International Journal of Advance Research in Science and Engineering
Volume No. 11, Issue No. 04, April 2022
www.ijarse.com

IJARSE
ISSN 2319 - 8354

Improvement in Power Quality using a Controller Assisted Dynamic Voltage Restorer

Kamlesh Patel[1], S.R. Kapoor[2]

1(Electrical Engineering, Rajasthan Technical University Kota, India)

2(Electrical Engineering, Rajasthan Technical University Kota, India)

ABSTRACT: *Power quality is one of the major issues in the power system. Power quality problems originate due to an increase in the demand for non-linear load and power electronic equipment. This study focuses on power quality problems found in distributed systems. The most commonly observed disturbances in the power system are voltage swell, voltage sag, harmonics, voltage flicker, etc. which are being analyzed here to improve the power quality. A dynamic voltage restorer (DVR) is the most convenient device that is used in power distribution networks to reduce the voltage sags and compensate for power quality problems. Analysis, modelling and simulation of a dynamic voltage restorer (DVR) test system using MATLAB/Simulink have been done to minimize voltage sag and swell by control strategies based on the Park's transformation. The Park's transformation converts the voltage into a rotation vector from the stationary frame. The total harmonic distortion (THD) is minimized at the load voltage. The use of DVR reduced rating compensate for the voltage sag, voltage swell, and harmonics. Performance and evaluation of the model have been done with and without DVR for voltage sag, voltage swell and total harmonic distortion (THD). By using Park's transformation, a total harmonic distortion with voltage sag of 1.04% and voltage swell of 1.21% is obtained for all three phases of the distribution system. A low passive filter is used to smooth the waveform. With the help of MATLAB Simulink, the performance of the dynamic voltage restorer (DVR) has been analyzed using the control unit technique.*

Keywords: Dynamic voltage restorer, power quality, voltage sag, voltage swell, harmonics, Park's transformation controller, MATLAB Simulink, Simulink simulation.

1. INTRODUCTION

The electrical power system is a complex network that is interconnected by many generating stations and thousands of loads are connected through long transmission lines and distribution networks. Electrical energy is a well-regulated and simple form of energy that can easily transform into other forms of energy along with continuity and its quality has been maintained for a good economy. Power quality has a major concern for today's power industries and domestic consumers. Industrial and domestic equipment is quite sensitive to voltage unbalances or disturbances in equipment. Even a small fraction of the second voltage sag can damage the equipment which results in the maintenance of power quality problems in the distribution system [1].

Power quality is the main concern to variation of voltage and current waveform. This power quality issue is due to short interruptions like voltage swell, voltage sag, flickers, harmonics, transients, etc. [2]. The short circuit fault in the distribution system is mainly due to the voltage sag and swell, flicker, voltage unbalance and harmonics etc. Among these, power quality causes the voltage related disturbance problem and malfunction of devices and leads to disconnection of the power system [3],[4].

Voltage sags and swell occur frequently in the power distribution system and are responsible for malfunction in the system [5-6]. As per IEEE standards, voltage sag is defined as "The decrease in the root mean square (RMS) voltage level to 10-90% of nominal value, at the power frequency for durations of half-cycle to one minute" [7-8].

For many custom power devices, the DVR is the most advanced and economical device used for sag mitigation in distribution power systems. The study and design of the DVR control scheme and modelling structure and the operating principle of DVR are shown and different techniques are discussed [9-12].

The basic operational principle of the DVR is to inject the voltage in series with the sources through a transformer. When this problem voltage, i.e., voltage sag and swell detected in power disturbance in line, then DVR restore the load to a nominal value of voltage by injecting active and reactive power into the feeder connected between source to load. For voltage stability, DVR injects voltage into the distribution power system. When the disturbance occurs in the system, DVR calculates the voltage requirements to protect the load through the SPWM and Park's transformation [13-17].

The main aim is to control a unit that maintains constant voltage at the side of a sensitive load connected under system disturbance. The technique of sinusoidal pulse width modulation and the PI controller is used for controlling the DVR. The output of VSI may contain the harmonics which can be filtered on the VSI side to smooth the voltage waveform. DVR also performs harmonics compensation and total harmonics distortion is within the acceptable limit [18-21]. This paper analyses dynamic voltage restorer (DVR) test systems using MATLAB/Simulink to reduce voltage sag and total harmonic distortion (THD) by use of Park's transformation control strategies and compares the better result than the output [22-23].

2. DYNAMIC VOLTAGE RESTORER

The power quality problem sags, swells, harmonics, flickers and transients etc. can be mitigated using custom power devices. One of these devices is a dynamic voltage restorer (DVR). DVR is the most effective and efficient power device used in the distribution system. A DVR is a solid-state device located in series with the load voltage to inject a voltage into the distribution network. A DVR is a voltage source inverter that injects a controlled voltage in series to supply voltage through an injected transformer to improve the load voltage. A schematic diagram of DVR is shown in figure 1. It consists of IGBT or GTO based voltage source inverter, injection transformer, a low passive filter, energy storage instruments, capacitor bank and control units.

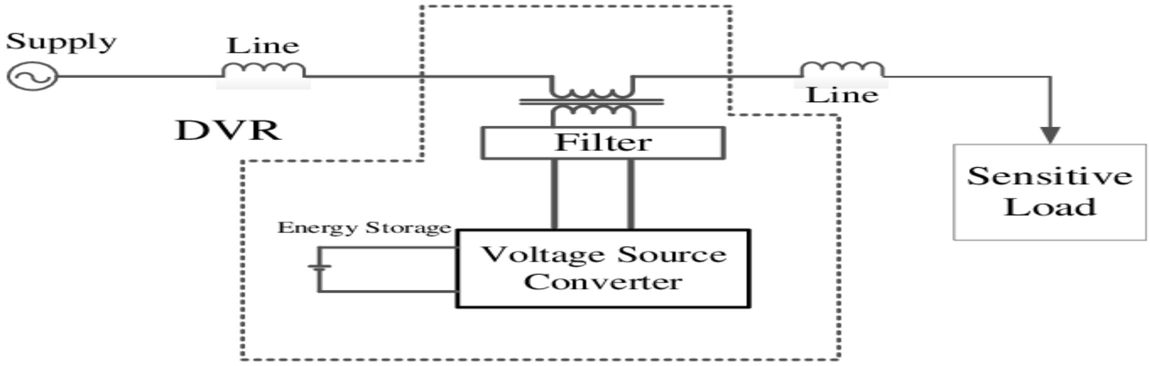


FIGURE 1. Schematic diagram of DVR

2.1. Voltage Source Inverter (VSI)

The function of VSI is to convert fixed supply voltage to variable supply voltage (DC -AC). In modern pulse width modulation, VSI is used widespread. The AC output of VSI is connected to the secondary winding of a series injection transformer voltage through an AC low passive filter and input is connected to energy storage. The output voltage of VSI is balanced and pure sinusoidal voltage with the same phase sequence and desired magnitude of the system.

2.2. Voltage Injection Transformer

A voltage injection transformer is a step-up transformer, whose primary terminal is connected through a distribution line in a series and the second terminal is connected through the power circuit of DVR. For a three-phase DVR, a single three-phase transformer or three single-phase transformers can be used. The role of DVR is to properly compensate for the missing voltage. The amount of voltage swell and voltage sag compensated by DVR depends on the rating of the inverter and injection transformer.

2.3. Passive Filter

The function of a low passive filter is to remove the harmonics components when the pulse width modulation VSI pulse waveform gets converted into the sinusoidal waveform and changes the compensated output voltage. It can either be used with the inverter side or voltage injection transformer. Putting the filter on the inverter side to helps to overcome the maximum value of harmonics passing through the transformer.

2.4. Energy Storage Unit

Many devices are used for energy storage such as lead-acid batteries, superconducting magnetic energy storage (SMES), DC capacitors, flywheels, and supercapacitors. During compensation, the storage unit provides the required active power to the system.

2.5. Control Unit

The detection of the disturbance in a network system by comparing the reference voltage and supply voltage is done by the control unit. It also generates the signal to the VSI in order to compensate for the voltage of the DVR. Park's transformation is used to control the resulting voltage in such systems.

3. CONTROL UNIT BASED ON PARK'S TRANSFORMATION

The efficiency of a DVR mainly depends on the Park's transformation control unit technique. This control scheme is proposed to improve DVR operation. It has a faster response when a requirement under disturbance occurs. In this process of voltage disturbances, DVR reacts very fast and injects AC voltage into the given system network. Then this DVR detects the disturbance voltage by sensing the load voltage and transfers from abc/dqo Park's transformation controller which converts the three-phase load into a sinusoidal waveform. The controller helps to estimate the error value as a difference between the reference voltage and load voltage measured on the system. After that, inverse transformation takes place and converts the three-phase voltage(abc) to three-phase sinusoidal AC output using dqo/abc inverse Park's transformation controller which is directly injected into the PWM generator. The PWM provides the best way of controlling VSI to produce AC power to DC power. The pulse width modulation technique is used to obtain the sinusoidal output voltage. The reference is needed from VSI so it could modulate the carrier signal from its shape. A phase loop (PLL) is used to maintain frequency and phase matched with the output signal with a reference. This is the use of a phase shift detector and frequency of the feedback system in a phase-locked loop controller.

The equation shows the dqo Park's transformation controller is used to employ in control of DVR:

$$\begin{bmatrix} Va \\ Vb \\ Vc \end{bmatrix} = \frac{2}{3}\begin{bmatrix} \cos\omega t & \cos\left(\omega t - \frac{2\pi}{3}\right) & \cos\left(\omega t + \frac{2\pi}{3}\right) \\ \sin\omega t & \sin\left(\omega t - \frac{2\pi}{3}\right) & \sin\left(\omega t + \frac{2\pi}{3}\right) \\ \frac{1}{2} & \frac{1}{2} & \frac{1}{2} \end{bmatrix} * \begin{bmatrix} Vd \\ Vq \\ V0 \end{bmatrix}$$

The control unit circuit of the dynamic voltage restorer can be summarized from of control DVR with the Park's transformation controller.

4. SIMULATION AND RESULTS

The model of DVR is described in Fig. 1 and is displayed using MATLAB/Simulink Sim Power System toolbox using MATLAB 2020 software. The performance of DVR is studied with the dq0 based algorithm.

Table 1. Parameters and values of the test system

Parameters	Values
Supply Voltage	415V
Frequency	50Hz
Load power factor	0.75
Converter	IGBT
Load active power	7.50KW
Load reactive power	6.61KW

The MATLAB software simulation parameters of the distribution system are given in Table 1. The system load of 10KVA with a load power factor of 0.75 has been taken into consideration and the load is considered a sensitive load. The Simulink model of the test system with DVR is shown in Figure 2.

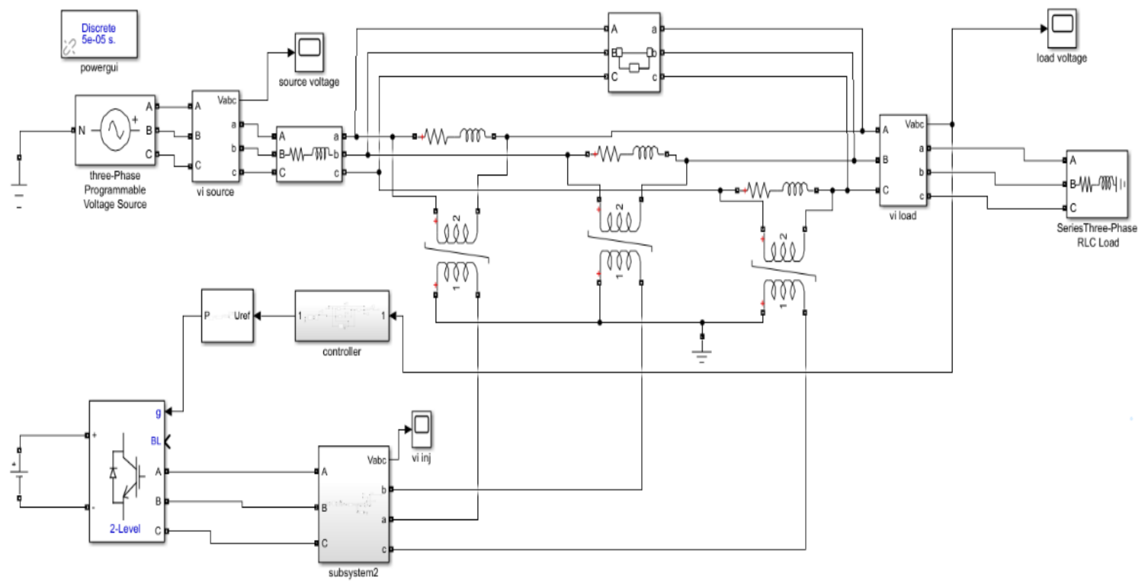


FIGURE 2. Simulink model of the test system with DVR

A load is supplied with the 415 V, 50Hz frequency in a three-phase programmable voltage source through the RL source, and an active and reactive load is connected to the system. For control purposes, the injected transformer is connected through the three-phase lines. This injected transformer is connected to the three-phase low passive filter to voltage sources inverter. A gate pulse is connected to the PWM generator and Park's transformation control unit. The load when connected from 0.6s to 0.9s time, there occurs a sag and swell in the voltage when DVR comes into action. A schematic diagram of the control unit of DVR is shown in Figure 3.

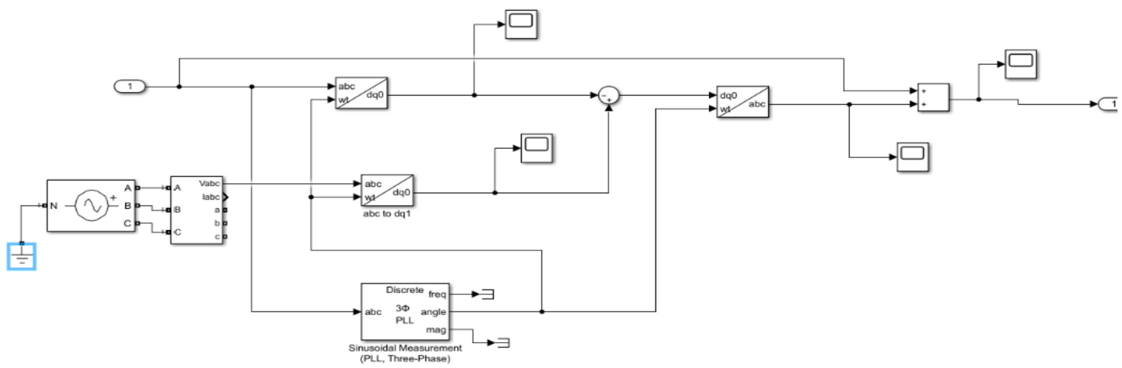


FIGURE 3. Schematic diagram of a control unit of DVR

The DVR system is connected through the distribution transmission line with the help of an injection transformer. A gate pulse to the PWM voltage source converter with connected through the controller circuit and a pulse from the error signal is compared through reference voltage. The reference voltage is brought out by the control algorithm from source voltage to load voltage V_{ref}, the whole process is succeeded in the feedback control technique.

The simulation of a three-phase system has been conducted with and without DVR connected with the load in the MATLAB/Simulink system. In scenario 1, THD is found for voltage sag with or without DVR with the Park's transformation control unit. Voltage sag without DVR is connected to the test system, and then the distorted output load voltage waveform is shown in Figure 4. The DVR is disconnected from the system. The load is connected during transient time 0.6s to 0.9s and there is sag that occurs in the system.

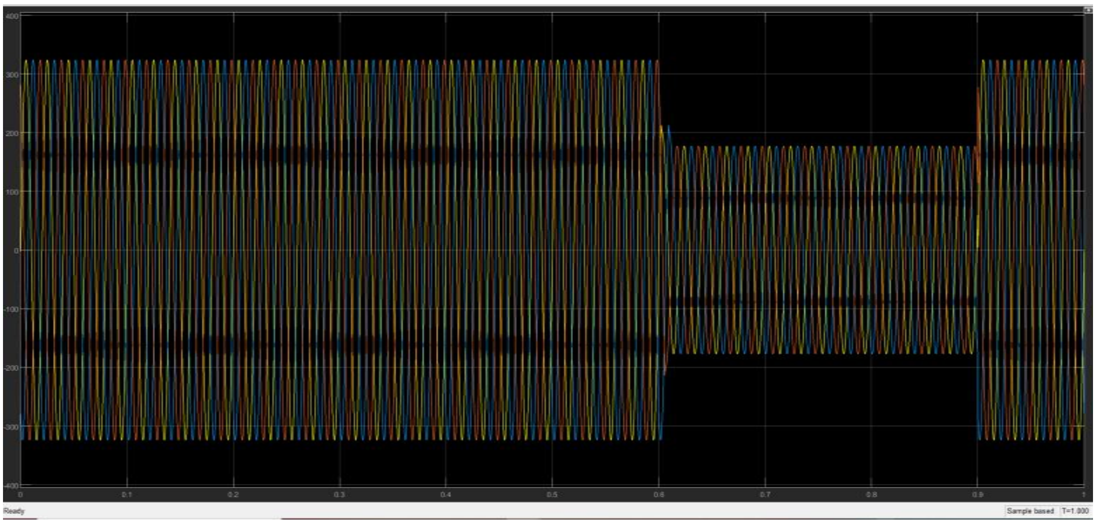


FIGURE 4. Output distorted load voltage in the test system without DVR for voltage sag

When DVR is connected to the test system, then DVR is used to compensate for the output load voltage during transient occurs at 0.6 to 0.9 seconds in the test system. During this injection, the voltage during transient continuous power is supplied to the load without any distortion in load voltage. Compensated load voltage in the test system with DVR for voltage sag is shown in Figure 5. DVR is used to inject the voltage when distortion occurs in the line. DVR is used to inject voltage at transient power conditions from 0.6 to 0.9 seconds as shown in Figure 6.

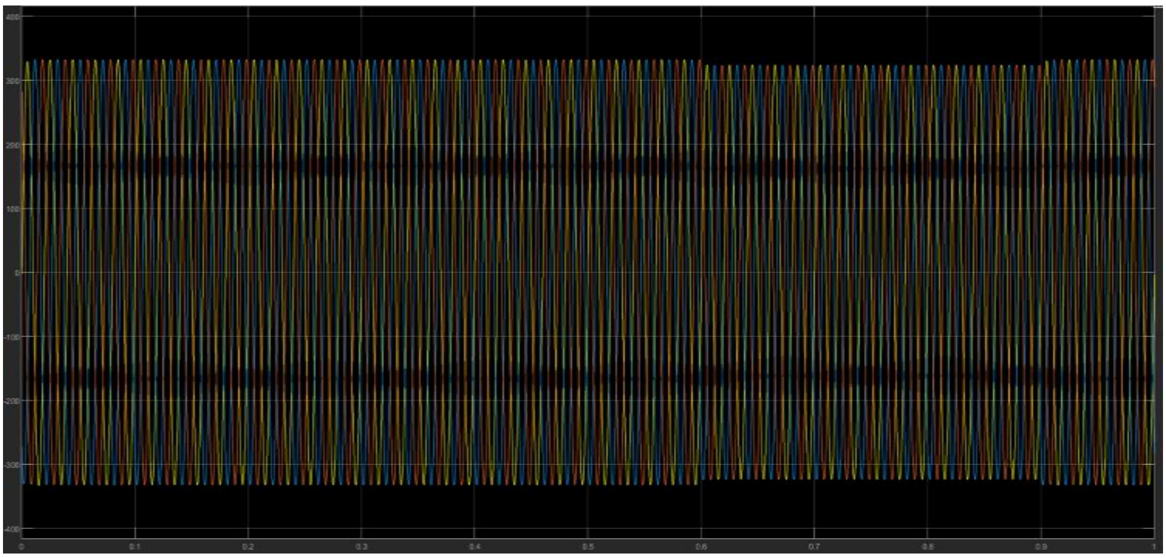


FIGURE 5. Compensated load voltage in the test system with DVR for voltage sag

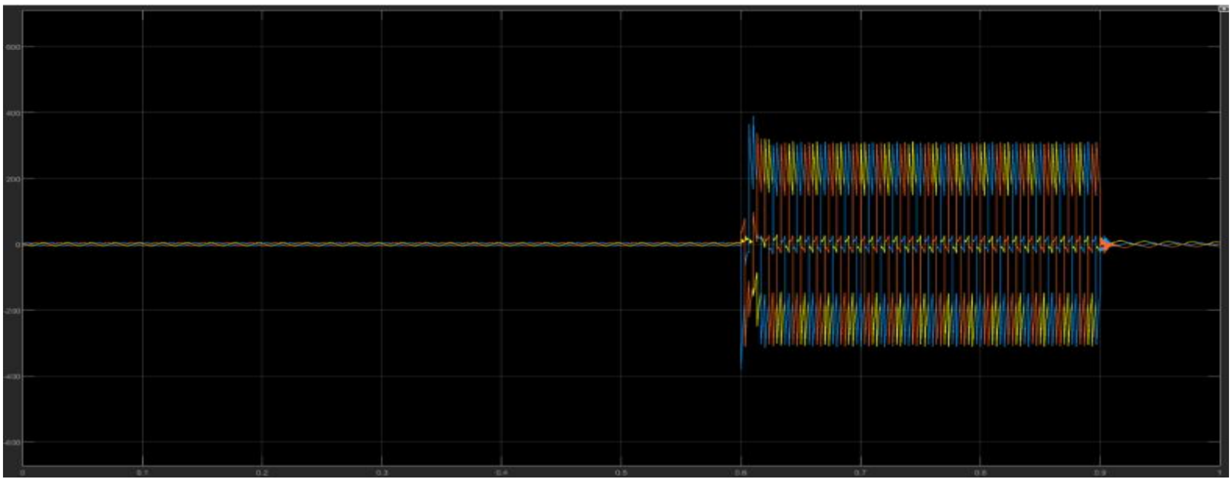
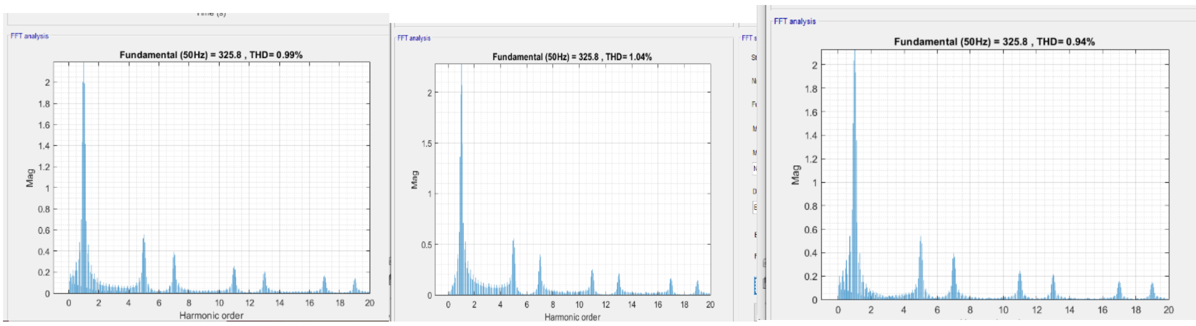


FIGURE 6. Injected voltage (V_{inj}) by DVR in all three phases for voltage sag

The THD is calculated for all three phases of the line. The impact of THD when the distortion of load voltage occurs in a test system without DVR, THD is considerably high, i.e., phase A (17.47%), phase B (17.05%), and phase C (17.85%). According to IEEE standard 519 to 1992, the THD rate must be less than 5% of the fundamental frequency. Due to disturbances occurring in voltage mitigation, the DVR is included. To maintain the THD distortion under IEEE standards, power quality improvement with control unit DVR is implemented. By using DVR, the THD distortion of all three-phase is reduced within a limit, i.e., for phase A (0.99%), phase B (1.04%), and phase C (0.94%). A small flicker is observed during the transient time of 0.6 to 0.9 seconds. Figure 7 shows the THD of all three phases of the system.



(a) (b) (c)

FIGURE 7. With DVR for voltage sag (a)THD in phase A (b)THD in phase B (c) THD in phase C

In scenario 2, THD is found for voltage swell for both with and without DVR with the Park's transformation control unit. Voltage swell without DVR is connected to the test system and the distorted output load voltage waveform is shown in Figure 8. The DVR is disconnected from the system. The load is connected during a transient time of 0.6 to 0.9 seconds and swell is observed in the system.

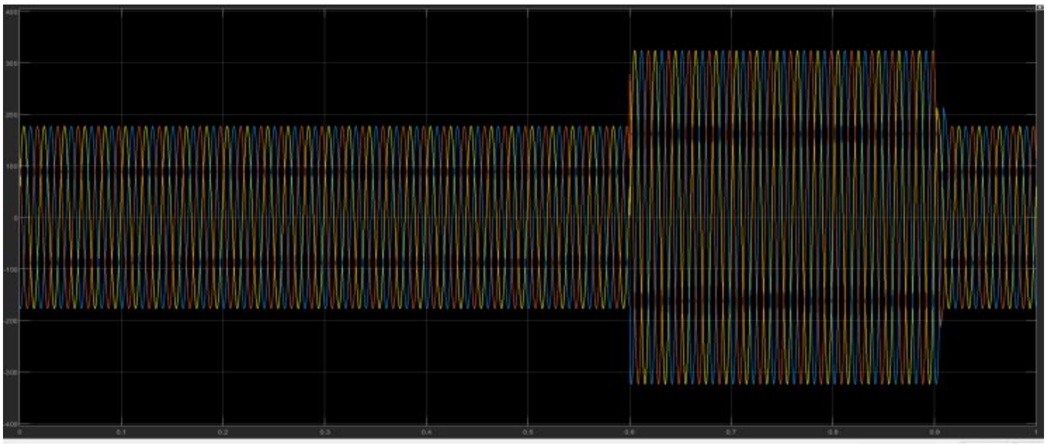


FIGURE 8. Output distorted load voltage in the test system without DVR for voltage swell

When DVR is connected to the test system, then DVR is used to compensate for the output load voltage during the transient time from 0.6 to 0.9 seconds in the test system. DVR injected the voltage during the transient time to continue the power supply to the load without any distortion in load voltage. Compensated load voltage in the test system with DVR for voltage swell is shown in Figure 9. The voltage injected by DVR, when the distortion occurs in the line, at transient time occurs during 0.6 to 0.9 seconds is shown in Figure 10.

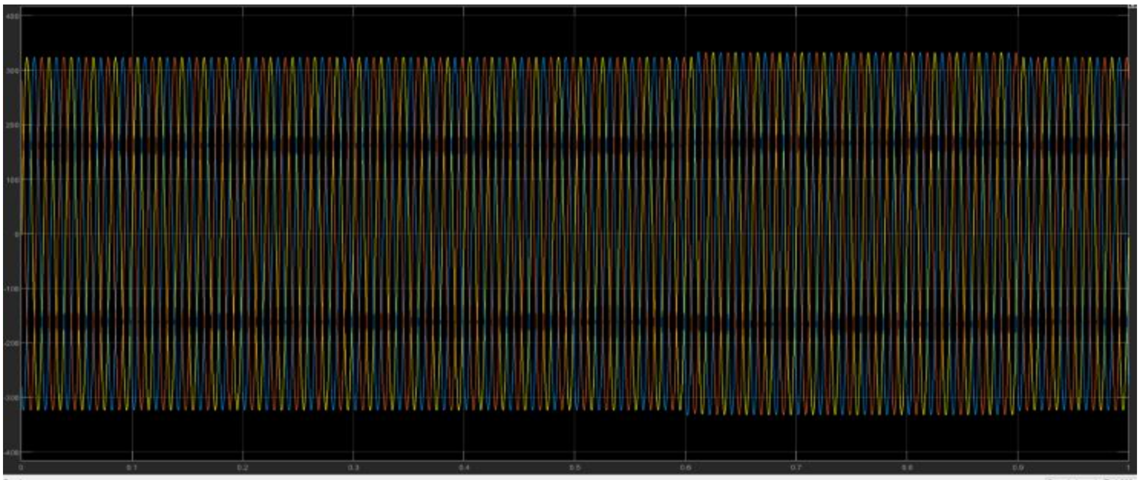


FIGURE 9. Compensated load voltage in the test system with DVR for voltage swell

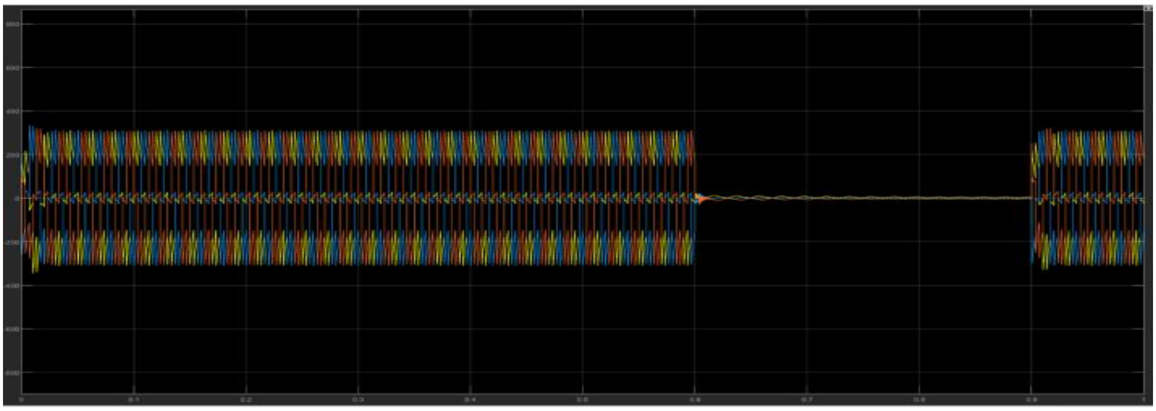
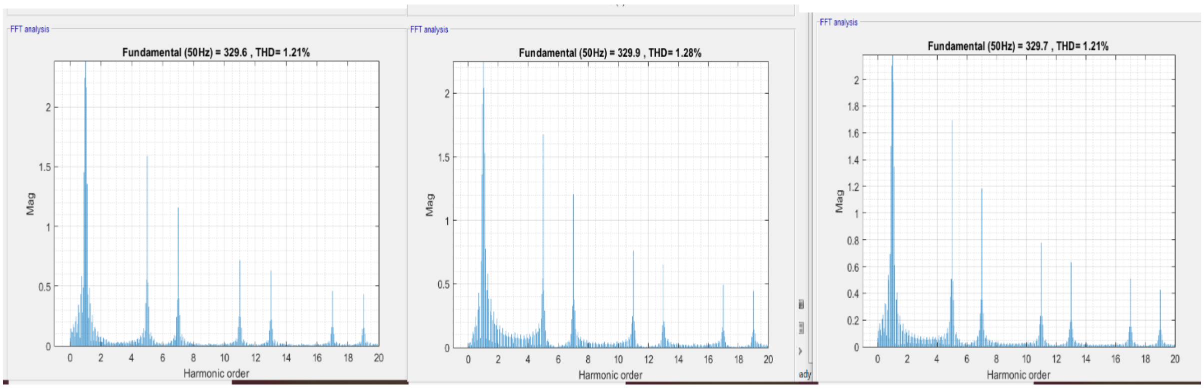


FIGURE 10. Injected voltage (V_{inj}) by DVR in all three phases for voltage swell

IJARSE
ISSN 2319 - 8354

The impact of THD when the distortion of load voltage occurs in a test system without DVR is considerably high, i.e., phase A (23.74%), phase B (24.52%), and phase C (25.25%). Now, THD distortion under IEEE standards power quality improvement with control unit DVR has been implemented. By using DVR, the THD distortion of all three-phase is reduced within a limit, i.e., for phase A (1.21%), phase B (1.28%), and phase C (1.21%). A small flicker is observed during the transient time of 0.6 to 0.9 seconds. Figure 11 shows the THD of all three phases of the system.



(a) (b) (c)

FIGURE 11. With DVR for voltage sag (a)THD in phase A (b)THD in phase B (c) THD in phase C

A final evaluation of the THD of the test system with or without DVR for load voltage sag and swell is shown in Table 2.

TABLE 2. THD % of the test system with or without DVR for voltage sag and swell

Phase	Scenario 1 THD (%) for sag		Scenario 2 THD (%) for swell	
	without DVR	with DVR	without DVR	with DVR
Phase A	17.47	0.99	23.74	1.21
Phase B	17.05	1.08	24.52	1.28
Phase C	17.85	0.94	25.25	1.21

5. CONCLUSION:

DVR is the most important device to enhance the power quality of the system. The main purpose of using DVR is to maximize efficiency in industries and production. In this study, Park's transformation control technique is used. A DVR is connected to the test system and investigated with and without DVR for voltage sag and swell conditions. A DVR control technique is effective in compensating for the distorted output load voltage and maintaining smooth voltage with very fewer harmonics content in it. A DVR injects the suitable voltage to maintain the load voltage in the optimal range. In scenario 1 (sag condition), the THD with DVR is reduced by around 0.99%, 1.04%, and 0.94% respectively. In scenario 2 (swell condition), the THD with DVR is reduced by around 1.21%, 1.28%, and 1.21% respectively. The improvement in voltage profile and reduction in THD in load voltage is effectively used by the DVR based controller, i.e., Park's transformation used in this work. The different applications are also used for control strategy based on soft computing like fuzzy logic controller, neuro-fuzzy controller, PI controller etc.

REFERENCES

[1] R.S. Vedam and M.S. Sharma, "*Power Quality: VAR Compensation in Power Systems",* Boca Raton FL, USA: *CRC Press,2009.*

[2] A. Ghosh and G. Ledwich, "*Power quality enhancement using power devices",* Springer Science and Business Media,*2012.*

[3] *IEEE Recommended practice for monitoring electric power quality* ,IEEE Standard 1195,*2009.*

[4] J. A. Martinez and J. Martin Arenado, "*Voltage sag studies in distribution network's part I system modelling",* IEEE Trans. Power Del., *vol. 21, no. 3, pp.1670-1678, Jul. 2006.*

[5] C. Benachaiba and B. Ferdi, "*Voltage quality improvement using DVR*," Electt. Power Qual. Utilisation, Journal, *vol. 14, no. 1, 2010.*

[6] H. Lakshmi, and T. Swapna, "*Modelling and Simulation of Dynamic Voltage Restorer for Power Quality Improvement"*, International Journal of Scientific & Engineering Research, *Vol. 4, Issue. 2, February 2013*.

[7] M.N. Tandjaoui, C. Benachaiba, O. Abdelkader, and M.L. Doumbia, "*Mitigation of voltage sags/swells unbalanced in low voltage distribution systems"*, International Journal of Science and Advanced Technology, *Vol. 1, No. 6, August 2011.*

[8] M.A. El-Gammal, A.Y. Abou-Ghazala and T.I. El-Shennawy, "*Dynamic Voltage Restorer (DVR) for Voltage Sag Mitigation"*, International Journal on Electrical and Informatics", *Vol. 3 no. 1, pp. 1-11, 2011.*

[9] A. A. D. Ranjith Perera and S. S. Choi, "*Performance improvement by a dynamics voltage restorer with closed-loop voltage and current mode control,"* IEEE Transaction on power electronics, *vol. 17, no. 5, 2002.*

[10] Chris Fitzer, Mike Barnes and Peter Green, "*Voltage sag detection technique for a dynamic voltage restorer,"* IEEE Transactions on Industry Application, *vol. 40, no. 1, 2004*.

[11] N. G. Hingorani and L. Gyugyi, "*Understanding FACTS concepts and technology of flexible AC transmission system",* IEEE Press *ISBN 0-7803-3455-8, 2012*.

[12] S. A. Rahman, P. A. Janakiraman and P. Somasundaram, "*voltage sag and swell mitigation based on modulated carrier PWM*," International journal elect. Power energy system, *vol.66, pp. 78-85,2015*.

[13] M. F. Mcgranaghan, D. R. Mueller and M. J. Samotyj, "*Voltage sags in industrial systems*," IEEE Transaction Industry Application, *vol. 29, pp.397-403, 1993*.

[14] E. Babaei, M. FarhadiKangarlu, "*Sensitive load voltage compensation against voltage sags/swells and harmonics in the grid voltage and limit downstream fault currents using DVR*", Electric Power Systems Research, *vol. 83, no. 1, pp. 80-90, Feb. 2012.*

[15] Prafull A. Desale, Vishvadeep J. Dhawale, Ranjeet M. Bandgar, "*Brief Review Paper on the Custom Power Devices for Power Quality Improvement", vol. 7, no. 7, ISSN 0974-2174, 2014.*

[16] P. Roncero Sanchez and J. E. O. Calderon, "*A versatile control scheme for a dynamic voltage restorer for power quality improvement"*, IEEE Transaction on Power Delivery, *vol. 24, no. 1, 2009*.

IJARSE
ISSN 2319 - 8354

[17] Saripalli Rajesh, Mahesh K Mishra, and Sridhar K, *"Design and simulation of dynamic voltage restorer using sinusoidal pulse width modulation,"* 16th National Power System Conf. Andhra Pradesh, India. *pp. 317-322, Dec. 2010*.

[18] M. Mani Sankar and S. b. l. Seksena, "*A cost effective voltage sag compensator for distribution system ,"* international journal system engg. Manage.,*vol.8,no.S1,pp.56-64,jan 2017.*

[19] C.S. Chang, Y.S. Ho, and P.C. Loh, "*Voltage Quality Enhancement with Power Electronics Based Devices*. IEEE Power Engineering Society Winter Meeting*, 4: pp. 2937-2942, 2004.*

[20] M.R. Banaei, S.H. Hosseini, S. Khanmohamadi, and G.B.Gharehpetian, "*Verification of a new control strategy for a dynamic voltage restorer by simulation*", ELSEVIER Simulation modelling practice and theory (14*), pp.112-125, 2006.*

[21] S. S. Rao, P. S. R. Krishna, and S. Babu, ``*Mitigation of voltage sag, swell and THD using dynamic voltage restorer with a photovoltaic system*," in Proc. Int. Conf. Algorithms, Methodol., Models Appl. Emerg. Technol. (ICAMMAET), *pp 1-7, Feb. 2017*.

[22] H. Lakshmi, and T. Swapna, "*Modelling and Simulation of Dynamic Voltage Restorer for Power Quality Improvement",* International Journal of Scientific & Engineering Research, *Vol. 4, Issue. 2, February 2013*.

[23] Naeem Abas, Saad Dilshad, Adnan Khalid, Muhammad Shoaib Saleem, and Nasrullah Khan, "*Power quality improvement using dynamic voltage restorer*," IEEE access *2020.3022477.*