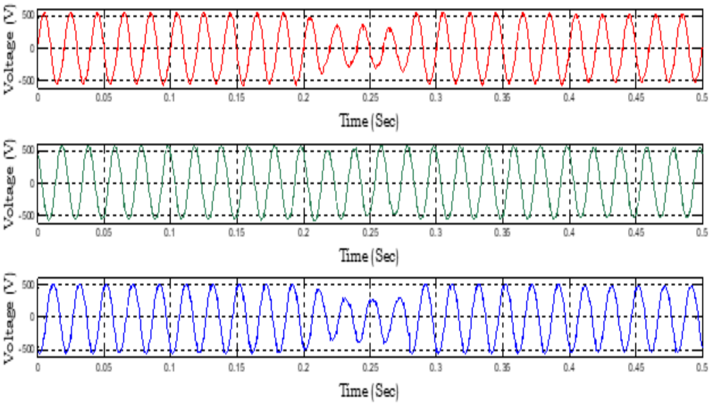

Figure 22 Source voltage with sag

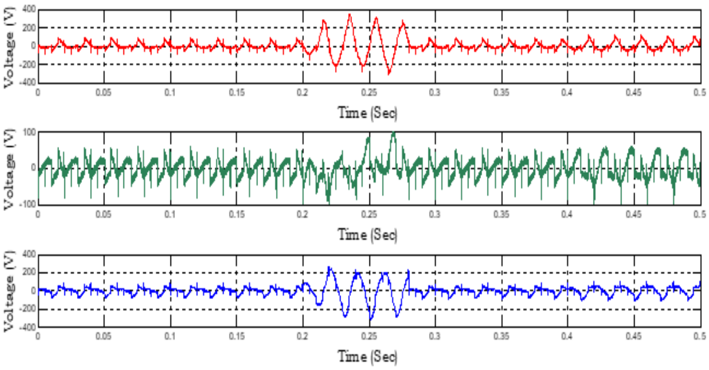

Figure 23 DVR Injected voltage

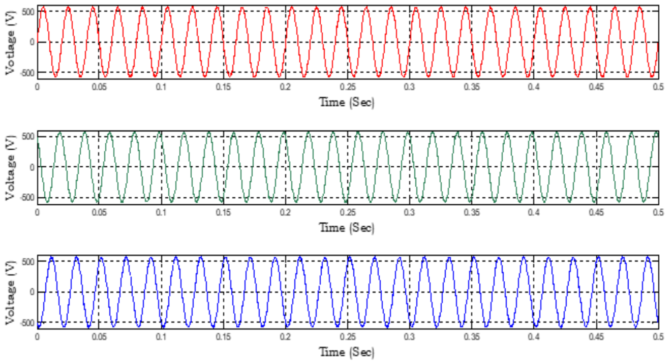

Figure 24 Load voltage

The Total Harmonic Distortion of source and load voltages with PI controller, Repetitive controller and Discrete Fourier transforms can be seen in Table-II.

Table-II

	PI Controller	Repetitive Controller
Source Voltage THD	19.76%	15.42%
Load Voltage THD	4.77%	3.50%

VI. Conclusion

Dynamic Voltage Restorer (DVR) is a series compensating device used to reduce the voltage harmonics injected due to various faults and nonlinear loads. In this paper working of DVR is considered with PI controller and Repetitive controller. The source and load voltage waveform are shown for all the conditions. The THD values of source and load voltages are checked for PI and repetitive controllers and compared. With PI controller the source voltage THD is 19.76% and load voltage THD is 4.77%. With repetitive controller the source voltage THD is 15.42% and load voltage THD is 3.50%. Working of DVR is much faster with repetitive controller and the THD of load voltage is reduced considerably. The waveforms obtained with this controller is also much superior when compared to PI controller. This shows that the working of DVR with repetitive controller is effective in mitigating voltage sag and improving voltage quality.

References

[1]. Chennai Salim and Benchouia Mohamed Toufik, “Three-phase Three-level (NPC) Shunt Active Power Filter Performances based on PWM and ANN’s Controllers for Harmonic Current Compensation”, International Journal on Electrical Engineering and Informatics, IJEEI, Volume 6, Number 1, March 2014, PP- 203-224.

[2]. M.Sharanya, Dr Basavaraja.B and Dr M.Sasikala, “Voltage quality improvement and harmonic mitigation using Custom Power Devices : DVR and Hybrid Filters”, 2013 IEEE Asia Pacific Conference on Postgraduate Research in Microelectronics and Electronics (PrimeAsia), 978-1-4799-2751-7/13 2013 IEEE.

[3]. Navid Khorrami,” Analyzing of Dynamic Voltage Restorer in Series Compensation Voltage”, Research Journal of Applied Sciences, Engineering and Technology 4(3): 159-164, 2012.

[4]. Rosli Omar, N.A. Rahim and Marizan Sulaiman,” Dynamic Voltage Restorer Application for Power Quality Improvement in Electrical Distribution System: An Overview**”,** Australian Journal of Basic and Applied Sciences, 5(12): 379-396, 2011.

[5]. P. Usha Rani, S.Rama Reddy, “ European Journal of Scientific Research, ISSN 450-216X Vol.56 No.4 (2011), pp.462-470, EuroJournals Publishing, Inc. 2011.

[6]. Ms. M. Sharanya, Dr. Basavaraja Banakara and Dr. M. Sasikala,"Comparison of Control Methods for Power Quality Improvement Using Dynamic Voltage Restorer and Hybrid Active Power Filter", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) e-ISSN: 2278-1676,p-ISSN: 2320-3331, Volume 13, Issue 1 Ver. III (Jan. – Feb. 2018), PP 52-63.
[7]. K.Sandhya, Dr. A.Jaya Laxmi, Dr. M.P.Soni, 2012, Design of PI and FUZZY controllers for Dynamic Voltage Restorer (DVR), 2012 AASRI conference on power and energy, AASRI Procedia 2(2012) 149-155.
[8]. Hirofumi Akagi, New trends in active filters for power conditioning**,** IEEE Transactions on Industry Applications, VoL 32, NO 6, November- December 1996.
[9]. R. H. Salim, K. R. C. de Oliveira, A. D. Filomena, M. Resener, and A. S. Bretas, "Hybrid fault diagnosis scheme implementation for power distribution systems automation," IEEE Trans. Power Deliv., vol. 23, no. 4, pp. 1846–1856, 2008.
[10]. M. Pourahmadi-Nakhli and A. A. Safavi, "Path characteristic frequency-based fault locating in radial distribution systems using wavelets and neural networks," IEEE Trans. Power Deliv., vol. 26, no. 2, pp. 772–781, 2011.
[11]. M.Sharanya, Dr. Basavaraja.B and Dr. M.Sasikala," An Overview of Dynamic Voltage Restorer for Voltage Profile Improvement", International Journal of Engineering and Advanced Technology (IJEAT) ISSN: 2249 – 8958, Volume-2, Issue-2, December 2012.

AUTHORS PROFILE

Mrs. M. Sharanya[1] have completed her B. Tech and M.Tech in 2001 and 2007 respectively from Jawaharlal Nehru Technological University, Hyderabad. She is pursuing her Ph.D. from the same university. She is having 18years of teaching experience. Her areas of interest include Electrical machines, power electronics, drives, power quality and custom power devices. She is presently working as HoD, Department of EEE, Malla Reddy College of Engineering and Technology, Hyderabad, Telangana, India. M. Sharanya is a Life Member of the Indian Society of Technical Education (ISTE), Institute of Engineers (India) (IEI) and Institute of Electronics and Telecommunication Engineering (IETE).

Dr.Basavaraja Banakara2 was born in 1970. He is senior IEEE member SINCE 2005. He Obtained his B.Tech (EEE) Degree from Gulbarga University and M.Tech from Karnataka University, INDIA. He obtained his Doctorate degree from National Institute of Technology Warangal in 2007.Presently he is working as Registrar, Davangere University, Davangere, Karnataka, India. His areas of interest include Adjustable Speed drives, high voltage Engineering, Micro grids and EMTP applications.

Dr M.Sasikala3 was born in 1962. She is a member of IEEE. She has obtained her BE and ME from Osmania college of Engineering, Osmania University, Hyderabad, India. She has obtained her Doctorate degree from Jawaharlal Nehru Technological University Hyderabad in 2008. Presently she is working as Principal in Godutai Engineering College for Women, Gulbarga, Karnataka, India. Her areas of interest include Electrical machines, sensors and Fuzzy logic controllers.

M.Sharanya. "Control Strategies for Power Quality Improvement Using Dynamic Voltage Restorer". IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE) 14.6 (2019): PP 35-44.