Compensation of Voltage Sags and Swells by using Dynamic Voltage Restorer (DVR)

[1]Mr.Yogesh R. Ikhe, [2]Prof. Madhu Upadhyay

M.tech Student (Power electronics), Assistant Professor
Department of Electrical Engineering
NIIST, Bhopal,(MP), India

***Abstract-* The most important aspect for electrical engineering is power quality in recent year. Power quality problem is an event of abnormal voltage, current or frequency. Utility distribution networks experience from various types of disturbances. The major problems dealt here are the voltage sags/swells. Now the fast developments in power electronics technology have made it possible to mitigate power quality problems. Such as, dynamic voltage restorer can provide the most mercantile solution to compensate voltage sag/swell by injecting voltage in to the sensitive system. Dynamic Voltage Restorer is a series connected power electronics based device that can mitigate the power quality issues in the system and restore the load voltage to the pre-fault value. This review paper first gives an introduction to related power quality problems for a DVR and power electronics controllers for voltage sag/swell compensation. Afterwards the operation and elements in DVR is described by using new control strategy.**

***Key words*: Dynamic Voltage Restorer (DVR), Power Quality, Sinusoidal Pulse Width Modulation (SPWM), Voltage Sags and Swells, Voltage Source Converter (VSC).**

I. INTRODUCTION

Voltage sags and swells in the industrial distribution system are the most severe disturbance at electrical grid because of the sufficient clearing time of the faults which create voltage sag and propagation of sags from the transmission and distribution system to the low voltage loads [1]. Voltage sags are decrease of the normal voltage level between 10 to 90% of rms voltage, for durations of 0.5 cycle to 1 min. Voltage swells are increase of the voltage beyond the normal voltage level with duration of more than 3 cycles [2].

There are many types of methods are used to compensate the power quality issues mostly voltage sags and swells are active power filters, battery energy storage systems, Distribution static synchronous compensators, distribution series capacitors, surge arresters, super conducting magnetic energy systems, static electronic tap changers, solid state transfer switches, solid state fault current limiter, static VAR compensators, Thyristor switched capacitor, Uninterruptable power supply (UPS) and and Dynamic Voltage Restorer (DVR). One of them is the use of FACTS for the transmission system which improves just power transfer capability and stability margins. Also by using transformer taps possibility of compensating the sags and Swells is low because of the tap changing under load goes to very costly.

The most frequently used way to improve power quality issue is to install DVR on the sensitive load side which provide both voltage compensation and fault current limiting Functions [3]. DVR is a recently proposed series connected solid state device which injects voltage into the system by using injecting transformer to regulate the voltage at the sensitive load side. It is normally installed in a distribution system between the supply and the sensitive load line at the point of common coupling (PCC) [4]. Reduces the transient response and steady error due to the inclusion of controller. In this paper the DVR system acts as virtual impedance. This system can be used to protect a group of customers when the fault occurrence is in the DVR's feeder and the large fault current passes through that DVR. This DVR can limit the faulted current and protect the sensitive loads in parallel feeders until the breaker works and disconnects the faulted feeder. In this system, the DVR acts like a pure effective inductance which does not take any real power from the external source and hence, it protects the dc link capacitor and battery [5]. However, it continues to consume the energy in the dc link capacitor [2].

The first DVR was installed in North America in 1996 - a 12.47 kV system located in Anderson, South Carolina. Since then, DVRs have been applied to protect critical loads in utilities, semiconductor and food processing.

A. Principle of DVR:

The basic functioning principle of a DVR is to introduce a voltage of essential magnitude and phase in series with a distribution feeder to preserve the desired Amplitude and waveform for the load voltage [4]. Furthermore, the compensation potential is sensitive to the load level, and is independent of the system short circuit capacity and the installation position. To recover the mitigation capability of DVR, such as the large amplitude or long duration voltage variation, the energy storage unit is necessary to supply the power transfer during the voltage compensation [5].

II. PERFORMANCE OF DVR SYSTEM

Loads connected downstream of the DVR are thus confined from any power quality problems due to faults occur on the network. The location of DVR, in terms of the connection arrangement of upstream injection transformers and type of protection is to propose to potentially sensitive loads, is a major factor when determining the type of the inverter control requisite. The DVR is located downstream of a delta-star distribution transformer [8].

A. Basic Configuration of DVR:

The conventional DVR basically consists of:

1. An Injection/ Booster transformer
2. A Harmonic filter
3. Storage Devices
4. A Voltage Source Converter (VSC)
5. DC charging circuit
6. A Control and Protection system.

A schematic diagram of a conventional DVR built-in into a distribution network is shown in fig.1.

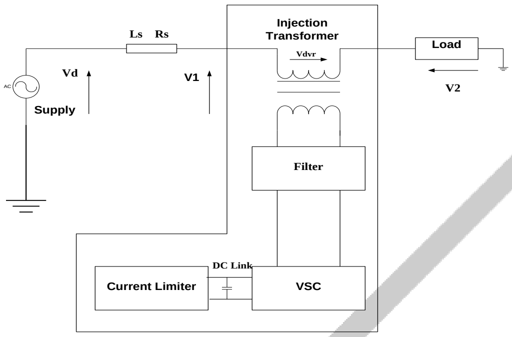

Fig.1. Block Diagram of DVR

1. **Injection Transformer**- The Injection transformer is a specially designed transformer that attempts to limit the pairing of noise and transient energy from the primary side to the secondary side.
2. **Harmonic Filter**- The harmonic filter is inserted to reduce the switching harmonics; common sources of harmonics are electronic loads. Due to these sources of harmonics, harmonic currents generate harmonic voltage as they pass through the system impedance. These harmonic equipments can cause input voltage fluctuations, additional heating, over voltages in power system.
3. **Storage Device**- A DC-link voltage is used by the VSC to produce an AC voltage into the grid and during a majority of voltage sags active power injection is required to restore the supply voltages.
4. **DC Charging Circuit**-It has two main tasks: Firstly is to charge the energy source after a sag mitigation event. The second task is to continue dc link voltage at the supposed dc link voltage.
5. **Voltage Source Converter**- The converter is most likely a Voltage Source Converter (VSC), which Pulse Width modulates (PWM) the DC from the DC-link/storage to AC-voltages injected into the system. A VSC is a power electronic device consists of a storage device and switching devices, which can generate an AC voltage at any essential frequency, magnitude, and phase angle. In the DVR application, the VSC is used to provisionally replace the reference voltage or to generate the part of the supply voltage which is missing.

The MVA rating is calculated by using power calculation equation by considering safety margin indicated as Ks. V_1 is primary voltage of the injection transformer and I_1 is the primary current rating of the injection transformer.

$$P = K_s V_1 I_1 \qquad (1)$$

The rating of the injection transformer can be calculated by using equation 2.

$$V_{inj} = DV_r \qquad (2)$$

$$V_s = (1-D) V_r \qquad (3)$$

Vr is the rated rms voltage of the primary feeder; D is the maximum single phase voltage sag to be compensated (D<1); Vinj is the injection voltage. The filter is inserted to reduce the switching harmonics generated by the VSC. The active filters can compensate the harmonics having different frequencies. The converter is most likely a Voltage Source Converter (VSC), which Pulse Width modulates (PWM) the DC from the DC-link/storage to AC-voltages injected into the system [5].

B. Equation related to DVR:

The equivalent circuit diagram of DVR is illustrated in Fig. 2.

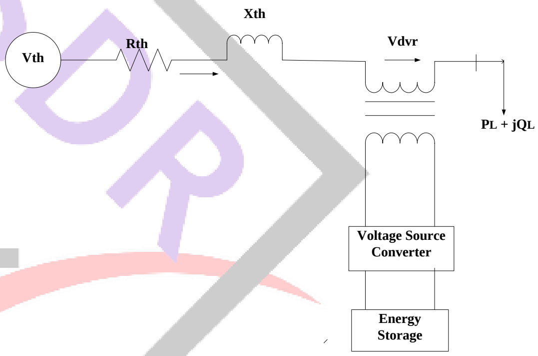

Fig.2. Equivalent circuit diagram of DVR

The system impedance (Z_{th}) depends on the fault level of the load bus. When the system voltage (V_{th}) drops, the DVR injects a series voltage V_{dvr} through the injection transformer so that the needed load voltage magnitude V_L can be maintained [6]. The series injected voltage of the DVR can be written as:

$$V_{dvr} = V_L + Z_{th} I_L - V_{th} \qquad (4)$$

$$V_{dvr} = V_L + Z_{th} I_L - V_{th} \qquad (5)$$

$$Z_{th} = R_{th} + jX_{th} \qquad (6)$$

$$I_L = \left[\frac{P_L - jQ_L}{V_L}\right] \qquad (7)$$

III. Topologies for DVR

There are different topologies used for DVR are:

1. *DVR topology with no energy storage*: DVR topologies with no energy storage utilize the fact that a considerable Part of the source voltage residue present during the dips and this enduring supply can be used to provide the enhance energy requisite to maintain full load power at rated voltage.

An inactive shunt converter is used because only unidirectional power flow is supposed required and it is low-priced clarification for voltage sag. Two basic topologies can be used, which are categorized here according to the location of shunt converter [8].

System-I- Supply side connected shunt converter**:**

The supply side connected converter has an unmanageable dc-link voltage and the passive converter will charge the dc-link capacitor to the real state of the supply voltage. The dc-link voltage is approximately equal to the peak phase-phase value of supply voltage and hence, during voltage sags the dc-link voltage drop proportionally to sag voltage according to,

$$V_{dc}=V_{supply}=\alpha \tag{8}$$

The maximum pu voltages for the shunt and series converter can be expressed as

$$V_{shunt}=1 \;\&\; V_{series}=1-\alpha \tag{9}$$

System-II- Load side connected shunt converter**:** With the load side connected shunt converter, the input voltage to the shunt converter is embarrassed and the dc-link voltage can be supposed almost constant by inserting sufficient voltage.

$$Vdc = Vload = \alpha + \mathrm{Vdvr} \tag{10}$$

*2. Topology with energy storage***:** Storing of electrical energy is high-priced but for certain types of voltage dips the performance of the DVR can be improved and the damage on the net connection is lower. Two methods are discussed here and in both the current flow from the grid is unchanged during a voltage sag.

System-III- Variable dc-link voltage energy stored in dc link capacitor**:** Storing energy in the dc link capacitor is well suited solution for DVRs. A simple topology can be operated with a variable dc-link voltage. The stored energy$E_{storage}$ is proportional to the square of the rated dc-link voltage.

$$E_{storage}=12C_{dc}V^2{}_{dc,} \tag{11}$$

System-IV- Constant dc-link voltage**:** Direct energy storage method such as batteries or super capacitors can be used in a DVR by adding together detach high power rating converter to the system. Energy transferred from large energy storage to a analogous rated dc-link storage using this converter during sag. Hence the dc-link voltage remains constant.

IV. INJECTION METHODS

Voltage injection or compensation methods by means of DVR depend upon the DVR ratings, various conditions of load, and different types of voltage sags and swells. To compensate the voltage sag and swell there are 4 types of DVR voltage injection methods are as follows:

1. Pre-sag compensation method
2. In-phase compensation method
3. Phase Advance compensation technique
4. Energy optimization technique

Comparative to all above method pre-sag compensation method is widely used. Here we uses the non-linear load hence we prefer the pre-sag compensation method because both the non-linear load voltage magnitude and phase are restored the pre-sag values. But in case of in-phase method only load voltage magnitude is considered [7].

1. Pre-sag compensation method-

The pre-sag method tracks the supply voltage continuously and if it detects any distraction in supply voltage it will inject the difference voltage between the sag or voltage at PCC and pre-fault condition, hence the load voltage can be restored back to the pre-fault condition. In this method control of the injected active power cannot be possible and it is determined by external conditions such as the type of faults and load conditions [8][9].

$$\mathrm{Vdvr = Vprefault - Vsag} \tag{12}$$

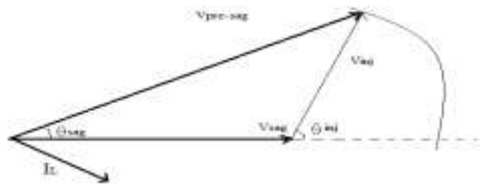

Fig.3. Pre-sag compensation method

2. In- phase compensation method-

In order to mitigate the voltage sags, DVR used In-phase compensation technique is the most straight forward method. In this technique the supply side voltage is in phase with the injected voltage irrespective of the load current and pre-fault voltage. In unbalanced dips, in-phase injection means to mitigate the nominal load voltage magnitude along the same phase as that of the supply voltage. This method cannot correct the phase jump. Fig.4. shows the phasor diagram of In-phase compensation method used by DVR for mitigating the voltage sags [8]. The DVR inject the voltage in In-phase compensation method is given as:

$$Vdvr = Vinj \tag{13}$$

$$|Vinj| = |Vpre - sag| - |Vsag| \tag{14}$$

$$<Vinj = \theta inj = \theta s \tag{15}$$

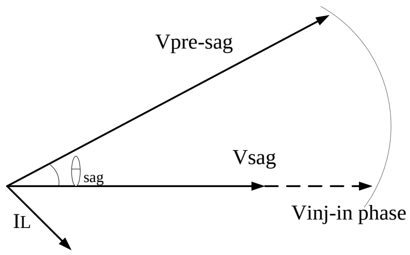

Fig.4. In-phase Compensation Method

3. Phase Advance compensation technique-

In this method the real power depleted by the DVR is decreased by minimizing the power angle between the sag voltage and load current. In pre-sag and in-phase compensation method the active power is injected into the system during power quality disturbances. The active power supply is some degree of stored energy in the DC links. The minimization of injected energy is achieved by building the active power component zero by having the injection voltage phasor perpendicular to the load current phasor. This method consisting the values of load current and voltage are fixed in the system so we can change only the phase of the sag voltage. In Phase Advance Compensation method uses only reactive power and unfortunately, not al1 the sags can be compensated without actual power, as a effect, this method is only suitable for a limited range of sags. Fig.4. shows the phasor diagram of phase advance compensation method [9].

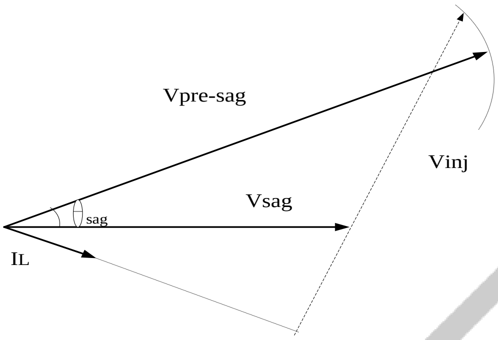

Fig.5. Phase Advance compensation method

4. *Energy optimization technique-*

Another active scheme is to use as much mechanical power as probable to compensate the sag. Therefore, the Vdvr is controlled in such a way that the required compensation voltage of the DVR is controlled perpendicular to the load current. The fundamental idea of this scheme is to draw as much active power from the grid as promising and thus to reduce the amount of active Power required from the DC-link. As long as the voltage sag is quite trivial, it is possible to mitigate sag with pure reactive power and therefore the compensation time is not limited. In Fig.6, the voltages for the energy optimized compensation are depicted. Adjacent to the vast advantage of not requiring active power, this strategy has in most cases two major drawbacks. On the one hand, a phase jump occurs and, on the other hand, the required DVR voltage amplitude can become quite high. Additionally, the compensation with pure reactive power is only possible for trivial sags. If deep sag occurs, a large amount of Active power is also needed with this strategy [10][11].

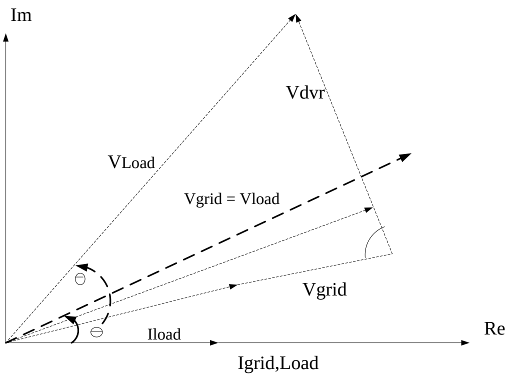

Fig.6. Energy optimization technique

V. Conclusion

This paper has presented a comprehensive study on performance of DVR. The above study shows that the DVR is suitable for compensation of voltage sag and swell by the use of different controlling techniques. From these discussion paper presents DVR may be work in Inferior cost, smaller size, and its quick dynamic response to the disturbance due to power quality issues, Ability to control active power flow, Higher energy capacity and lower costs compared to the other active devices and also Less maintenance required. This study also gives helpful acquaintance for the researchers to develop a new design of DVR for voltage disturbances in electrical system. From this study of DVR applications, this work concluded that the trends of DVR through the years are still assumed as a powerful area of research.

References

[1] J. G. Nielsen and Frede Blaabjerg, "A detailed Comparison of system topologies for dynamic voltage restorers", IEEE transaction on Industry applications, October 2005.

[2] Anand B. Kumbhar, Mahamadnayeem Tahasildar, Y. R. Atre, " Compensation of Voltage sag/swell and harmonics by DVR", International journal of advanced electronics and communication systems, February 2014.

[3] Firouz Badrkhani Ajaei, Shahrokh Farhangi, and Reza Iravani, "Fault Current Interruption by the Dynamic Voltage Restorer", IEEE TRANSACTIONS ON POWER DELIVERY, APRIL 2013.

[4] Chris Fitzer, Mike Barnes, IEEE transaction , "Voltage sag detection Technique for Dynamic Voltage Restorer", IEEE transaction on industry applications, February 2004.

[5] Ahmed Abu Hussein, Mohd. Hasan Ali, "Comparison between DVR and SFCL for fault ride through capability improvement of fixed speed wind generator", IEEE transaction 2014.

[6] Zhikang Shuai, Peng Yao, Z. J. shen, Chunming Tu, Fei Jiang and Ying Cheng,"Design Consideration of a fault Current Limiting dynamic Voltage Restorer(FCL-DVR)", IEEE transaction on smart grid, January 2015.

[7] Abdul Mannan Rauf and Vinod Khadkikar, " An Enhanced Voltage Sag Compensation Scheme for Dynamic Voltage Restorer", IEEE Transaction on industrial electronics, May 2015.

[8] Sanjay Haribhai Chaudhary, Mr. Gaurav gangil, " Mitigation of voltage sag/swell using Dynamic voltage restorer (DVR)", IOSR Journal of Electrical and Electronics Engineering (IOSR-JEEE), Dec 2013.

[9] Muhammad Taha Ali, Zhang Jianhua, Muhammad Yaqoon, Farukh Abbas, S. Furqan Rafique, "Design of an Efficient Dynamic Voltage Restorer for Compensating Voltage Sags, swells, and Phase jumps", 16th International power electronics and Motion control conference and Exposition, 21-24 Sept.

[10] Anita Pakharia, Manoj Gupta, "Dynamic Voltage Restorer For Compensation Of Voltage Sag And Swell: A Literature Review", International Journal of Advances in Engineering & Technology, July 2012.

[11] Mohammad Faisal1, Md. Shahedul Alam2, Md. Imam Mahadi Arafat, Md. Mizanur Rahman, Sk. Md. Golam Mostafa, "PI Controller and Park's Transformation Based Control of Dynamic Voltage Restorer for Voltage Sag Minimization" , The 9th International Forum on Strategic Technology (IFOST), October-2014.