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Application of DVR for Power Quality Improvement

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Abstract— In this paper various power quality problem caused by voltage sag or swell on power system are discussed. These problems will create failure of end user equipments which are sensitive to power quality supply. By the introduction of Custom power devices namely DVR, DSTATCOM, UPQC various problems are reduced. Here an attempt is taken in this paper to review from its establishment to an up to date bibliography on DVR for power quality improvement. Basically the main function of DVR is to eliminate voltage sag or swell. Various control strategies and its improvement is analyzed. Finally, the explorations on DVR incorporating with BESS, different voltage injection method have also been discussed.

Keywords- *DVR, sensitive load, voltage injection technique,voltage sag, voltage swell*

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I. INTRODUCTION

Voltage sag due to fault has become one of the most important power quality problem facing industrial consumers. Any disturbance to the voltage waveform can result in problem related with the operation of electrical and electronics devices which uses need constant sine wave shape, constant frequency and symmetrical voltage with constant RMS value to continue production. This increasing interest to improve overall efficiency and eliminate variation in the industry have resulted more complex instrument that can sensitive to voltage disturbance.

Static Series Synchronous Compensator (SSSC) commercially known as Dynamic Voltage Restorer (DVR) inject voltage in series with the system voltage provides most cost effective solution to mitigate voltage sags by improving power quality level that is required by the customer When fault s in a distribution network sudden voltage sag will appear adjacent loads. DVR installed on sensitive load (critical load) resistors the line voltage to its normal value in few milliseconds.

The conception of custom power is to use static controller or power electronics devices in the medium voltage distribution system aim to supply reliable & high quality power to the user's sensitive load. Sensitive load on distribution side like semiconductor manufacturing plant, paper mil, food industries etc, uses DVR for eliminating voltage sag.

DVR as a custom power device could be means to overcome some major power quality problems such as voltage sag by the way of injecting active or/and reactive power into two system. .

DVR is connected in series with the transmission line which is shows in figure 1. When source supply voltage changes DVR connected in series injects dynamically controlled voltage in series with supply voltage through a series transformer correct the sag or swell present in system. However in control of DVR not only voltage magnitude (injection) but also active and or reactive power injection is needed.

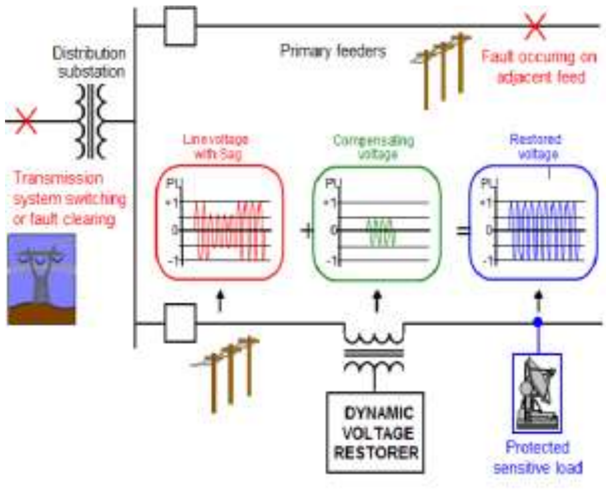

Figure1. DVR Location

The rating of DVR as module is 2 MVA per module. It compensates 35% of voltage sag for a very less duration of time of half a second. If SLG (single line to ground) fault is occurs than it compensate voltage sag greater than 50%. For Energy storage device capacitor is used which requires 0.2 to 0.4 MJ per MW of load served through a transformer, connected in series with DVR.[6]

When the DVR is used as standby mode at that time no voltage is injected and converter is bypassed. At a instant when voltage sag is detected, DVR inject a series voltage of required value this is called as boost mode.

DVR can also be used as active filter for isolating harmonics current from source side to load side. In this operation IGBT or IGCT is used with it.

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II. DYNAMIC VOLTAGE RESTORER

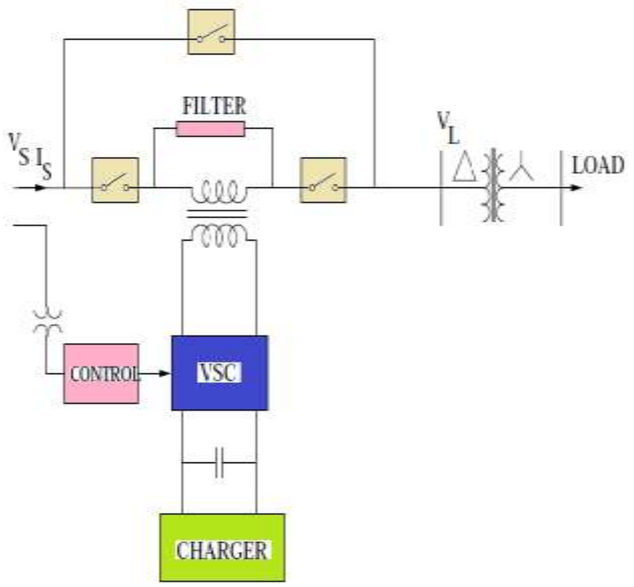

Figure 2. Basic Construction of DVR

Figure 2. Shows the main component of DVR connected in series with the distribution system used for voltage correction. Typically DVR consist of energy storage system force commutated VSC, passive filters and series booster transformers.[6]

Voltage source converter used is of 3 phase 3wire or 3phase 4 wire. The passive filter is connected on converter side or transformer side. When it is on converter side the higher order harmonics current doesn't flow through transformer winding.

The ESS can be used to protect sensitive production equipments from shutdowns caused in voltage sags. These is usually DC storage systems such as UPS, batteries, superconducting magnetic energy storage (SMES), storage capacitor or even flywheels driving DC generators is used. The enough energy is feed to the system to compensate the energy that would be lost by voltage sag.

A delta /open or star/ open winding can be used in series transformer. A delta/open winding Is preferably used since it prevents the third harmonic sand zero sequence current entering into the system and also maximize the use of DC link compare to star/open winding.

The control apparatus of the general configuration typically consists of hardware with programmable logic.

III. FIRST INTALLATION OF DVR

Duke Power System in U.S.A employed first DVR for commercial service in August 1996. 2 MVA rating 660 KJ of energy storage capable of 50% voltage sags for 30 cycles. It is providing protection against voltage sag in automated yarn manufacturing and rug weaving industries.[7] DVR of voltage rating 11 KV to 69 KV installed in substation. [7]

In May –June, 1992 a survey was conducted to determine how the customers got disturbance free electricity. The utility provide solution but the cost was included in their electricity bills as it requires installation and operation of their one site equipment for the elimination of voltage disturbance. The DVR provides the solution to the customer for their power quality problems in less cost. In this DVR uses solid state IGBT power electronics devices with PWM inverter. [8]

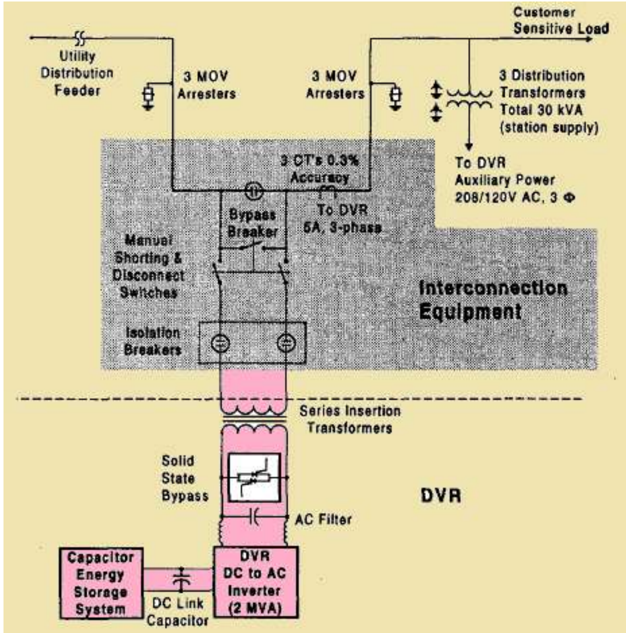

Figure 3. Single line diagram of first DVR installation

In the above figure it is shows that DVR is connected in distribution network, it would require 7.5% of the available stored energy for compensation. The main work is to developed DVR with reduced rating and battery energy storage system.[1]

III. OPERATION OF DVR

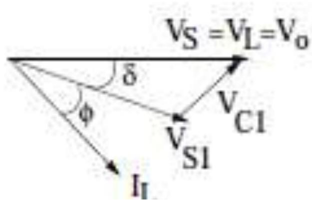

Figure 4. Voltage Injection

It shows that the initial voltage of DVR is V_S and as the sag occurs V_S reduces to V_{S1} DVR must supply voltage equal to V_{C1} in that case

$$V_L = V_{S1} + V_{C1}$$

When injected voltage is in phase with the supply voltage the desired injection (voltage correction) may be achieved with a minimum voltage injection, but it may require a considerable amount of active power injection into the system.

When the injected voltage leads to supply voltage, same correction can be made with a lower value of active power

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injection. This is possible at an expense of high voltage injection. Such a operation requires careful determination of injected voltage and angle.

In general the active and reactive power flow is controlled on the angle between the voltage that is injected in series with the line and the line current. When the injected voltage is in phase with the current only active power is changing with the line otherwise if the voltage is in quadrature with the current only reactive power will change with the line, with minimum active power injection will be required if the power factor of supply is unity.

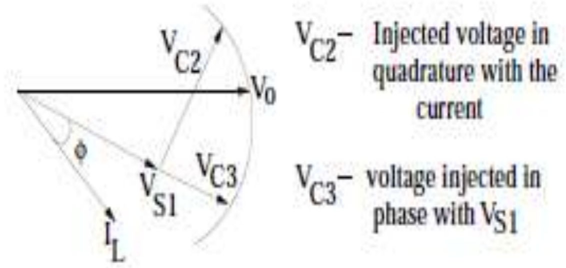

Figure 4. In-phase and quadrature voltage injection

Without energy storage system (ESS), the DVR can only inject voltage in quadrature with the load current to mitigate the voltage sag. In addition reactive power compensation is only effective for small voltage sag. ESS gives flexibility to inject voltage at any phase angle and compensate for deeper voltage sag, voltage sag with phase jumps and longer duration voltage sag. From figure 4. [6]

$$V_s=V_L+I_LZ$$

Where,

V_s= supply voltage
Z = impedance
I_L = Line current
V_L= load voltage

A disturbance or fault in the system may reduce the supply voltage magnitude 'V_s' to a new value $V_{S.New}$. The supply voltage can be maintained by the injection of V_i

$$V_{S.New}+V_i = V_L+I_LZ$$
$$V_{S.New}= (V_L+I_Lz)-V_i$$

Where,

$V_i = (V_L+I_LZ)-V_{S.New}$
V_i = injected voltage
α = phase angle of V_i

The ratio of ESS (Complex Apparent Power) is

$S_i = 3.V_i.I_L$

I_L = current representing complex conjugate.

$S_i = 3(V_L+I_LZ-V_{S.New}).I_L$

When α = S, S_i will be minimum.

The direction of I_LZ depends on the power factor of load (lagging P.F in this case) and impedance of line. However injected complex power depends on the amplitude & phase of V_i.

If V_d is % voltage dip then

$V_{S.New} = V_S - V_d.V_S$ {V_d is phaser quantity}
$= (1-V_d)$ Vs

S_i is given by

$S_i =3 (|V_d|\ |V_s|.\ |I|e^{(\delta+\Phi)})$

The voltage deviation 'V_d' of the system is reffered as a voltage in the utility industry.

$$V_D =(V_S - V_L)/\ V_L$$

$$V_S = V_D.V_L+V_L$$
$$V_S = V_L\ (1+V_D)$$

The absolute value of amount of KVA injected by ESS of DVR is

$|S_i| = 3\ (|V_d|.V_L(1+V_D).|I|-\delta+\Phi)$

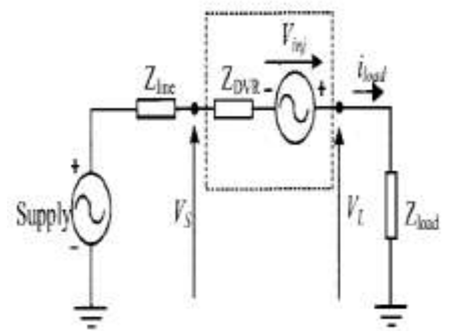

Figure 5. Equivalent circuit diagram

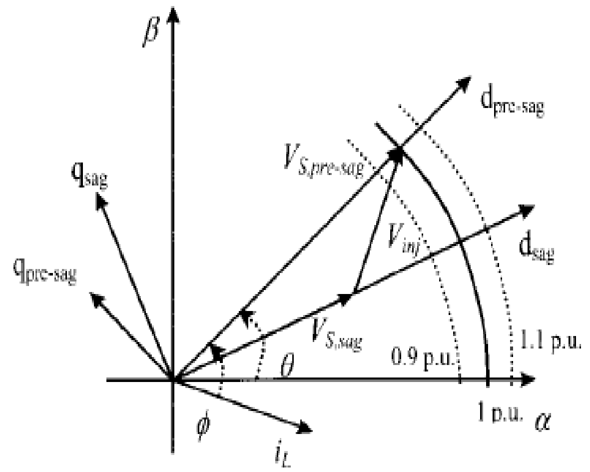

Figure 6.Phasor Diagram for Voltage Injection

A DVR is a device that injects a dynamically controlled voltage V_{inj} 1n series to the bus voltage by means of a booster transformer as depicted in Figure .2 there are three single phase booster transformers connected to a three phase converter with energy storage system and control circuit. The amplitudes of the three injected phase voltages are controlled s to eliminate any harmful effects of a bus fault to the load voltage V_L. This means that any differential voltage which is caused by transient disturbances in the ac feeder of distribution system will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the booster transformer. [8]

The single phase DVR is employed for low power loads while three phase DVR is employed for all practical high power applications as in industrial loads and domestic loads.

The basic function of the DVR is to inject a dynamically controlled voltage which is generated by DVR having a force commutated converter in series to the bus voltage by means of a boost transformer. The momentary amplitudes of the three injected phase voltages are controlled such as to eliminate any detrimental effects of a bus fault to the load voltage VL .This means that any differential voltages caused by transient disturbances in the ac feeder will be compensated by an equivalent voltage generated by the converter and injected on the medium voltage level through the boost transformer.

Thus it is suggested to particularly focus on the losses of a DVR during normal operation. Two specific features addressing this loss issue have been implemented in its design, which are a transformer design with low impedance and the semiconductor devices used for switching. An equivalent circuit diagram of the DVR and the principle of series injection for sag compensation is Shown in Figure 2 .Figure 3 shows the equivalent circuit of DVR.

$$V_{inj(t)} = V_{L(t)} + V_{S\ Sag(t)}$$

where $V_{L(t)}$ is the load voltage $V_{s\ sag(t)}$ is the sagged supply voltage and $V_{inj(t)}$ s the voltage injected by the mitigation device as shown in Figure 4.

Under nominal voltage conditions, the load power on each phase is given by (2):

$$S_L = V_L I_L {}^* = P_L - jQ_L$$

Where I_L is the load current, and P_L, and Q_L is the active and reactive power taken by the load, respectively, during a sag/swell. When the mitigation device is active and restores the Voltages back to normal, the following equation applies to each phase.

$$S_{L=} P_L - jQ_{L=} (P_{Sag} - jQ_{sag}) + (P_{inj} - jQ_{inj})$$

Where sag subscript refers to the sag supply quantities. The inject subscript refers to injected voltage quantities.

IV. METHOD OF VOLTAGE SAG COMPENSATION USING DVR

A. Voltage Sag Compensation by DVR with Discrete PWM Scheme Using PI Controller

When DVR is controlled by discrete PWM scheme using PI controller the three phase's balanced fault is applied with a fault resistance. The fault condition is applied between the time period of 0.1 to 0.2s and voltage sag condition is created in the system. This control scheme based on PI controller is able to compensate 65 percentage of voltage sag value.[9]

B. Voltage Sag Compensation by DVR with Hysteresis Voltage Control Method

When DVR is controlled by hysteresis voltage control method voltage sag condition created by the three phase balanced fault. Hare the fault resistance is 0.01**Ω** and sag time is 0.1s. The fault condition is applied between for same period. This DVR based on hysteresis voltage controller compensated 100 percentage of voltage sag condition.[9][1]

C. Voltage Sag Compensation by DVR with Hysteresis Current Control

Method Three phase balanced fault is applied to the same system with DVR which is controlled by hysteresis current control method with a fault resistance of 0.01**Ω** and sag time of 0.1 sec. The fault condition applied for same time period and if voltage sag condition is created in the system. This DVR based on hysteresis current controller compensated 98 percentage of voltage sag.[9]

D. Voltage Sag Compensation dy DVR with a reduced-rating VSC.

A new control technique is proposed to control the capacitor supported DVR. The control of a DVR is estimated using the unit vectors. The synchronous reference frame theory is used for the conversion of voltages from rotating vectors to the stationary frame. In this method again DVR is use BESS (Battery energy storage system). It reduced the error caused by different injection method.[1][7][9]

V. CONCLUSION

In this rewiev paper we have analyzed the control of DVR based on discrete PWM technique using PI controller, hysteresis voltage control method and hysteresis current control method. The hysteresis voltage control method works efficient while compared to the discrete PWM technique using PI controller and hysteresis current control method. The discrete PWM scheme using PI controller compensated 65% of the voltage sag condition and 98% of compensated by using hysteresis current control method of the voltage sag condition. But, the hysteresis voltage control technique compensated 100 % of the voltage sag condition.[9] The new technique with reduced rating VSC for sag compensation are errorless, provide 100 percentage compensation. [1]

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