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Voltage based Power Quality Improvement by DVR in Distribution System

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Abstract—Most of the power quality problems are related to voltage. Among all power quality problems Voltage based problems is the major. Most of the time voltage based problems create critical situation for operating sensitive equipment at distributed load end.. As from many research papers dynamic voltage restorer is effectively mitigate voltage based power quality problems. Voltage sag is major one in all voltage based power quality problems. This paper concentrates on effective control strategy for dynamic voltage restorer and controller analysis is based on the compensation of voltage sags with phase jump. This paper is to recommend effective control method that can improve voltage based power quality. This paper describe a method of determining the exact amount of voltage injection required to systematically correct voltage sag with phase jump is described. Energy storage system based DVR is used for compensation of voltage sag in simulation. The result obtained are such that DVR effectively compensate symmetrical voltage sag.

Keywords- *Voltage based power quality, Static Custom power Devices, voltage sag, DVR, Energy Storage System(ESS), sinusoidal pulse width modulation.*

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I. INTRODUCTION

Votage sag is a major problem in voltage based power quality problem. Voltage sags are characterized by momentary decrease in rms voltage magnitude lasting between half a cycle and several seconds [1]. Two important voltage sag parameters are magnitude and time duration. However, the sag magnitude is not constant on feeder where induction motor is present as a load [2]. Fig. 1 gives the idea about operating principle of DVR. Most of the time the voltage sag occur due to short circuit fault facing industrial customer. Disturbances occurring due to short circuit of line, change in load and starting of inductive type load has adverse effect on voltage waveform which causes problems for the operation of sensitive equipment connected at the load end.

There are various solutions to these problems. One of the most effective solution is installation of Dynamic voltage restorer at the load end as it can eliminate most sags and minimize the risk of load tripping. The DVR is used for improving the PQ of the load voltages against voltage sag, swell, transients and harmonic distortions in the source voltages. It is voltage source converter (VSC) based power electronic device connected in series in between supply and sensitive load. It protects sensitive load by injecting required compensating voltage at the load terminal in the distribution line. The controller of DVR has requirement of fast response to improve both transient and dynamic voltage stability. Hence the controller is not linear it depends on many parameters. Industrial and sensitive load needs constant magnitude of voltage sine wave, constant frequency and symmetrical voltage with constant rms value to continue the production [3].

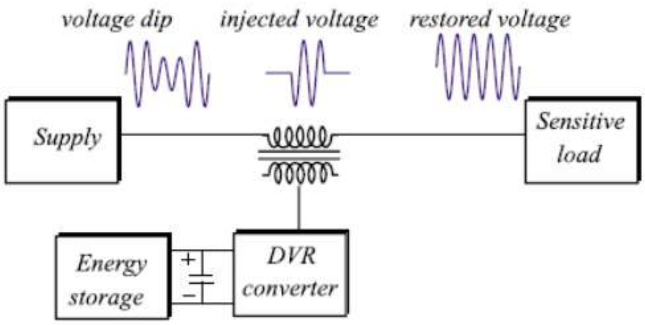

Fig. 1: Operating principle of a DVR.

Dynamic Voltage Restorer (DVR) device used in distribution side injects a voltage in series with the system voltage provides the most cost effective solution to mitigate voltage sags by improving power quality level that is required by customer [4]. When a fault happens in a distribution network, sudden voltage sag will appear on adjacent loads. DVR installed on a sensitive load, restores the line voltage to its nominal value in few milliseconds. Sags are often nonsymmetrical and accompanied by a phase jump. Control strategies for DVR's have been addressed in [3] and [7].

II. COMPONENTS OF DVR AND ITS OPERATION

The basic scenario of custom power is to use power electronic in the medium voltage distribution system which will supply reliable and high quality power to sensitive users [4]. As a custom power device, DVR could be the effective means to overcome some of the major voltage related power quality

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problems such as voltage sag by way of injecting active and/or reactive power into the system [5].

DVR is mainly connected jn series with the distribution system as shown in Fig. 2 for voltage correction. DVR basically consists of series transformer, energy storage system (ESS), voltage source converter, LC filter.

When instantaneous value of supply voltage Vs changes, DVR injects dynamically controlled voltage Vi in series with the supply voltage by means of a series transformer to correct the sag so as to maintain the desired load voltage magnitude. If there is phase jump in supply voltage then not only voltage injection but also active and/or reactive power injection is needed. The DVR itself is capable of generating the reactive power, however, but the injected active power must come from the energy storage system of the DVR. When the injected voltage is in phase with the supply voltage, the desired voltage correction can be achieved with a minimum voltage injection but it may require a considerable amount of active power injection into the system [5]. When the injected voltage leads the supply voltage, however, the same correction can be made with a lower value of active power injection [5]. This is possible at an expense of higher voltage injection. Such an operation requires careful determination of injected voltage magnitude and angle.

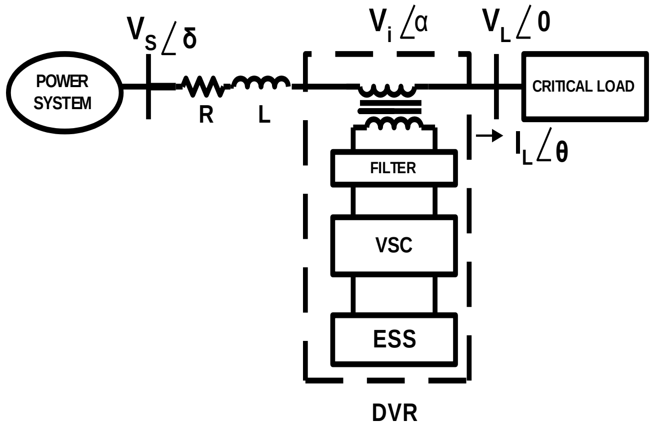

Fig. 2 Dynamic voltage restorer

In general, the active and reactive power flows are controlled by the angle between the voltage that is injected in series with the line and the line current. For example, if the 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, nothing more than reactive power, will change with the line, also minimum active power injection will be required if the power factor of supply is unity [6].

Without energy storage system, the DVR can only inject voltages in quadrature with the load current and hence a larger voltage injection is required to mitigate the voltage sag. In addition, reactive power compensation is only effective for small voltage sag. Energy storage system gives the flexibility to inject voltage at any phase angle and compensate for deeper voltage sags, voltage sags with phase jumps and longer duration voltage sag.

As From fig 2, the equation governing the system without series compensation is:

$$V_S=V_L+I_LZ \qquad (1)$$

Where: V_L is the load voltage (reference phasor), δ is the power (or torque) angle, I_L is the line current and V_S is the supply 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 .

The voltage equation for the compensated system is:

$$V_{S-new}=V_L+I_LZ-V \qquad (2)$$

Where: V_i is the injected voltage

α is the phase angle of V_i.

The rating of the ESS is: $S_i =3V_i I_L$ (3)

Where the above current represents the complex conjugate.

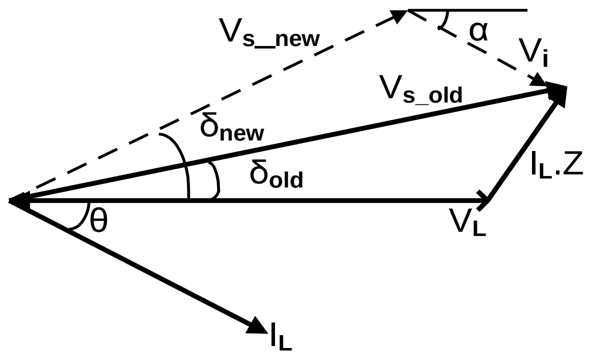

Fig. 3 shows the vector diagram of the compensated system. The direction of the vector (I_LZ) depends on the power factor of the load (in this case a lagging power factor) and the impedance of the line. For distribution feeders, the ratio of reactance to resistance is less than for transmission lines, which implies that the impedance angle will be less than 90 degree.

Fig. 3 illustrates that the injection of an arbitrary voltage V_i can maintain the load voltage constant when the supply voltage dips. However, the injected complex power depends on the amplitude and phase angle of V_i. Visual observation of Fig. 3 suggests that S_i will be minimum when α = δ. This is shown in Fig. 4

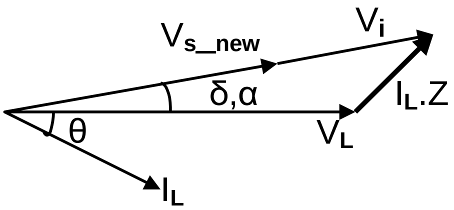

Fig. 4 phasor representation

The effectiveness of the series compensation can be obtained by the determination of injected power as a function of system parameters. Therefore, minimization of injected kVA from the ESS should be used as the criteria.

Solving for V_i in (2) and substituting into (3) yields:

$$V_{S\text{-}new}=3.\ (V_L+I_LZ - V_{S\text{-}new}).I_L \quad (4)$$

$V_{S\text{-}new}$, the new source voltage is simply a function of the transient voltage dip (V_d**)** in the line from the original source voltage **(**V_S**):**

$$V_{S\text{-}new} = (1- V_d).\ V_S \quad (5)$$

Note that V_d is a phasor quantity since both V_S and $V_{S\text{-}new}$ are phasor quantities. Substitution of (5) and (1) into (4) yields after simplification:

$$Si = 3[\,|V_d|\ I.|V_S|.e^{j(\delta+\phi)}\,] \quad (6)$$

Where: ϕ is the phase angle of V_d

The voltage deviation (VD) of the system which is referred to as voltage regulation in the utility industry is found from:

$$VD = |V_S|-|V_L|/|V_L| \quad (7)$$

Since V_L is the reference vector, the absolute value marks can be removed from it. Solving for the absolute value of the supply voltage and substituting into (6**)** yields the amount of KVA injected by ESS of DVR:

$$|Si| = 3[\,|V_d|.\ |I|.V_L.(1+VD)] \quad (8)$$

Equation (8) is the calculation of the injected KVA of the ESS of DVR as a function of the system parameters.

III. SYSTEM UNDER CONSIDERATION

A balanced sinusoidal three phase source is considered with a radial distribution system which is connected to bus to which two parallel loads with one as a critical load is connected as shown in Fig 5. If symmetrical three phase fault happens in the system at other load the critical load gets followed by balanced voltage sag. The system under consideration with fault location and DVR connection with Energy storage system (ESS) is clearly indicated in (5). ESS are usually DC storage systems such as UPS, batteries, superconducting magnet energy storage (SMES), storage capacitors or even flywheels driving DC generators which protects sensitive equipment's from deep voltage sag [8]. The voltage source inverter (VSI) converts DC link voltage into AC by applying gate pulses to switches of the VSI. The energy is gained by the system to compensate the voltage that would be lost by the voltage sag or interruption. A delta/open winding is used in series transformer since it prevents the third harmonic and zero sequence currents from entering into the system and also maximizes the use of the dc-link compared to y/open winding. A delta-connected LC filter bank is used to smooth the injected voltage [9]. This series compensation method is capable of restoring the load voltage to its rated value for a much larger load than the parallel compensation method [10].

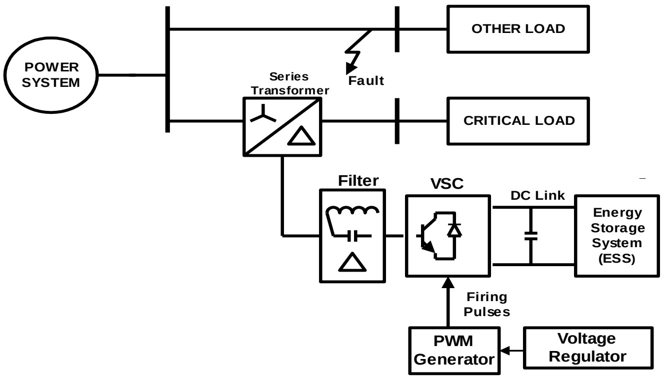

Fig. 5 System and DVR model layout

IV. PROPOSED CONTROLLER DETAILS

The outer control system consists of a sag detector, sag corrector and energy control system as shown in Fig. 6(a) and 6(b).

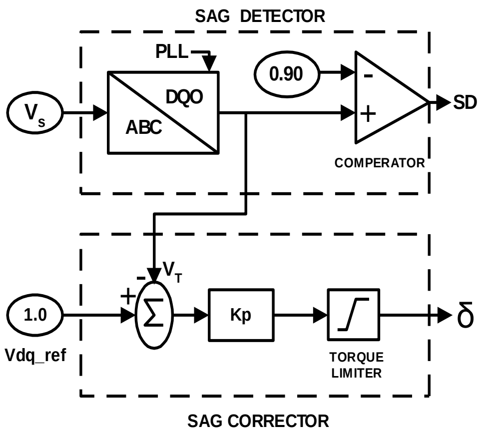

Fig. 6(a) Sag detector and sag corrector

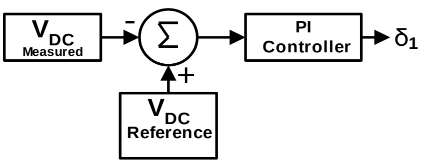

Fig. 6(b) Energy control system

A. Voltage Sag detector and its correction

The sag detector detects the voltage sag and activates the control system for sag correction. The output of it is a pulse with duration equal to the duration of voltage sag. The inputs are the voltages measured on the supply side. The measured

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voltages are converted to d-q space vector in p.u. in synchronously rotating reference frame. The magnitude of the space vector is compared to a reference value (1.0pu). The detector can give accurate result only for balanced voltage sags.In sag corrector, the controller input is an error signal obtained from the reference voltage and the p.u. rms value of the terminal voltage measured. Such error is processed by a PI controller and the output is the angle δ, which is provided to the PWM signal generator. The PWM generator then generates the pulse signals to the IGBT gates of voltage source converter.

B. SPWM method for pulse generation

The voltage source inverter is the major component of the DVR, and its control will directly affect the performance of the DVR. In the proposed DVR, a discrete PWM scheme will be used. The inverter used in this study is a six-pulse inverter. The carrier waveform is a triangular wave with high frequency (8000 Hz). The modulating index will vary according to the input error signal. The required compensating reference voltage is obtained by SPWM which compares a sinusoidal control signal of normal 50 Hz frequency with a modulating (or carrier) triangular pulses of higher frequency. When the control signal is greater than the carrier signal, three switches of the six are turned on, and their counter switches are turned off. As the control signal is the error signal, therefore, the output of the inverter will represent the required compensation voltage. A proportional integral (PI) controller is used for controlling DC link storage voltage. If the sag detector detects sag SD goes low. The DC bus voltage controllers during sag improve the response time.

V. SIMULATION RESULTS

The response and performance of DVR is judged by generating three phase symmetrical fault at the point shown in Fig. 5. The fault results in a balanced voltage sag of 55% on the supply side. The simulation MATLAB results are given for electrical system without compensation and with compensation. Using MATLAB simu-link block [7] only for the duration of fault the DVR is in action as it is generally consider in situation of practical condition.

Battery and super capacitor as ESS required for DC link is considered and extensive simulation based on it is done. The result obtained as shown in fig. 8 indicates that the variable SD is one until the fault is detected and then it becomes zero when the supply voltage goes out of tolerance band. The output V-dqo is per unit magnitude of supply side voltage, and Vdql is the per unit magnitude of load side compensated voltage. Note that the space vector voltage magnitude changes much more quickly since it is based on instantaneous quantities, and not averaged over a cycle as the RMS voltages are. Therefore, a RMS voltage reference based sag detector will react more slowly, and hurt the response of the system. The space vector based d-q voltage is used to provide faster, more accurate detection of the voltage sag in the system described in this paper.

When SD goes low as shown in Fig 7, the sag corrector is activated. The DC bus controllers are bypassed when SD is one. The ESS was in standby mode until SD goes low. Fig.8 shows the per-unit phase to phase RMS voltages on the supply side and critical load side. Figure 9 and 10 shows the voltage injected by DVR in abc & dqo system.

Figures 11 show the pu line voltage of phase A on the supply side and critical load side respectively. The ESS responded within 2 cycles to keep the critical load voltage within the 10% tolerance (i.e. the sag is corrected to 0.90 per unit, not 1.0 per unit). The sag correction can be done for 0% tolerance but it will result in over voltages at the end of the sag, with the potential to cause insulation damage. Figure 12 and 13 shows the active power on load side with and without DVR. In this case, the critical load voltage was regulated below 10% of the nominal.

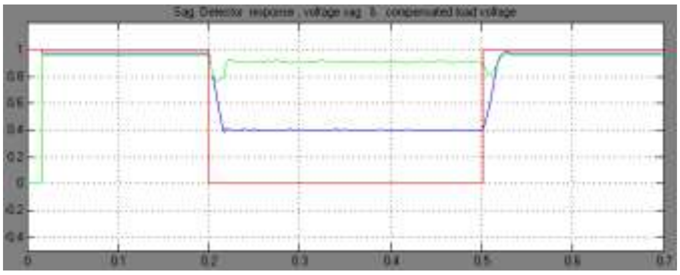

Fig. 7 Sag detection, voltage sag, compensated critical load voltage

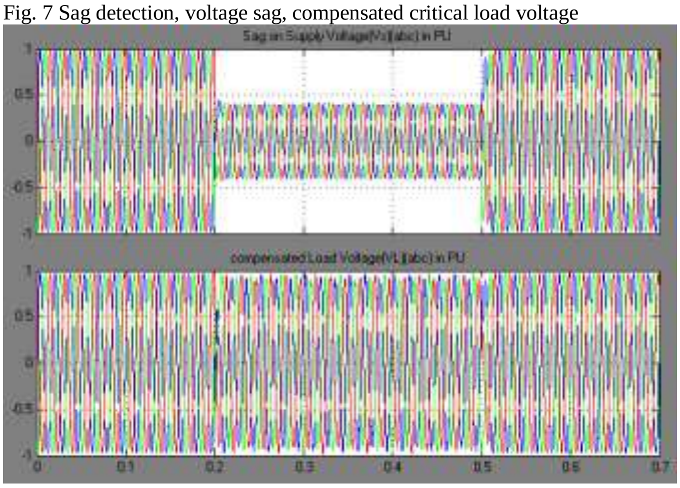

Fig.8 Voltage sag in supply & load compensated voltage in pu

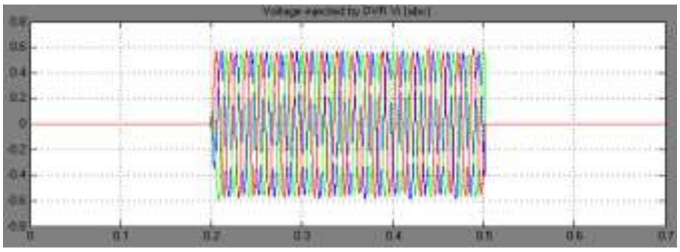

Fig. 9 Voltage submitted by DVR in three phase system

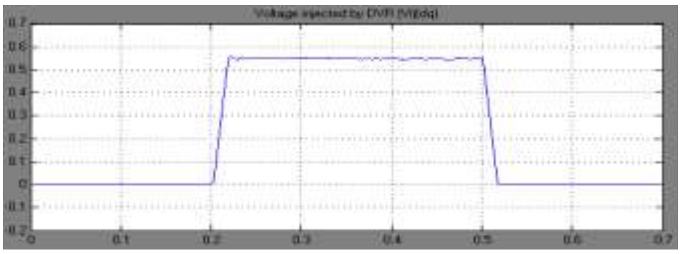

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Fig. 10 Voltage submitted by DVR in dq system

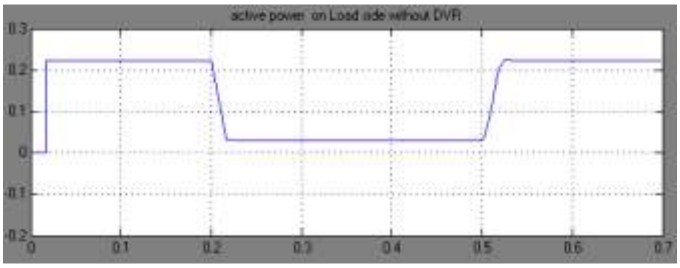

Fig. 12 Active power at load end without compensation

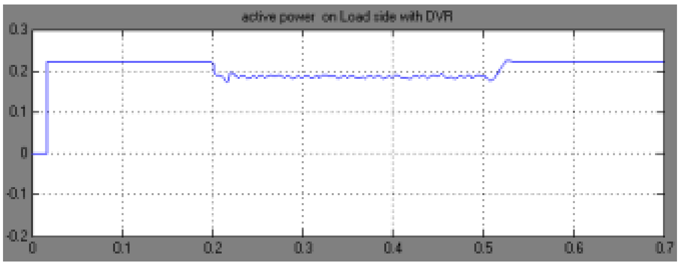

Fig. 13 Active power at load end during compensation

TABLE 1 provides a list of system data used in this paper.

TABLE I
SYSTEM DATA

Power System	3ph,415V,50Hz,25KVA
Series Transformer	415/415V,25KVA,8%
LC Filters	15mH,25μP
Critical Load	3ph-Resistive Load,10Ω,Passive
Other Loads	Passive,3ph-RL Load,5Ω,10mH,Passive
Line Impedance to both Loads	0.25Ω,1.5mH
DC Link	15000μF
PWM Switching Frequency	8000Hz
Nominal voltage of battery	200V
Maximum Capacity	1.2Ah

VI. CONCLUSION

In the presented paper simple, fast, and low cost robust Dynamic Voltage Restorer (DVR) is proposed for effectively compensating the issues of voltage sags in distribution systems. Calculation of the compensating voltage is done with reference to voltage only, since induction motors are not sensitive to changes in phase angle. A controller based on feed foreword technique is used which utilizes the error signal (difference between the reference voltage and actual measured voltage) to trigger the switches of an inverter using a sinusoidal Pulse Width Modulation (SPWM) scheme. A new SPWM-based control scheme has been implemented to control the switches in the two –level VSC generally used in the DVR. The proposed DVR utilizes energy drawn from the ESS during sag duration which is converted to regulated three phase ac voltage suitable for compensation of voltage sags. DC energy controlling system which regulates the DC link voltage has been proposed. The advantages has been discussed of a d-q based sag detector as compare to instantaneous.

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