Power quality enhancement & Sag mitigation by Dynamic Voltage Restorer (DVR)

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ABSTRACT

Power peculiarity is one of the most touching issue in this present era. It became prominent with the presentation of adulterate devices, whose execution is very responsive to the peculiarity of power supply. Power attribute dilemma is a happening exhibited as a nonstandard current, voltage and frequency which result in collapse of equipments. Voltage sag is considered to be one of the most severe occurrences in power system which largely affects the quality of power. To obtain better power attribute custom power devices is used in the system. The most precious technology used in improvement of power quality is assigned as Dynamic voltage restorer (DVR) & considered as most powerful & efficient devices among the other technology available in system. The operation of DVR is very fast & dynamic in nature.. This presentation works also allow position of Dynamic voltage restorer (DVR) to amend load voltage.

Keyword- Custom power devices, DVR, Power quality, Sag, Swell.

Power quality

The word power quality may be defined as "analysis, measurement and improvement of bus voltage" to maintain that voltage at specified potential quantity & amplitude of current Or Frequency. Power quality may be illustrated as "it is a provision of system plan and voltage for the electric utility consumer that they can hold electrical energy from the power system network without any disturbance or interference". The IEEE standard dictionary for electrical and electronics, defines power quality as a concept of grounding and powering sensitive electronic equipment in a manner which is suitable for the operation of that equipment.

POWER QUALITY- The Burning issue

So far we have discussed about power quality and came to know that, the ultimate reason for which we are too much interested in power quality is nothing but economic value. The power quality may give direct economic impact on industrial customer, in the industries where semi-conductor material is being manufactured; the economic impact which is associated with equipment sensitivity is momentary voltage sag. Besides the financial impact on both utilities and industrial customer, there are various costs which are not easy to describe associated with power quality. Residential consumer generally do not suffer economically as a result of problem in power quality, but they have right to demand quality of power when they perceive that utility is providing poor services.

PROBLEMS CORRELATED WITH POWER QUALITY

TRANSIENTS

a) Impulsive transient and

b) Oscillatory transient,

- ✓ Long-duration voltage variations
- ✓ Short-Duration voltage variation
- ✓ Interruptions:-
- ✓ Sags (dips)
- ✓ Swell (rise)
- ✓ Waveform Distortion:-
- ✓ DC offset:-
- ✓ Harmonics:-
- ✓ Notching:-
- ✓ Noise
- ✓ Inter-harmonics
- ✓ Voltage fluctuation and voltage flicker
- ✓ Power frequency variation

. **Category and characteristics of power system electromagnetic phenomena:-**

This table summarizes the factor which mainly leads to power attributes dilemma, their magnitude and sustained duration.

S. no	Category	Spectral content	Duration	Voltage magnitude
1.0	Transient			
1.1	Impulsive			
1.1.1	Nanosecond	5-ns rise	<50ns	
1.2	Microsecond	1-µs rise	50 ns-1 ms	
1.1.3	Millisecond	0.1-ms rise	> 1 ms	
1.2	Oscillatory			
1.2.1	Low frequency	< 5 khz	0.3-50 ms	0-4 pu
1.2.2	Medium frequency	5-500khz	20µs	0-8 pu
1.2.3	High frequency	0.5-5 Mhz	5µs	0-4 pu
2.0	Short duration variation			
2.1	Instantaneous			
2.1.1	Interruption		0.5-30 cycles	< 0.1 pu
2.1.2	Sag (dip)		0.5-30 cycles	0.1-0.9 pu
2.1.3	Swell		0.5-30 cycles	1.1-1.8 pu
2.2	Momentry			
2.2.1	Interruption		30 cycles-3s	<0.1 pu
2.2.2	Sag (dip)		30 cycles-3s	0.1-0.9 pu
2.2.3	Swell		30 cycles-3s	1.1-1.4 pu
2.3	Temporary			
2.3.1	Interruption		3s- 1 min	<0.1 pu
2.3.2	Sag (dip)		3s- 1 min	0.1-0.9 pu
2.3.3	Swell		3s- 1 min	1.1-1.2 pu
3.0	Long duration variation			
3.1	Interruption		>1 min	0.0 pu
3.2	Undervoltages		>1 min	0.8-0.9 pu
3.3	Over voltages		>1 min	1.1-1.2 pu
4.0	Voltage unbalance		Stedy-state	0.5-2%
5.0	Waveform distortion			
5.1	DC offset		Steady-state	0-0.1%
5.2	Harmonic	0-100th harmonics	Steady-state	0-20%
5.3	Inter harmonic	0-6 Khz	Steady-state	0-2%
5.4	Notching		Steady-state	

5.5	Noise	Broadband	Steady-state	0-1%
6.0	Voltage fluctuation	<25 Hz	intermittent	0.1-7%
7.0	Power freq variation		<10 s	

Way to solve power quality problem:-

There are two different ways for the improvement of power quality namely load conditioning and line conditioning with both approaches we can mitigate power quality problem, the There solution for power quality may be achieved either from th consumer end or the various utility side. The very first approach of solution is called load conditioning which is more liable for the equipment sensitivity requirement for the power disturbances and also give great flexibility for operating in large voltage oscillation. One more way is to establish the line conditioning which minimizes the power system instability. The compensating devices used in low voltage or medium voltage distribution system are come in application by use of series or parallel connection with the distribution system. There are two type of compensating devices are available in the system from the manner of connection one is series active power filter for voltage source control & shunt active filter in order to eliminate load current harmonics. These both scheme are very much helpful for the power quality improvement with voltage source PWM converters with pulsating source component which sustain reactive component preferably like capacitor.

Thyristor based static switches:-

In the sense of voltage support need the static switching technology is more comfortably used in distribution sector. The vibrant response time is about 1 cycle, & for this static switch can be used more affectively for the alternatively power line, capacitor filter Battery storage system to correct voltage flicker sags or interruption quickly. This all can be used in alternate power line application.

Energy Storage Systems:

The energy storage system is broadly used as a protective system to protect responsive fabrication equipment from shutdown which is mainly outcome of either of voltage sag or interruptions. The above said storage system is nothing but a direct current (DC) storage system and they may be categorized as Batteries, UPS, super conducting magnet energy storage (SMES), and even that may be the fly wheels that accelerate the DC generators etcetera. The outcome of these devices is directly applied across the inverter circuit for the emergency backup by fast acting electronic devices like IGBT and GTO. Whenever fault condition such as voltage sag or interruption in power occurs a sufficient energy is provided by inverter to minimize the effect of fault energy. For the mitigation of voltage sag and swell the application of custom power devices (CPDs) is most effective as compare to other method. The word custom power employs the application of power electronic devices in distribution system. There are numerous type of custom power device such as Battery energy storage system (BESS), Surge arrester (SA), Dynamic voltage restorer (DVR), Active power filters (APF), Distribution static synchronous compensator (DSTATCOM) , Distribution series capacitors (DCR), Super conducting magnetic energy system (SMES), Solid state transfer switches (SSTS), Static electronic tap changers (SETC), Solid state fault current limiter (SSFCL), Static Var compensator (SVC), Uninterruptible power supply (UPS), Thyristor Switched capacitor (TSC), and Unified power quality conditioner (UPQC).

Custom power devices

For the purpose of power quality improvement and reliability of the system initially FACT devices like Static synchronous series compensator (SSSC), Static synchronous compensator (STATCOM), Unified power flow controller (UPFC), and Interline power flow controller (IPFC) is being

widely used in the system. These FACT devices are used in system at transmission level. But now a day our more concentration is on distribution side for power quality enhancement, for this these FACT devices is modified and called as "custom power devices". The term Custom power pertain value-added power offered by electric utilities to their customer. The value addition involves use of efficient power electronic controller to distribution system which is connected with end user of various order in magnitude preferably given as commercial consumer & industrial consumer. There are many type of custom power devices available for the enhancement of power quality in which widely used given as Active power filter(APF),), Dynamic voltage restorer (DVR), Unified power quality conditioner (UPQC) and Distribution static synchronous compensator (DSTATCOM), Etcetera. These are the devices which are normally connected to the distribution network. Furthermore these are categorized as in 3 types & based on VSC

1. Series connected Dynamic voltage restorer (DVR)
2. Shunt connected Distribution STATCOM (DSTATCOM)
3. Combined series and shunt, unified power quality conditioner (UPQC).

The operating principle of Dynamic voltage restorer (DVR) is identical with SSSC while UPFC is identical with UPQC. Although these are identical but still there is some differences between them from the point of improving power attribute. The biggest over difference found in between them is the injection of harmonic current & voltage in system by load. DVR has tendency to neutralizing the harmonic component in the system from the non linear load with adding more quality such as providing better voltage regulation & balance between receiving & sending end voltage. UPQC is a collectively defined as combination of DSTATCOM and DVR where DSTATCOM is taken in operation for eliminating harmonic content, adding with injection of reactive power in the system to raise the power factor & regulate the load bus, voltage and to raise power factor.

Topology based classification

Dynamic voltage restorer

The Dynamic Voltage Restorer (DVR), also quoted as the Series Voltage Booster (SVB) or the Static Series Compensator (SSSC), it is a device which utilizes solid state (or static) power electronic elements, and is connected in the series to the utility primary distribution circuit. The DVR provides three phase controllable voltage, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag condition.

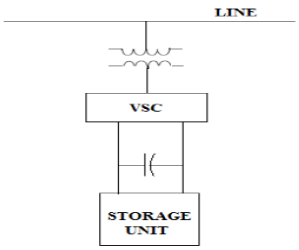


Fig [1]- Series connected DVR

DSTATCOM:-

DSTATCOM is given as sort of *CPDs* which is used to eliminate the harmonic from the source current and also balance them in order to provide reactive power compensation and to gain power factor or govern the load bus voltage.

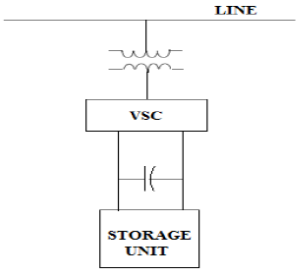


Fig [2] distribution shunt connected STATCOM

UPQC (Unified Power Quality Conditioner):-

A UPQC also comes into the category of custom power devices (CPDs) which combines the operation of Dynamic Voltage Restorer (DVR) and DSTATCOM together.

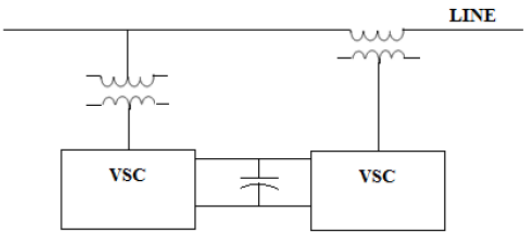


Figure [3] unified power quality conditioner

Fig [4] Role and Location of the DVR

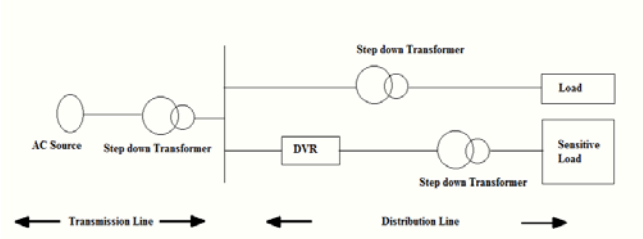
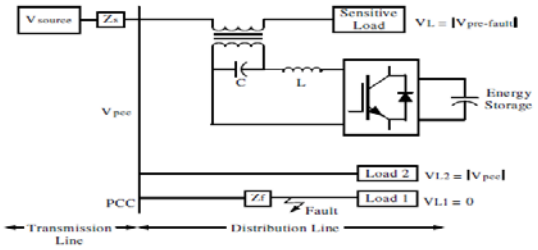


Fig- [5] location of DVR

DYNAMIC VOLTAGE RESTORER

The Dynamic Voltage Restorer (DVR), also quoted as the Series Voltage Booster (SVB) or the Static Series Compensator (SSC), it is a device which utilizes solid state (or static) power electronic elements, and is connected in the series to the utility primary distribution circuit. The DVR provides three phase controllable voltage, whose vector (magnitude and angle) adds to the source voltage to restore the load voltage to pre-sag condition. A DVR is a custom power device which can act as a harmonic isolator to obstruct the harmonics in the source voltage attaining the load, in addition to balancing the voltages and accumulate voltage regulation. Among the problem which affects power attribute like (Sags, Swells, and Harmonics etc.). Voltage sag is the most severe disturbance which greatly affects the system. The concept of CPD is recommended to conquer such dilemma.

In the CPDs technology DVR is major concerned of power quality improvement & considered as the most effective & advance custom devices. The custom devices are mostly located on the distribution level at the point of common coupling (PCC). Apart from voltage sag & swells compensation DVR also find importance in reduction of transient in voltage, harmonic content & line voltage as well as limitation in fault current.



Principle of operation of DVR:-

The DVR is made up from solid state power electronics devices mainly by GTO & IGBT, capacitor bank is employed for storage of energy & injecting reactive power in transformer & load. The DVR is connected with distribution system & load in series manner as shown in figure [3]

The very important pattern about DVR is that to inject a controlled voltage being produced by commutated converter connected in series with bus voltage with the help of injecting transformer. This voltage is being modulated by means of a DC-AC inverter by the use of sinusoidal PWM technology. To neutralize the potential drop of injection transformer and devices loss while running in normal operating condition the Dynamic voltage restorer introduce only a partial amount of voltage. Whenever a voltage sag arises in the network, the Dynamic voltage restorer performs calculation and also produce the voltage which is sufficient to protect voltage which appears at output to the load by means of a injection of a controlled voltage having a definite magnitude and phase angle. within the distribution system to the severe load. The response time of DVR is very short and it is limited by power electronic devices. The anticipated response time is about 25 millisecond, and it is considerably less than that of the other classical method of voltage correction such as changing transformer.

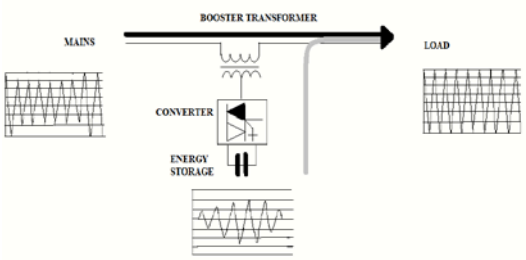


Fig [6] Configuration of DVR

Configuration of DVR:-

The general configuration of DVR consisting of following:-

a. An injection transformer/ booster transformer
b. DC charging unit
c. Harmonic filter
d. Voltage source converter (VSC)
e. A control and protection system
f. Storage devices

An injection transformer/ booster transformer:-

It is a specially designed transformer whose role is to limit the behavior of sudden changes beside the sending end to the receiving end and also it reduces the coupling of unwanted sound. A part from this the major function of booster or injection transformer is as following:

- the injection or booster transformer connects the dynamic voltage restorer to the end user by means of high-voltage winding and also its function is to alter and couple the injected voltage which is developed by VSC with the incoming supply voltage

- Furthermore By means of this, the injection or booster transformer also serves the function of separating the load from the system (VSC and control mechanism).

DC charging unit:-

There are mainly two task assigned to the DC charging unit which is given as

- The very first and important task which is assigned to the charging unit is to charge the energy sources whenever a sag compensation incident takes place.

- The second task of this unit is to keep maintain the DC link voltage at a specified DC link voltage..

Harmonic filter:-

The most important purpose of the harmonic filter is nothing but to maintain the harmonic voltage at ease which is produced by the voltage source converter at a permitted value.

Voltage source converter (VSC):-

A voltage source converter (VSC) is a solid state power electronic system which consists of normally with a switching device and storage device. This can produce a voltage of sinusoidal nature at a suitable frequency, voltage magnitude and phase angle. In DVR application the voltage source converter (VSC) is mainly applied to generate absence of supply voltage, or to temporarily change the supply voltage. The mean of storage device is to supply the needed energy to the VSC via DC link for the formation of injected voltages. The various family of energy storages are Batteries, capacitances and superconductive magnetic energy storage (SMES).

There are four leading sort of switching devices namely, Gate Turn-Off Thyristor (GTO), Integrated Gate Commuted Thyristor (IGCT), Metal Oxide Semiconductor Field Effect Transistor (MOSFET), and Insulated gate Bipolar Transistor (IGBT). Individual kind has its own perfection and drawbacks. The IGCT is a modern compact device with enhanced attainment and authenticity that allows building VSC with very wide power rating, By means of very high sophisticated converter scheme with IGCTs, the DVR can amend dips which are above the capability of past DCRs using predominant devices.

A control and protection system

A controller is also applied for the proper action of the DVR system. In this unit load voltage is compared and then it is transmitted to sequence analyzer. The application of pulse width modulated (PWM) control is implemented for inverter switching because of achieving a 3-phase having frequency 50 Hz and sinusoidal nature of voltage at the end terminal. Chopping frequency is kept fixed in advance having order of a few Kilo HZ. The PI controller in addition with IGBT inverter is implemented to carry 1 PU voltage in magnitude very close to the load terminal. The controller input is the difference between the reference voltages (V_{ref}) and actual voltage (V_{in}) and it is an actuating signal. The main advantage of proportional plus integral is that at the step input, it originates the steady-state error almost to zero. The typical arrangement of the control mechanism contains hardware with programmable logic. The software implements all the defensive job of Dynamic voltage restorer. The main two example of many defensive action carried out by software is Differential current security of transformer and short circuit current at the end user side.

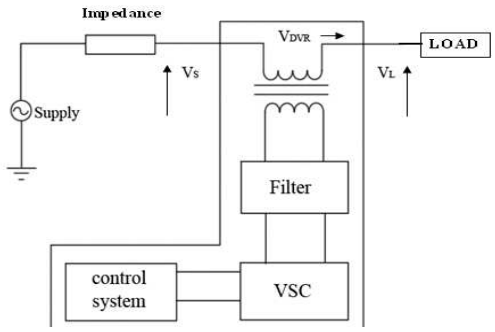


Figure [7] Schematic diagram of DVR

Operating mode of DVR:-

The fundamental role of DVR is to establish a dynamically controlled voltage V_{DVR} produced by forced commuted converter in a manner of series to line voltage by means of booster transformer. The temporary amplitude of the phase-voltage which has been injected is being controlled at the same time to reduce undesirable effects of line fault to the load voltage V_L. it shows that if there is a any degree of difference in voltages caused by sudden changes in system in AC feeder, it will be satisfied by an equivalent voltage which is being generated by the converter and implanted on the medium voltage network by means of a booster transformer. The DVR has three operational mode viz standby mode, Injection/ boost mode and protection mode.

Standby mode (V dvr = 0):-

In the standby mode the low voltage winding of booster transformer is shorted through the converter. In this mode of operation no switching of semiconductor arises and the full load current will pass through primary.

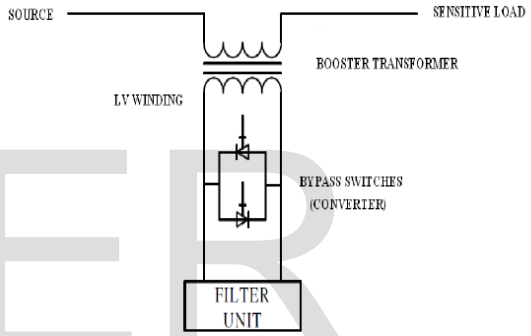


Fig [8] Stand by mode of DVR

Injection mode (Vdvr > 0):-

In the injection/ boost mode the DVR is implanting a compensating voltage through the booster transformer for the sake of exposure of a disturbance in the supply voltage.

Protection mode:-

If the over current on the load side pass a permissible limit due to short circuit on the load or huge inrush current, the DVR will be isolated from the system by using the bypass switches (S2 and S 3 will open) and supplying alternate path for current (S 1 will be closed).

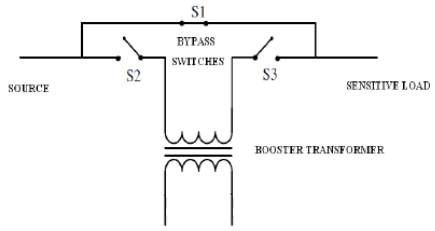


Fig [9] protection mode of DVR (creating another path for current)

Equation related to DVR:-

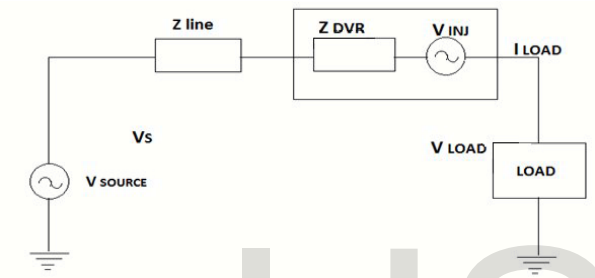


Figure [10] Equivalent circuit of DVR

Above circuit shows the equivalent circuit diagram of dynamic voltage restorer. From the above circuitry the impedance Z_{LINE} is dependent on the fault level of the load bus. When there is a reduction or drop occur in system voltage which is given as V_{SOURCE} from a prescribed value the DVR implant a series voltage given as V_{DVR} with the help of injection transformer, so that we can maintain the load voltage V_{LOAD} up to a desirable magnitude. Now the voltage magnitude of DVR which is being implanted is given by,

$$V_{DVR} = V_L + Z_{TH} I_L - V_{TH}$$

OR

$$V_{dvr} = V_{load} + Z_{line} I_{load} - V_{source}$$

Where,

V_{load} / V_L = Magnitude of load voltage which is Desirable.

Z_{line} / Z_{TH} = Load or line impedance

I_{load} / I_L = Load current

V_{source} / V_{TH} = It is the voltage which appears during fault condition.

Hence the load current I_L may be expressed as

$$I_L = \frac{(P_L + jQ_L)}{V}$$

If V_L is taken as a reference equation then,

$$V_{DVR} \angle 0 = V_L \angle 0 + Z_{TH} \angle(\beta - \theta) - V_{TH} \angle \delta$$

In the above equation the α, β and δ is the angle with respect to V_{DVR}, Z_{TH}, and V_{TH}

If θ represents the load power angle then,

$$\theta = tan^{-1} (\theta_L / P_L)$$

The complex equation for the DVR power injection is given as,

$$S_{DVR} = V_{DVR} I_L^*$$

Above equation shows that the DVR may itself having capability to generate Reactive Power, and it only require to inject reactive power.

Voltage injection methods of DVR:-

Voltage injection or compensation methods by means of a DVR depend upon the limiting factors such as; DVR power ratings, different types of voltage sags, and various conditions of load. Some loads are sensitive towards phase angel jump and some are sensitive towards change in magnitude and others are tolerant to these. Therefore the control strategies depend upon the type of load characteristics.

There are four different method of DVR voltage implantation which is:

A. In- phase compensation method
B. In- phase advanced compensation method
C. Pre-sag compensation method
D. Voltage tolerance method with minimum energy injection

In- phase compensation method:-

This is the simplest method. In this method the voltage which is injected by DVR is always in phase with the supply voltage irrespective of the load current and pre-sag voltage (Vo). This control strategy results in the minimum value of the injected voltage (magnitude). However, the phase of the load voltage is distributed. This control strategy results in optimum utilization of

thevoltage rating of the DVR. The main advantage of this method is that the amplitude of DVR injection voltage is minimum for certain voltage sag in comparison with other strategies.

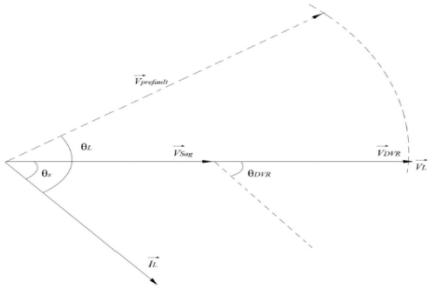


Figure [11] In phase compensation method

In phase advance compensation method:-

In this technique the standards of voltage and load current is being fixed in advance to the system, now through this we can alter only the phase of sag voltage. This methodology implies only reactive power and that is the reason unfortunately we fail to mitigate all the sags, because of not including the real power. Hence the significance of such method is only appropriate for some degree of sag. In this method the real power sent by DVR is decreased by minimizing the power angle between the sag voltage and load current. The minimization of injected energy is achieved by making the active power component zero by having the injection voltage phasor perpendicular to the load current phasor. In case of pre-sag and in-phase Compensation method the active power is injected into the system during disturbances.

Minimum energy injection method

With the help of this technique very little amount of voltage drop and very small jump in phase angle can be maintained by the load itself. The characteristics of load have no effect till amount of voltage i.e voltage magnitude comes between the range of 90 to 110 percent of nominal voltage, and 5 to 10 percent of nominal state. The two control parameter which is nothing but both magnitude and phase may be obtained by small energy injection technique.

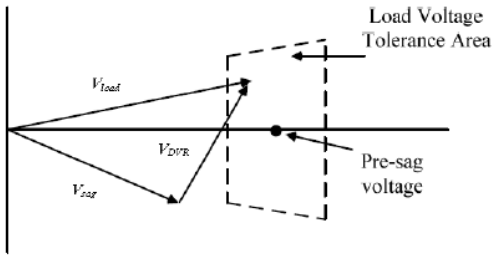


Fig [12] minimum energy injection method

Benefits with the application custom power devices:-

The custom power devices like DSTATCOM, UPFQ and DVR etcetera are used to increase the reliability of the distribution system by accumulating voltage support at critical buses in the system (with series connected controllers) and control power flow in critical lines (with shunt connected controllers) like DSTATCOM. The two, Voltage and power flow are governed by the combined series and shunt controller which is referred as UPQC. When the system is subjected to the disturbances power electronic control is quite rapid and this enables regulation, both under steady state and dynamic condition in comparison to the other controller. The several main advantages of custom power devices are as following:-

a. The dilemma of starting voltage dip in case of industrial load like induction motor can be overcome by these devices.
b. They contribute to superior system operation by improving voltage profile and attenuate power losses.
c. Through these devices dilemma of voltage fluctuation especially dynamic over voltages can be conquer.
d. The steady-state or small signal stability region can be promoted by providing auxiliary stabilizing controllers to depress low frequency oscillations.
e. The transient stability limit is enhanced thereby enhancing Dynamic security of the system and decreasing the incidence of

Blackouts originated by cascading outages.

f. The power flow in critical lines may be made better as the operating margin can be attenuated by fast controllability.
g. The power carrying capacity of lines may be enhanced to values up to the thermal limits prescribed by current carrying capacity of the conductor.

Conclusion

This paper work shows the problem concern with power quality like, voltage sag, swells etc. the factor which mainly affect the power attributes and their mitigation technique, brief description about custom power devices and their role for enhancing power quality is being taken out. This paper also shows the DVR control for the purpose of sag mitigation based on in phase compensation strategy, their role and location. As we have already discussed it is much more simple and its response time is faster which make its very much useful.

References

[1]H.P. Tiwari and Sunil Kumar Gupta *"Dynamic Voltage Restorer against Voltage Sag"*, International Journal of Innovation, Management and Technology vol.1,no.3, pp. 232-237, 2010.

[2] S. S. Choi, B. H. Li and D. D.Vilathgamuwa, *"Dynamic Voltage Restoration with Minimum Energy Injection," IEEE Trans.* Power Syst, vol. 15, pp. 51–57, Feb. 2000.

[3]Omar R and Rahim, N.A. *"New Control Technique Applied in Dynamic Voltage Restorer for Voltage Sag Mitigation"* Industrial Electronics and Applications, 2009. ICIEA 2009. 4th IEEE Conference, pp.848 -- 852.

[4]R. H. Salimin and M. S. A. Rahim *"Simulation Analysis of DVR Performance for Voltage Sag Mitigation"* The 5th International Power Engineering and Optimization Conference (PEOCO2011), Shah Alam, Selangor, Malaysia: 6-7 June 2011, pp. 261-266.

[5] C. Sankaran, "Power quality," (CRC Press, New York, 2001)

[6] Arindam Ghosh, Gerard Ledwich, "Power Quality Enhancement Using Custom Power Devices" Kluwer Press, 2002.

[7] J. Stones and A. Collinson, "Power quality," Power Eng. Journal, vol.15, pp.58-64, April 2001.

[8] M. H. J. Bollen, "What is power quality?," Electric Power Systems Research, vol.66, pp.5-14, July 2003.

[9] A.El Mofty,K. Youssef, "Industrial power quality problems," in Proc. on IEE Int. Conf & Exhib. on Electricity Distribution, 2001, vol.2, June 2001.

[10] E.W.Gunther and H. Mebta, "A survey of distribution system power quality-preliminary results," IEEE Trans. Power Delivery, vol.10, pp.322-329, Jan.1995.

[11] J.M.Salzer, "Worldwide review of power disturbances," IEEE Aerospace and Electron. Systems Magazine, vol.3, pp.2-5, April 1988.

[12] Shailendra Jain, Pramod Agarwal and H.O. Gupta, "A survey of harmonics: Indian scenario," in Proc. on IEEE Conf India Annu. Conf., pp.84-89, Dec.2004.

[13] T. M. Gruzs, "A survey of neutral currents in three-phase computer power systems," IEEE Trans. Ind. Appn., vol.26, pp.719-725, July/Aug. 1990

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