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Power Quality Improvement using Dynamic Voltage Restorer (DVR)

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ABSTRACT: *The most important problem for electrical engineering is power quality problem. A power quality problem manifested by the interruption or distortion of the ideal 60 Hz sine wave. Power quality problem is event of abnormal voltage and current. The major problem due to power quality issue are voltage sag. In this paper we deal with the various techniques not only to mitigate the voltage sag but also to detect the voltage sag with the help of new algorithm that is the notch filter with reduced delay time. This paper has the comparative study of various voltage injection techniques and voltage sag detection methods.*

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

I.INTRODUCTION

In power system, power quality affects the transmission system, distribution system. Hence power quality problem is an event of abnormal voltage, current or frequency. Power quality disturbances such as voltage sag, voltage swell, harmonics, voltage fluctuation leads failure of any sensitive electric drives loads. Among the various power quality problems the voltage sag usually resulting from the fault on parallel transmission distribution feeder. 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 [2]. Many studies in recent years have focused on the performance evaluation of mitigation devices of voltage sag [1]. The first step towards mitigation the sag problem is to detect the start and the end time as well as the level of the voltage sags.

There are various methods used to compensate the power quality issues mostly voltage sags 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 Dynamic Voltage Restorer (DVR)[1]. Among these DVR is mostly used in industries to mitigate the voltage sag on sensitive loads.

Dynamic Voltage Restorer 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 [1]. It is installed in a transmission line between the supply and the sensitive load line at the point of common coupling (PCC).

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 [1].

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 [1].The amount of real and reactive power provided by the DVR depends on the type of voltage disturbances, power requirement of load, magnitude and direction of injected voltage. The energy storage unit is necessary to supply the power transfer during the voltage compensation.

II.PERFORMANCE OF DVR

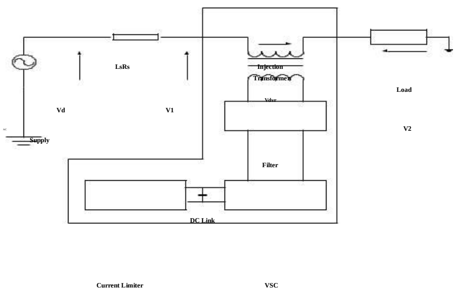
A. Basic Configuration of DVR:

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.

Types of filters:

- **a.** Capacitor filter
- **b.** Series inductor filter
- **c.** LC filters
- **d.** RC filters

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. Capacitor and battery is used as storage device.
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

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 [1].

A. Equation related to DVR:

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

Pulse Width modulates (PWM) the DC from the

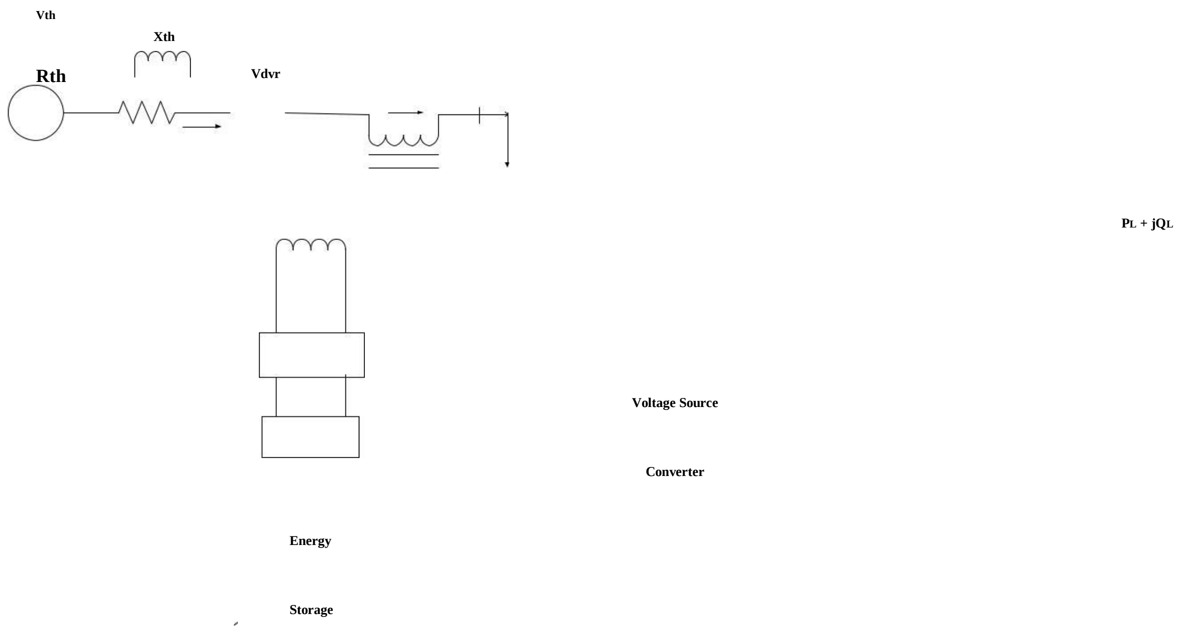
DC-link/storage to AC-voltages injected into the system. A VSC is a power electronic device

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.

III. OPERATION OF DVR



The voltage sag is caused due to short circuit in adjacent feeder or any fault occur in source side. Magnitude and phase of the voltage variation in the source side, is continuously monitoring at the point of common coupling by means of control algorithm. A fault current can lead to reduce magnitude of voltage. Under this circumstances the DVR generates a compensating voltage corresponding to the estimated magnitude of voltage variation by means of DC source. This compensating voltage is injected to the distribution system via an injection transformer and stabilizes the load side voltage.

Fig.2. Equivalent circuit diagram of DVR

The system impedance (*Zth*) depends on the fault level of the load bus. When the system voltage (*Vth*) drops, the DVR injects a series voltage dvr through the injection transformer so that the needed load voltage magnitude can be maintained [1]. The series injected voltage of the DVR can be written as:

$$\text{dvr} =+ Zth\, I \;-\; h \qquad (4)$$

$$Vdvr = V_L + Zth\, I_L - Vth \qquad (5)$$

$$Zth = Rth + jXth \qquad (6)$$

$$I_L = [\quad\quad] \qquad (7)$$

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. To compensate the voltage sag and swell there are four types of DVR voltage injection methods are as follows:

1. In-phase compensation method
2. Pre-sag 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 [1].

1. *In- phase compensation method-*

In order to overcome 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 [2]. The DVR inject the voltage in In-phase compensation method is given as:

$$Vdvr = Vinj \qquad (13)$$

| |=|− |−|| (14)

$$<Vinj = \theta inj = \theta s \qquad (15)$$

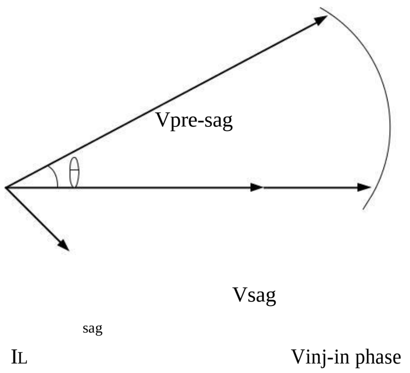


Fig.4. In-phase Compensation Method

2. *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
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 [1].

$$Vdvr = Vprefault - Vsag \qquad (12)$$

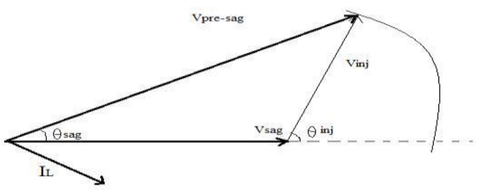


Fig.3. Pre-sag compensation method

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 [1].

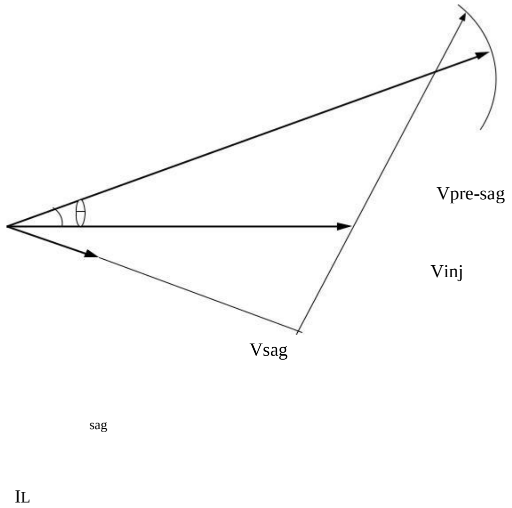


Fig.5. Phase Advance compensation method

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 [1].

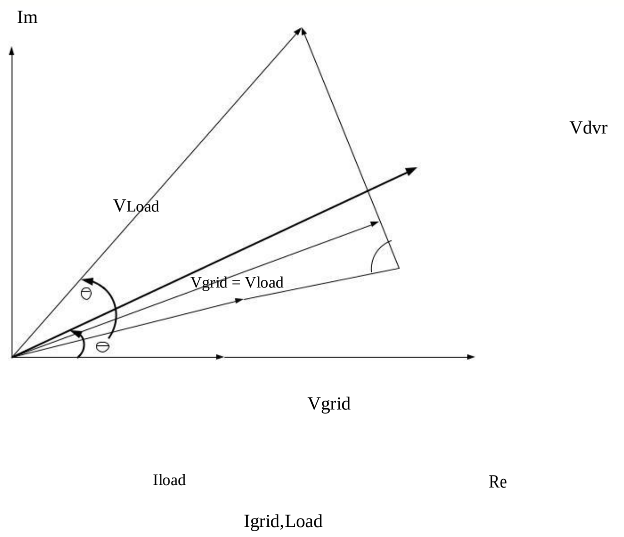


Fig.6. Energy optimization technique

V. SENSING TECHNIQUES

Voltage sag detection plays an important role for the dynamic performance of voltage sag regulator there are different methods use to measure and detect voltage sag are as follows:

A. RMS voltage detection method

B. Peak voltage detection method

C. Discrete Fourier transform (DFT) method

By using the above conventional method stimulation result shows that proposed algorithm able to detect the sag faster. It has the ability to track they amplitude, phase, frequency of a voltage signal with reduced time. This is distinct advantage over other methods of sag detection .No complex mathematics is required for implementation of notch filter on a digital signal processor. For analysis the notch filter offers the ability to calculate the amplitude, frequency and phase angle jump of voltage sag. The presented result in the literature demonstrate the effectiveness of the proposed technique i.e using notch filter for voltage sag detection.[3]

VI. CONCLUSION

This paper presented a review on various techniques used to detect and compensate the voltage sag. The results given in the different literature illustrate the capability of using notch filter to detect voltage sag in real time. The notch filter has been compared with the rms voltage sag detection method to reduce the delay time.

This paper also presented a comprehensive study on performance of DVR. The above study shows that the DVR is suitable for compensation of voltage sag by use of different sensing 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. This study also gives 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.

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