Voltage Sag/ Swell Mitigation Using Dynamic Voltage Restorer (DVR)

Geena Sharma[1] Dr. Vinay Bhatia[2] Dr. Jaydeep Chakarvorty[3]
1Assistant Professor, Department of Electrical Engineering, Baddi University of Emerging Sciences & Technology Baddi, India
[2] Dean& HOD, Department of Electronics Engineering, Baddi University of Emerging Sciences & Technology Baddi, India
[3] HOD, Department of Electrical Engineering, Indus University, Gujraat, India
*Correspondence: geena@baddiuniv.ac.in

Abstract::- The Dynamic Voltage Restorer (DVR) is fast, flexible and efficient solution to voltage sag problem. The DVR is a power electronic based device that provides three-phase controllable voltage source, whose voltage vector (magnitude and angle) adds to the source voltage during sag event, to restore the load voltage to pre-sagconditions. The DVR is designed for protecting the whole plant with loads in the range of some MVA. The DVR can restore the load voltage within few milliseconds. Several configurations and control methods are proposed for the DVR. In this paper, an overview of the DVR, its functions, configurations, components, compensating strategies and control methods are reviewed along with the device capabilities and limitations.

Keywords: *Dynamic Voltage Restorer (DVR), Voltage Sags, Power Quality, Custom Power.*

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Introduction

The Dynamic Voltage Restorer (DVR), also referred to as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), is a device that utilizes solid state (or static) power electronic components, and is connected in series to the utility primary distribution circuit. The DVR provides three phase controllable voltage, whose vector (magnitude andangle) adds to the source voltage to restore the load voltage to pre-sag conditions [1].

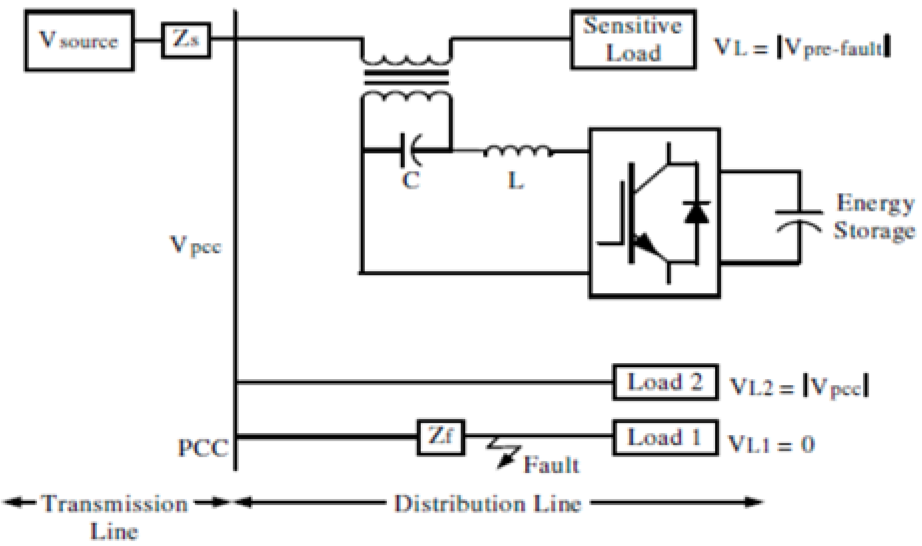

Figure 1. Role and Location of the DVR

Figure 1 is a simplified circuit for the role and location of the DVR in the distributionsystem. When a fault occurs on the line feeding Load 1, its voltage collapses to zero. Load 2 voltage experiences a sag which magnitude is equal to the voltage at the PCC, and the voltageof the sensitive load protected by the DVR is restored to its prefault value [2].

Principles of DVR Operation

A DVR is a solid state power electronics switching device which comprises of either GTO or IGBT, a capacitor bank as energy storage device and injection transformers. From the figure 1.it can be seen that DVR is connected in between the distribution system and the load. The basic idea of DVR is that by means of an injecting transformer a control voltage is generated by a forced commuted convertor which is in series to the bus voltage. A regulated DC voltage source is provided by a DC capacitor bank which acts an energy storage device.

Under normal operating conditions when there is no voltage sag, DVR provides very less magnitude of voltage to compensate for the voltage drop of transformer and device losses. But when there is a voltage sag in distribution system, DVR will generate a

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195 – 204

required controlled voltage of high magnitude and desired phase angle which ensures that load voltage is uninterrupted and is maintained. In this case the capacitor will be discharged to keep the load supply constant. [3]

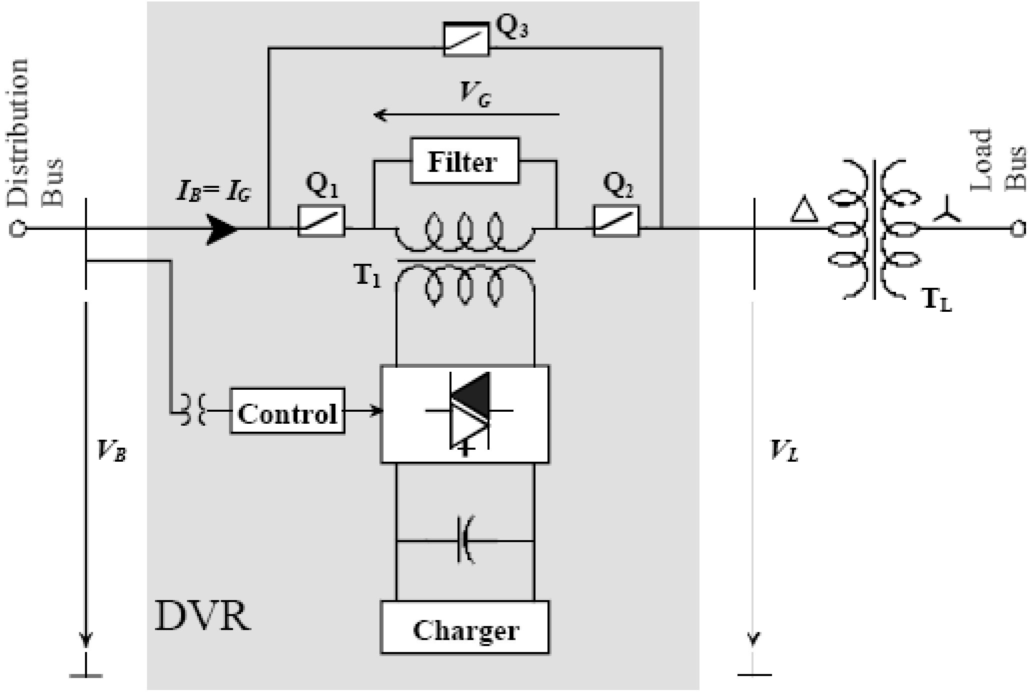

Figure 2: Principle of DVR with a response time of less then one millisecond [21]

Note that the DVR capable of generating or absorbing reactive power but the reactive power injection of the device must be provided by an external energy source or energy storage system. The response time of DVD is very short and is limited by the power electronics devices and the voltage sag detection time. The expected response time is about 25 milliseconds, and which is much less than some of the traditional methods of voltage correction such as tap-changing transformers.

Construction of DVR

Power circuit and the control circuit are the 2 main parts of the DVR. There are various critical parameters of control signals such as magnitude, phase shift, frequency etc. which are injected by DVR. These parameters are derived by the control circuit. This injected voltage is generated by the switches in the power circuit based on the control signals. Furthermore, the basic structure of DVR is described by the power circuit and is discussed in this section. The 5 main important parts of power circuit, their function and requirements are discussed ahead.

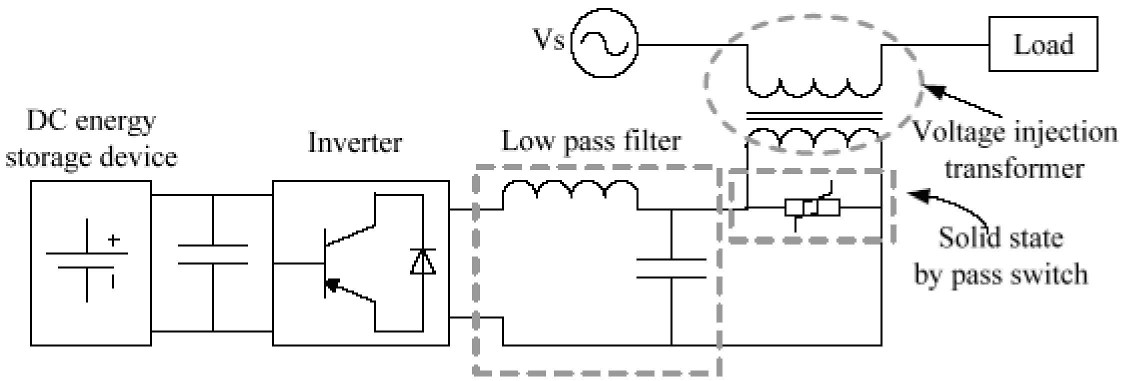

Figure 3 DVR Power Circuit [20]

Energy Storage Unit

Various devices such as Flywheels, Lead acid batteries, Superconducting Magnetic energy storage (SMES) and Super-Capacitors can be used as energy storage devices. The main function of these energy storage units is to provide the desired real power during voltage sag. The amount of active power generated by the energy storage device is a key factor, as it decides the compensation ability of DVR. Among all others, lead batteries are popular because of their high response during charging and discharging. But the discharge rate is dependent on the chemical reaction rate of the battery so that the available energy inside the battery is determined by its discharge rate.

Voltage Source Inverter

Generally, Pulse-Width Modulated Voltage Source Inverter (PWMVSI) is used. In the previous section we saw that an energy storage device generates a DC voltage. To convert this DC voltage into an AC voltage a Voltage Source Inverter is used. In order to boost the magnitude of voltage during sag, in DVR power circuit a step up voltage injection transformer is used. Thus a VSI with a low voltage rating is sufficient.

Passive Filters

To convert the PWM inverted pulse waveform into a sinusoidal waveform, low pass passive filters are used. In order to achieve this, it is necessary to eliminate the higher order harmonic components during DC to AC conversion in Voltage Source Inverter which will also distort the compensated output voltage. These filters which play a vital role can be placed either on high voltage side i.e. load side or on low voltage side i.e. inverter side of the injection transformers. We can avoid higher order harmonics from passing through the voltage transformer by placing the filters in the inverter side. Thus it also reduces the stress on the injection transformer. One of the problems which arise when placing the filter in the inverter side is that there might be a phase shift and voltage drop in the inverted output. So this could be resolved by placing the filter in the load side. But this would allow higher order harmonic currents to penetrate to the secondary side of the transformer, so transformer with higher rating is essential.

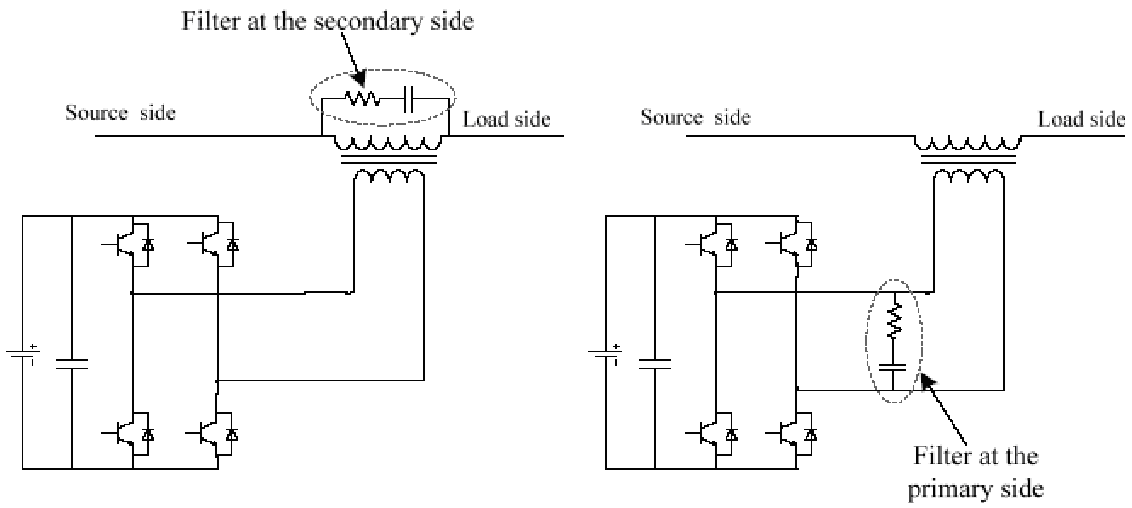

Figure 4 Different Filter Placements [18]

By-Pass Switch

Now DVR is a series connected device. If there is a fault current due to fault in the downstream, it will flow through the inverter. Now the power components of inverter are not highly rated but normally rated due to its cost. So in order to protect the inverter a By-pass switch is used. Generally a crowbar switch is used which bypasses the inverter circuit. So crowbar switch will sense the magnitude of the current, if it is normal and within the handling range of inverter components it (the crowbar switch) will be inactive. On the other hand if current is high it will bypass the components of inverter.[18]

Voltage Injection Transformers

The primary side of the injection transformer is connected in series to the distribution line, while the secondary side is connected to the DVR power circuit. Now 3 single phase transformers or 1 three phase transformer can be used for 3 phase DVR whereas 1 single phase transformer can be used for 1 phase DVR. The type of connection used for 3 phase DVR if 3 single phase transformers are used is called "Delta-Delta" type connection as shown in Figure.5 [22]. If a winding is missing on primary and secondary side then such a connection is called "Open-Delta" connection which is as widely used in DVR systems as shown in Figure 6 [22].

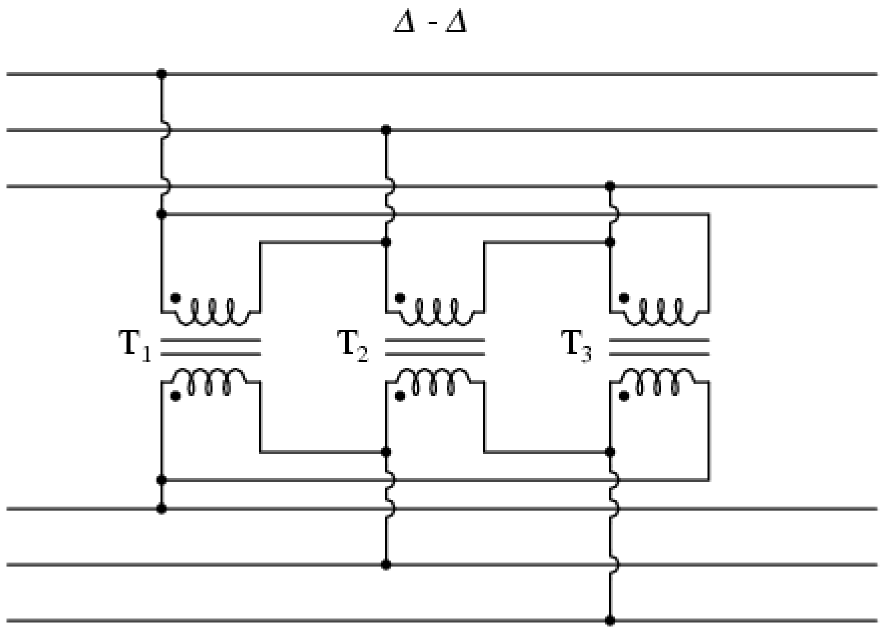

Figure 5 Connection Method for Injection Transformer Delta-Delta Connection [22]

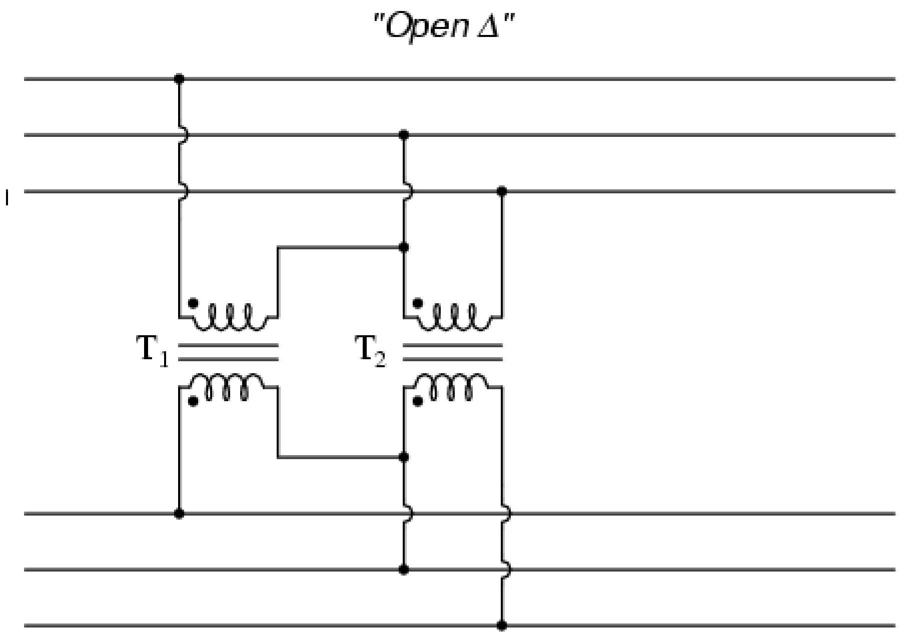

Figure 6 Connection Method for Injection Transformer Open-Delta Connection [22]

Basically the injection transformer is a step up transformer which increases the voltage supplied by filtered VSI output to a desired level and it also isolates the DVR circuit from the distribution network. Winding ratios are very important and it is predetermined according to the required voltage at the secondary side. High winding ratios would mean high magnitude currents on the primary side which may affect the components of inverter circuit. When deciding the performance of DVR, the rating of the transformer is an important factor. The winding configuration of the injection transformer is very important and it mainly depends on the upstream distribution transformer. In case of a Δ-Y connection with the grounded neutral there will not be any zero sequence current flowing into the secondary during an unbalance fault or an earth fault in the high voltage side. Thus only the positive and negative sequence components are compensated by the DVR.

Compensation Strategies

Three compensation strategies are normally used for sag compensation [30-32]:

A. Pre-sag Compensation

The DVR injects the difference (missing) voltage between during-sag and pre-sag voltagesto the system, the DVR must compensate for both magnitude and angle, as shown in Figure 7.It is the best solution to obtain the same load voltage as the pre-fault voltage and is best suitedfor loads sensitive to phase angle jumps like angle-triggered thyristors-controlled loads.

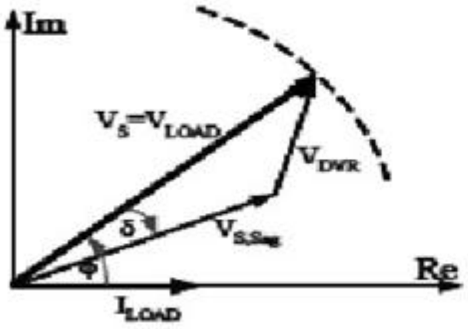

Figure 7 Pre sag Compensation

B. In Phase Compensation

The injected voltage is in phase with supply voltage, as shown in Figure 8. The phaseangles of the pre-sag and load voltage are different but the most important criteria for power quality that is the constant magnitude of load voltage is satisfied. In this configuration, the DVR is designed to compensate the voltage magnitude only. This method is suitable for loads that can withstand phase angle jumps.

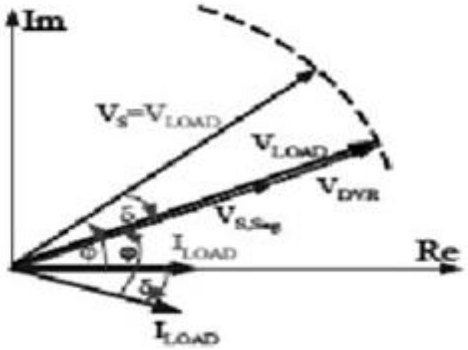

Figure 8 In Phase Compensation

C. Minimum (Optimized) Energy Injection

The third strategy is the minimum energy injection, which depends on maximizing theactive power supplied by the network (keeping the apparent power constant and decreasing thenetwork reactive power) by minimizing the active power supplied by the compensator(increasing the reactive power supplied by the compensator), as shown in Figure 9.

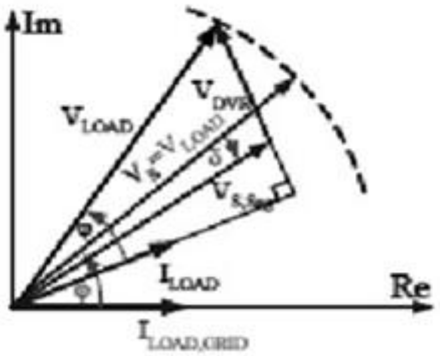

Figure 9 Energy Optimization

Sag Detection Techniques

A voltage sag detection technique detects the occurrence of the sag, the start point, the endpoint, sag depth (magnitude to be restored) and phase shift. Common voltage sag detectiontechniques are summarized as follows [33-34]:

A. Peak value method

The simplest method of monitoring the supply is to monitor the peak, or amplitude, of thesupply voltage, then comparing it with a reference. A controller could be set to recognize ifthere is a difference greater than a specified value (10%) and switch in the inverter.

B. Root Mean Square (rms) method

The start time of the sag can be defined as the first point of Vrms when drops below 0.9 pu.To find the end time of the sag, search for an interval where Vrms drops below 0.9 pu for atleast half a cycle. The recovery time is then chosen as the first point in this interval.

C. Fourier Transform (FT)

The FT is achieved through orthogonal decomposition of power system signal. In general,a trigonometrically orthogonal function set or exponential orthogonal function set is utilized.By applying FT to each supply phase, it is possible to obtain the magnitude and phase of eachof the frequency components of the supply waveform. For practical digital implementationWindowed Fast Fourier Transform (WFFT) is used, which can easily be implemented in realtime control system. The only drawback of this method is that it takes one cycle to return theaccurate information about the sag depth and its phase, since FT uses an averaging technique.

D. Space Vector method

The three phase voltages Vabc are transformed into a two dimension voltage Vdq, which inturn can be transferred into magnitude and angle. Any deviation in any quantity reveals theoccurrence of an event. Comparing these quantities with reference ones will quantify thedisturbance in the dq-frame, which had to be transformed back to the abc frame. This methodhas no time delay, yet requires complex controller.

Control Techniques

A. Linear Controllers

The three main voltage controllers, which have been proposed in literature, are Feed-forward (open loop), Feedback (closed loop) and Multi-loop controller [35-40].The feed-forward voltage controller is the primary choice for the DVR, because of itssimplicity and fastness. The supply voltage is continuously monitored and compared with areference voltage; if the difference exceeds a certain tolerance, the DVR injects the requiredvoltage. The drawback of the open loop controller is the high steady state error.In the feedback control, the load voltage is measured and compared with the referencevoltage, the missing voltage is supplied by the DVR at the supply bus in a feedback loop. Thiscontroller has the advantage of accurate response, but it is complex and time-delayed.Multi-loop control is used with an outer voltage loop to control the DVR voltage and an
inner loop to control the load current. This method has the strengths of feed-forward andfeedback control strategies, on the expense of complexity and time delay.

B. Non-linear Controllers

It appears that the nonlinear controller is more suitable than the linear type since the DVRis truly a non-linear system due to the presence of power semiconductor switches in theinverter bridge. The most non-linear controllers are the Artificial Neural Networks (ANN),Fuzzy Logic (FL) and Space Vector Pulse Width Modulation (SVPWM) [41-46].ANN control method has adaptive and self-organization capacity. The ANN has inherentlearning capability that can give improved precision by interpolation.FL controllers are an attractive choice when precise mathematical formulations are notpossible. When a FL controller is used, the tracking error and transient overshoots of PWM canbe considerably reduced.SVPWM control strategy is to adopt a space vector of the inverter voltage to get betterperformance of the exchange is gained in low switching frequency conditions.

Illustrative Case Study

In this illustrative study, the DVR control strategy is based on in-phase compensationstrategy, as it will be much simpler and hence, the controller and consequently the responsetime will be faster. It is worth mentioning that, although the proposed DVR does notcompensate for the phase angles, yet it tracks them. The sag detector block uses the traditional.

FT to calculate both the magnitude and angle of the fundamental component of voltage, tomake sure that the injected sine wave will be in-phase with the remaining sine wave during thesag event, to a have a constructive vector addition of the DVR and the supply voltages. In this study, a simple feed-foreword controller acquires its voltage values from the source,with no feedback from the load, aiming at simple and fast response.Figure 10 shows the block diagram of the proposed controller for the DVR.

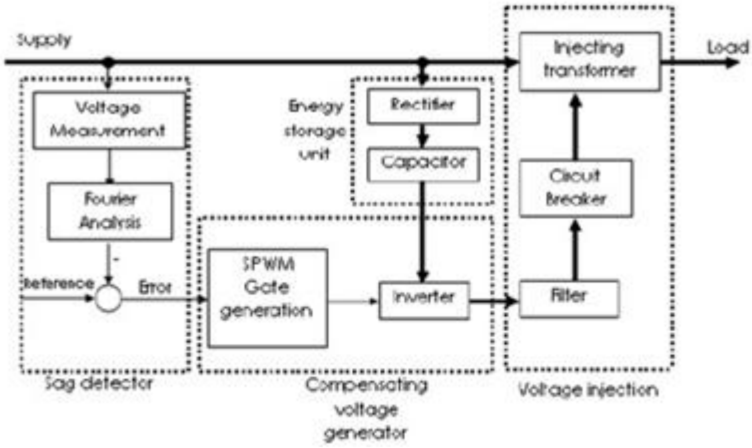

Figure 10 Block Diagram of Proposed DVR

Sag Detector

This includes determination of the sag start instant, the depth of the sag, the phase jumpangle, and the sag end instant. In this study, the FT technique is used. It requires at least oneoperating cycle to detect the sag start / end events.The reference voltage is the supply 11 kV with certain tolerance. The DVR will not operateon small voltage variation events to keep the operational losses to a minimum. In this study, atolerance of 550V (5% of rated voltage) is considered.Computation of the compensating voltage is done using a comparator with one input as thevariable system voltage and the other input being the fixed reference voltage. The comparison(subtraction) is done for magnitude only, since the compensation strategy is the In-phasemethod. The output of the comparator determines the voltage required to be injected by theDVR, and is called the error signal.

Generation of the Compensating Voltage

The inverter is the core component of the DVR, and its control will directly affect theperformance of the DVR. In the proposed DVR, a sinusoidal PWM scheme will be used. Theinverter used in this study is a six-pulse inverter, the carrier waveform is a triangular wave withhigh frequency (1000 Hz in the study). The modulating index will vary according to the inputerror signal.The basic idea of PWM is to compare a sinusoidal control signal of normal 50 Hzfrequency with a modulating (or carrier) triangular pulses of higher frequency. When thecontrol signal is greater than the carrier signal, three switches of the six are turned on, and theircounter switches are turned off. As the control signal is the error signal, therefore, the output ofthe inverter will represent the required compensation voltage.In this study, the frequency of the carrier waveform in the PWM is chosen to be 1000 Hz.The thyristors in the inverter circuit are chosen to be of type Integrated Gate Bipolar

Observations

The observations are shown in Figure 11 to Figure 13

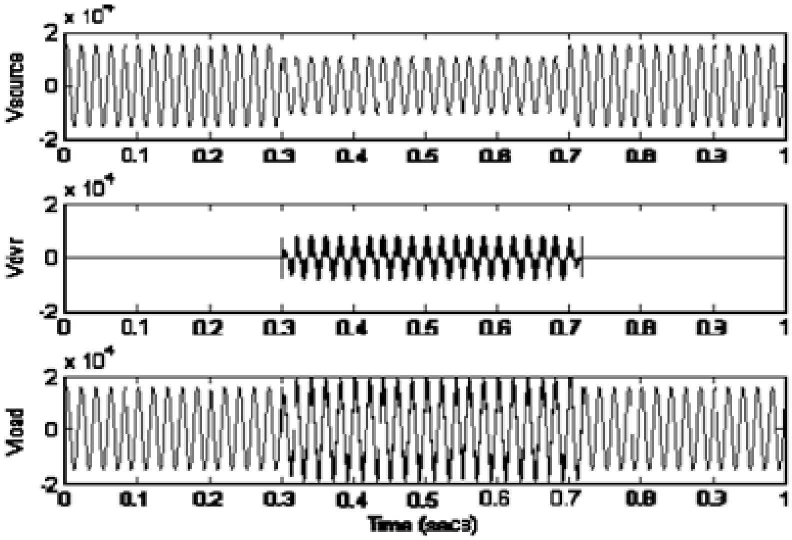

Figure 11 Three Phase balanced Voltage sag

ISSN: 2454-4248
195 – 204

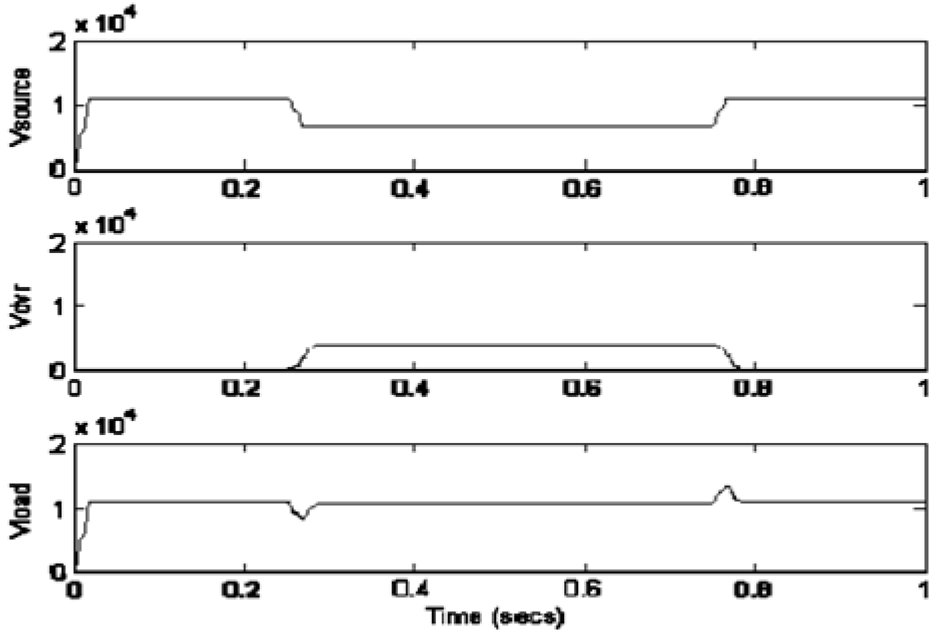

Figure 12 Single phase Voltage sag

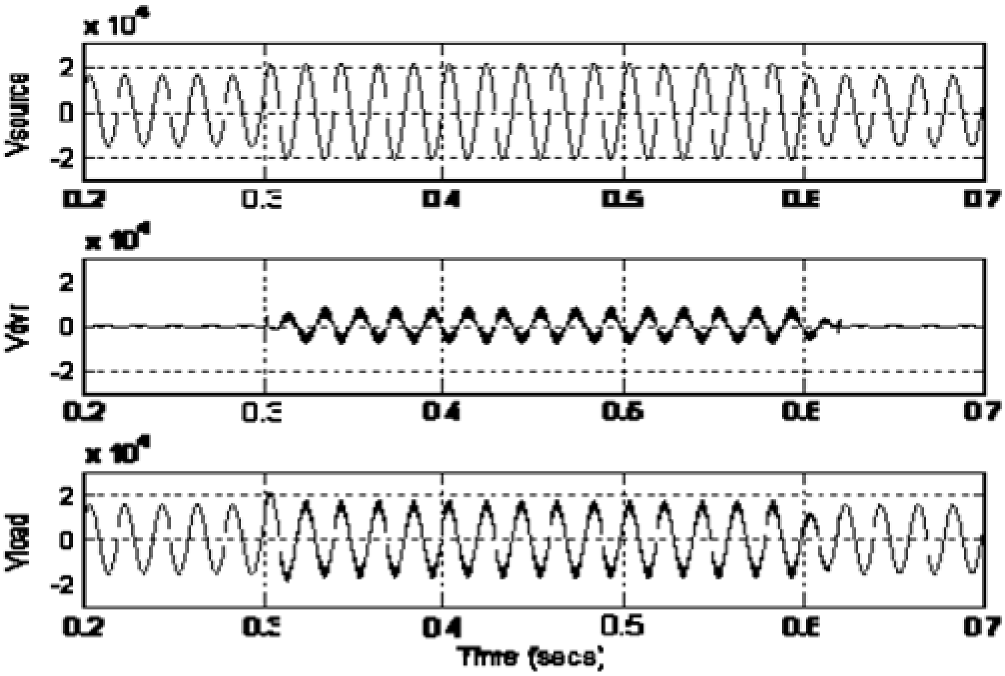

Figure 13 Voltage swell

Conclusion

In this paper, a litersrature review of the DVR for mitigating the problem of voltage sags is presented The DVR performance is satisfactory in mitigating voltage sags / swells. The DVR handles both balanced and unbalanced situations without any difficulties

REFERENCES

[1] Tarek I El-Shennawy, Abdel-Mon'em Moussa, Mahmoud A El-Gammal and Amr Y Abou-Ghazala "A Dynamic Voltage Restorer for Voltage Sag Mitigation in a Refinery with Induction Motors Loads" 2010 Science Publications available from http://www.scipub.org/fulltext/ajeas/ajeas31144-151.pdf

[2] Chellali Benchaiba,Brahim Ferdi "Voltage Quality Improvement Using DVR" Electrical Power Quality and Utilization,Journal Vol.XIV no.1,2008 available from http://www.leonardo-energy.org/webfm_send/972

ISSN: 2454-4248
195 – 204

[3] Shairul Wizmar Wahab and Alia Mohd Yusof "Voltage Sag and mitigation Using Dynamic Voltage Restorer (DVR) System" Faculty of Electrical Engg,University Of Malaysia available from http://myais.fsktm.um.edu.my/2489/1/paper6dec06_shairul_wizmar.pdf
[4] Brice J Quirl,Brain K Johnsom,Senior member IEEE " Mitigation of voltage sags with phase jump using Dynami Voltage Restorer"
[5] Paosan Boonchaiam and Nadarajah Mothulananthan "Understanding Dynamic Voltage Restorers through MATLAB simulation" Electrical Power system Management ,enerfy Field of Studey,Asian Institute of Technology,Thailand available from www.tijsat.tu.ac.th/issues/2006/no3/2006_V11_No3_1.PDF
[6] B H Lai,S S Choi D M Vilathgamuwa "A New Control Strategy for Energy-Saving Dynamic Voltage Restoration"School of Electrical and Electronic Engg. Nanyan Technological University Singapore 639798.
[7] Mehmet Tumay ,Ahmet Teke , K Cagatay Baymdr and M Ugras Cuma "Simuation and Modelling of a Dynamic Voltage Restorer" Departmetn of Electrical and Electronics Engg. Turkey available from http://www.emo.org.tr/ekler/ee5605917626676_ek.pdf
[8] ELECTROTEK Concepts, Voltage Sag Studies Date : 10/03/2009 http://www.electrotek.com/voltsag.htm.
[9] C S Chang, Y.S. Ho, P.C. Lo "Voltage Quality Enhancement with Power Electronics Based Devices.
[10] Glanny M Ch Mangindaan, M Ashari Mauridhi HP "Control of Dynamic Voltage Restorer For Voltage Sag Mitigation" ICTS 2008 available from http://ieeexplore.ieee.org/ebooks/5270869/5271123.pdf
[11] IEEE Standard 1159-1995 "IEEE Recommended Practice for Monitoring Electric Power Quality.Published 1995.
[12] Richard P. Bingham "Sags and Swells" available from http://www.dranetz-bmi.com/pdf/sags-swells.pdf
[13] Nita R. Patne, Krishna L. Thakre "Factor Affecting Characteristics Of Voltage Sag Due to Fault in the Power System" Vol. 5, No.1, May2008, 171-182, Serbian Journal Of Electrical engineering.
[14] Alexander Eigels Emanuel, John A. McNeill "Electric Power Quality". Annu. Rev. Energy Environ 1997.22:263-303.
[15] Mohd Izhwan Muhammad, Norman Mariun, Mohd Amran Mohd Radzi " Effects Of Power Quality to the Industries" 11-12 December 2007, Malaysia http://ieeexplore.ieee.org/stamp/stamp.jsp?arnumber=04451410
[16] Narain G. Hingorani, "Introducing custom power" IEEE spectrum, June 1995 pg.41-48.
[17] C. Zhan, V.K. Ramachandramurthy, A.Arulampalam, C.Fitzzer, M.Barnes, N.Jenkins, "Control of a battery supported dynamic voltage restorer", IEEE proceedings on Transmission and Distribution, Vol.149 (No.5), Sep. 2002, pg.533-542.
[18] P.T. Nguyen, Tapan K. Saha, "Dynamic Voltage Restorer against balanced and unbalanced voltage sags: Modelling and simulation". IEEE transactions on Power Delivery, 2004, pg1-6.
[19] G. Ramtharan, S.G. Abeyratne, A.Atputharajah,"Constant frequency control of an active power filter", National Science Foundation, Sri Lanka, 2006,34(1)pg.21-28
[20] Kasuni Perera, Arualpalam Atputharajah, Sanath Alahakoon, Daniel Salomonsson "Automated Control Technique for a Single Phase Dynamic Voltage Restorer" December 15-17, 2006, Colombo, Sri-Lanka.
[21] W. Raithmayr, P. Daehler, M. Eichler, G. Lochner, EricJohn, Kevin Chan "Customer Reliability Improvement with a DVR or a DUPS" ABB Industires AG [22]
[22] Lessons in Electric Circuits – Volume II Date: 20/03/2010 http://ftp.ibiblio.org/kuphaldt/electricCircuits/AC/AC_10.html
[23] A. TTeke, M. E. Meral, L. SariMibulut and M. Tumay, "Dynnamic Voltage Restorers: A Literature Review" ELEKTRIKA Vol. 12(1), 2",A,2010, pp. 7-13..
[24] H.P. Tiwari and S. K. Gupta "Dynamic Voltage Restorersagainst Voltage Sag",, InternationalJournal of Innovation, Management and Technology, Vol. 1(3), August.t 2010 pp. 232-237.0,
[25] D.Chowdary and G. Kumar, "Mitigation of Voltage Sags in a Distribution System due to three-phase to ground Faults Using Dynamic Voltage Restorer", India Journal of Engineering and Material ScienceVol. 17, A 2010, Apr.113-122.
[26] Benachaiba an B. Ferdi, "Voltage QualityImprovement Using Dynamic Voltage Restorer", Electric Power Quality and Utilization Journal, Vol. 14(1), 200 pp. 39-46.08,
[27] J. Nielsen and F. Blabjerg, "A Detailed Comparison of System Topologies for Dynamic Voltage Restorers" IEEE Trans. Industry App", Vol. 41(5), Sep. 2005, pp. 1272-.- 12800.
[28] A. Visser, J. Enslin and H. Mouton, "Transformer-less Series Sag Compensation With a Cascaded Multilevel Inverter", IEEE Trans. Industrial Electronics, Vol. 49(4), Aug. 2002, pp. 824-831.
[29] P. Loh, M. Vilathgamuwa, S. Tang and H. Long, "Multilevel Dynamic Voltage Restorer", IEEE Power Electronics Letters, Vol. 2(4), Dec. 2004, pp. 125-130.
[30] S. Choi, J. Li and M. Vilathgamuwa, "A Generalized Voltage Compensation Strategy for Mitigating the Impacts of Voltage Sags/Swells", IEEE Trans. Power Delivery, Vol. 20(3), July 2005, pp. 2289-2298.
[31] C. Meyer, C. Romaus and R. De Doncker, "Optimized Control Strategy for a Medium- Voltage DVR", IEEE Trans. Power Electronics, Vol. 23(6), Nov. 2008, pp. 2746-2754.
[32] Q. Wang and S. Choi, "An Energy-Saving Series Compensation Strategy Subject to Injected Voltage and Input-Power Limits", IEEE Trans. Power Delivery, Vol. 23(2), Apr. 2008, pp. 1121-1131.
[33] C. Fitzer, M. Barnes and P. Green, "Voltage Sag Detection Technique for a Dynamic Voltage Restorer", IEEE Trans. Industry Applications, Vol. 40(1), Jan. 2004, pp. 203- 212.

[34] B. Bae, J. Jeong, J. Lee and B. Han, “Novel Sag Detection Method for Line-Interactive Dynamic Voltage Restorer”, IEEE Trans. Power Delivery, Vol. 25(2), Apr. 2010, pp. 1210-1211.

[35] J. Nielsen, M. Newman, H. Nielsen and F. Blaabjerg, “Control and Testing of a Dynamic Voltage Restorer (DVR) at Medium Voltage Level”, IEEE Trans. Power Electronics, Vol. 19(3), May 2004, pp. 806-813.

[36] H. Kim and S. Sul, “Compensation Voltage Control in Dynamic Voltage Restorers by Use of Feed Forward and State Feedback Scheme”, IEEE Trans. Power Electronics, Vol. 20(5), Sep. 2005, pp. 1169-1177.

[37] M. Marei, E. El-Saadany and M. Salama, “A New Approach to Control DVR Based on Symmetrical Components Estimation”, IEEE Trans. Power Delivery, Vol. 22(4), Oct. 2007, pp. 2017-2024.

[38] M. Bongiorno, J. Svensson and A. Sannino, “An Advanced Cascade Controller for Series- Connected VSC for Voltage Dip Mitigation”, IEEE Trans. Industry Applications, Vol. 44(1), Jan. 2008, pp. 187-195.

[39] O. Abdelkhalek, A. Kechich, T. Benslimane, C. Benachaiba and M. Haidas, “More Stability and Robustness with the Multi-loop Control Solution for Dynamic Voltage Restorer”, Serbian Journal of Electrical Engineering, Vol. 6(1), May 2009, pp. 75-88.

[40] H. P. Tiwari, S. K. Gupta, “Dynamic Voltage Restorer Based on Load Condition”, International Journal of Innovation, Management and Technology, Vol. 1(1), April 2010, pp. 75-81.

[41] S. Ganesh, K. Reddy and B. Ram, “A Neuro Control Strategy for Cascaded Multilevel Inverter Based Dynamic Voltage Restorer”, International Journal of Electrical and Power Engineering, Vol. 3(4), 2009, pp. 208-214.

[42] P. Margo, M. Heri, M. Ashari, M. Hendrik and T. Hiyama, “Compensation of Balanced and Unbalanced Voltage Sags using Dynamic Voltage Restorer Based on Fuzzy Polar Controller”, International Journal of Applied Engineering Research, Vol. 3(3), 2008, pp. 879–890.

[43] H. Ezoji, A. Sheikholeslami, M. Rezanezhad and H. Livani, “A new control method for Dynamic Voltage Restorer with asymmetrical inverter legs based on fuzzy logic controller”, Simulation Modelling Practice and Theory, Vol. 18, 2010, pp. 806–819.

[44] C. Zhan, V. Ramachandaramurthy, A. Arulampalam, C. Fitzer, S. Kromlidis, M. Barnes and N. Jenkins, “Dynamic Voltage Restorer Based on Voltage-Space-Vector PWM Control”, IEEE Trans. Industry Applications, Vol. 37(6), Nov. 2001, pp. 1855-1863.

[45] H. Ding, S. Shuangyan, D. Xianzhong and J. Jun, “A Novel Dynamic Voltage Restorer and its Unbalanced Control Strategy Based on Space Vector PWM”, Electric Power and Energy Systems, Vol. 24, 2002, pp. 693-699.

[46] C. ZZhan, A. Arulaampalam and N Jenkins, “Four-Wire Dynamic Voltage Restorer Based on a Three-Dimensional Voltage Space Vector PWM Algorithm”, IEEE Trans. Power Electronics, Vol. 18(4), July 200 pp. 1093-11103,100.