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Voltage Quality improvement by Dynamic Voltage Restorer Modeling

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ABSTRACT

Voltage magnitude, waveform and frequency are the major factors that dictate the quality of power. The widespread application of non-linear power electronic loads has brought about degradation of power quality. Of all the power quality issues, voltage sags are the major cause of 80% of the problems experienced by sensitive loads. A Dynamic Voltage Restorer is a power quality device capable of protecting such loads against voltage variations. It injects a dynamically controlled voltage in series with the supply voltage through a booster transformer to correct the load voltage . Generally DVR can be connected to grid through inverter topologies such as Voltage Source Inverter (VSI) or Current Source Inverter (CSI).This device can be implemented to protect a group of medium or low voltage consumers. In this paper a model of a DVR for voltage and power injection, by the compensation method and phase advance voltage restoration method has been compared.
Keywords : Voltage Quality, DVR, Real Power, Reactive Power, Phase Advance Technique, Minimum Power

I. INTRODUCTION

A DVR is a power quality device used to correct the voltage disturbances by injecting voltage as well as active power in the system. It is a forced commutated Voltage Source Inverter that injects a controlled voltage in series with supply voltage through a booster transformer to correct the load voltage. In this paper two models have been discussed: the instantaneous phase advance voltage injection model and minimum power injection model of the compensation method. Control scheme is the heart of the DVR where its main function is to detect the presence of voltage sags in the system, calculating the required compensating voltage for the DVR and generate the reference voltage for PWM generator to trigger on the PWM inverter. This paper tries to compensate three phase voltage sag and swell, single voltage sag (SLG) and unbalance voltage sag and swell by the aid of the DVR has been presented. Simulation results carried out by Matlab/Simulink verify the performance of the proposed method.

There are various custom power devices which can be used to improve the power quality of the power system like, SVC (static var compensator), DSTATCOM (distributed static compensator), DVR (dynamic voltage restorer). Dynamic Voltage Restorer can provide the most cost effective solution to mitigate voltage sags and swells that is required by customer. The Dynamic Voltage Restorer (DVR) is a rapid, flexible and resourceful solution to power quality problems. The DVR can restore the load voltage within few milliseconds by injecting series voltage which is actually missing voltage in to system through series connected booster transformer, when it is subjected to voltage sags. Generally DVR can be connected to grid through inverter topologies such as Voltage Source Inverter (VSI) or Current Source Inverter (CSI).This device can be implemented to protect a group of medium or low voltage consumers. This study present compensation of sags and swells voltage during single line to ground, double line to ground and three phase line to ground faults. By using DVR technology, power quality enhances, which is shown in simulation waveform.

The organization of this document is as follows. In Section 2 (**Modelling of DVR**), In Section 3 (*Phase Advance Voltage Injection&* Minimum power injection model of the DVR by the compensation *technique* .In section **4(Result and Discussion**),

II. MODELLING OF DVR

The Dynamic Voltage Restorer(DVR) is made of a solid state DC to AC switching power converter that injects a set of three phase AC output voltages in series and synchronism with the distribution and transmission line voltages. The source of the injected voltage is the commutation process for reactive power demand and an energy source for the real power demand. The energy source may vary according to the design and rating of the DVR. The DC input terminal of a DVR is connected to an energy storage device of appropriate capacity. The real power exchanged at the DVR output AC terminals is provided by the DVR input DC terminal by an external energy source . The amplitude and phase angle of the injected voltages are variable, thereby allowing control of the real and reactive power exchange between the dynamic voltage restorer and the distribution system.

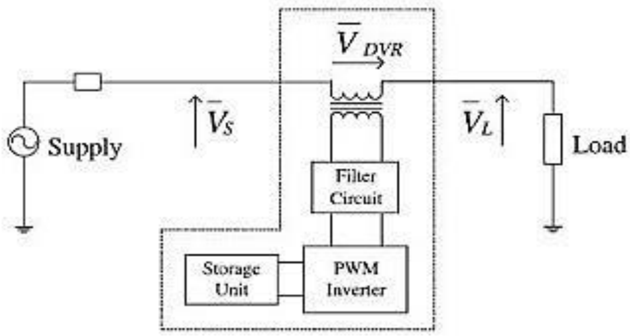

Figure 1 : Schematic diagram of a DVR

III. Phase Advance Voltage Injection

In this method of voltage restoration, the injected voltage can have a phase advance β, w.r.t the source voltage Vs as shown in figure (1). The phase advanced injection method is superior as compared to the conventional in phase injection method. In this the injected active power is reduced from Vi1* I to Vi2*I as shown in the figure (1). The corresponding relative power generated internally, in the inverter increases. This helps to boost the voltage and in turn forces the active power to flow from source to load.

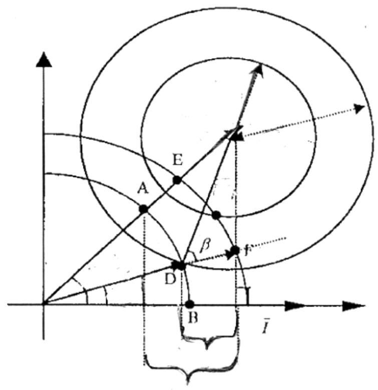

Figure 2 : *Phase Advance Voltage Injection*

For a given voltage sag, voltage restoration by injecting voltage with a phase advance therefore decreases the demand of energy injection from the energy storage device. Thus injected power by a DVR can be minimized. Minimum power injection strategy is determined by voltage magnitude injection limit of the DVR and the depth of the voltage sag. The combination of the sustained source voltage and, the voltage injection limit of the DVR determine the minimum power injection, operating point of the DVR. This operating point is D, in the fig (1). When β increases, θ decreases, and the injected active power decreases. Considering various cases below:

Case I: When $V_{inj} \geq V_L$ and $V_S < V_L Pf_L$ shown in figure (2). When $V_S < V_L Pf_L$ and no limit is placed on the magnitude of injection voltage of DVR, the operating point D can lie anywhere on the arc AB in figure (1).

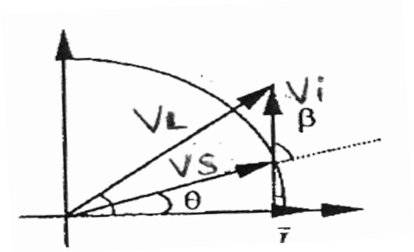

Figure 3 : case 1. $V_{inj} \geq V_L$ and $V_S < V_L Pf_L$ s

When θs = O, the injected real power, approaches a minimum. But voltage injection required will be more. As θs goes on decreasing, the magnitude of injected voltage V_i, goes on increasing

Thus there is a limit on the magnitude of the injected voltage. Two such limits V_{injl} and V_{inj2} are shown. If the DVR voltage injection limit is V_{injl} and $V_S < V_L Pf_L$, the point D, corresponds, to the situation of minimum power injection. From fig (2),

$V_i = (V_L - V_S)$

Hence, $V_i = \sqrt{V_L^2 + V_S^2 - 2V_L V_S \cos\theta_l}$

$$\beta = \sin^{-1}\left[\frac{V_L \sin\theta_L}{V_i}\right]$$

And

Case II: When $V_{inj} \geq V_L$ and $V_S > V_L Pf_L$. This is shown in figure (3).

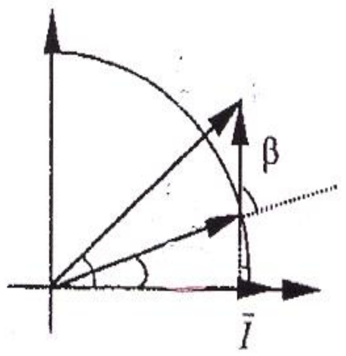

Figure: 3 $V_{inj} \geq V_L$ and $V_S > V_L Pf_L$

$V_i = V_L - V_S$

Magnitude of V_i is given by

$$V_i = V_L \sin\theta_L - \sqrt{V_S^2 - V_L^2 \cos^2\theta_L}$$

and angle of injected voltage is

$$\beta = 90 - \cos^{-1}\left(\frac{V_L Pf_L}{V_S}\right)$$

CaseIII: When $V_{inj} < V_L$ and $V_S < (V_L - V_{inj})$ shown in figure (4).

The injected voltage will be equal to voltage injection limit of the DVR i.e. $V_i = V_{inj}$

and the angle will be

$$\beta = 180 - \cos^{-1}\left[\frac{V_S^2 + V_i^2 - V_L^2}{2V_S V_i}\right]$$

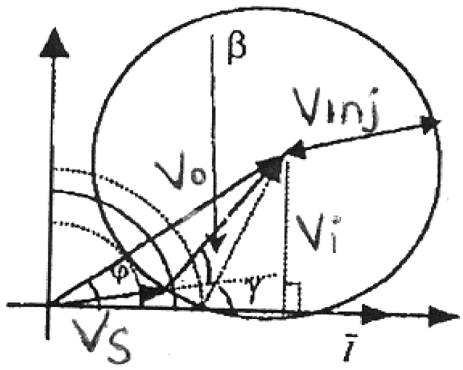

Figure 4 : $V_{inj} < V_L$ and $V_S < (V_L - V_{inj})$

IV. Minimum power injection model of the DVR by the compensation Method.

In this method, when the injected voltage is in phase with the supply voltage the correction can be achieved with a minimum voltage injection, but it may require a considerable amount of active power injection. When the injected voltage leads the supply voltage, however, the same correction can be made with a lower value of active power injection. When the power injection by the DVR is minimized, the same energy storage can be used for a longer period. The objective here is to determine the magnitude and angle of this injected voltage. The DVR injected power is, $P_i = P_L - P_S$

$P_i = V_L I_L \, Cos\theta_L - V_S I_L \, Cos\theta s$

$$= V_L I_L \left[Cos\theta_L - \frac{V_S}{V_L} Cos\theta_S\right]$$

Taking $V_L I_L$ and V_L as base quantities. Then in p. u. $P_{ipu} = Pf_L - V_S Cos\theta_S$.

Now, power injection will be minimum for unity power factor i. e. VS and IL are in-phase thus VL must lead VS by angle θ_L.

It can be realized by careful injection of Vi. Considering load voltage to be 1 pu and Vd to be the supply voltage drop, $V_S = 1 - Vd$. So equation for minimum power injection (Pimin) can be written as;

$$P_i^{\min} = Vd - (1 - Pf_L)$$

Case 1: When $Vd < 1 - Pf_L$

$P_i^{\min}$ becomes negative, thus the power flows in reverse direction from system to the DVR. Such a situation can be avoided by adjusting the value of θ_S so that that power flow becomes zero. The value of θ_S for zero power flow is: $\theta_S = Cos^{-1}\left(\frac{Pf_L}{1 - Vd}\right)$

Thus for this case the voltage correction can be made without injecting any active power.

The expression for magnitude (Vi) and phase angle (β) of injected voltage can be determined as;

The injected voltage Vi is given by: Vi = VL - Vs

Consider Vs as reference, then VL must have angle of (θ_L - θ_S) to avoid reverse flow of power

$$V_i \angle\beta = 1\angle\theta_L - \theta_S - (1 - Vd)\angle 0°$$

So, magnitude of injected voltage :

$Vi = \sqrt{Vd^2 + 2(1 - Vd)[1 - Cos(\theta_L - \theta_S)]}$ and angle of injected voltage is $\beta = \tan^{-1}\left[\frac{Sin(\theta_L - \theta_S)}{Cos(\theta_L - \theta_S) - (1 - Vd)}\right]$

Case: 2 When $V_D > 1 - Pf_L$:

Injection of active power is required to correct the voltage sag but its value can be minimized if V_S and I_L are in phase. Since V_S is considered as the reference, so, θ_S = 0, while V_L leads V_S by angle θ_L So the equation takes the form:

$$V_i \angle\beta = 1\angle\theta_L - (1 - Vd)\angle 0°$$

The magnitude of injected voltage is

$$Vi = \sqrt{Vd^2 + 2(1 - Vd)(1 - Cos\theta_L)}$$

Angle of injected voltage is

$$\beta = \tan^{-1}\left[\frac{Sin(\theta_L)}{Cos(\theta_L) - (1 - Vd)}\right]$$

Computational procedure for compensation method:

Step 1: Initially, get the values of $V_L, V_S, I, \theta_L, \theta_S$ for the power system under study.

Calculate $Pf_L = \cos\theta_L$ and $Pf_S = \cos\theta_S$. Calculate the load power by using the relation $P_L = V_L I_L\ Cos\theta_L$ Calculate the source power by using the relation $P_S = V_S I_L\ Cos\theta_S$

Step 2: Ask the user if there is any drop in the voltage. If there is no drop in voltage, then no injection will be required. Go to step (7).

Step 3: Calculate the power needed to be injected by the DVR by using the following relation $P_i = P_L - P_S$. Calculated the per unit power injection required by using the following relation. $P_{ipu} = Cos\theta_L - V_S Cos\theta_S$.

Set $Cos\theta_S = 1$ for minimum power injection.

Step 4: If magnitude of the voltage drop i.e. V_d satisfies the following relation. $Vd < 1 - Pf_L$ .Then set $P_i^{\min}$ = 0. Calculate $\theta_S = Cos^{-1}\left(\frac{Pf_L}{1 - Vd}\right)$, $Vi = \sqrt{Vd^2 + 2(1 - Vd)[1 - Cos(\theta_L - \theta_S)]}$ and $\beta = \tan^{-1}\left[\frac{Sin(\theta_L - \theta_S)}{Cos(\theta_L - \theta_S) - (1 - Vd)}\right]$ Go to step (6)

Step 5: Else if $V_D > (1 - Pf_L)$, set $\theta_S = 0$. Calculate $Vi = \sqrt{Vd^2 + 2(1 - Vd)(1 - Cos\theta_L)}$

Calculate $\beta = \tan^{-1}\left[\frac{Sin\ \theta_L}{Cos\theta_L - (1 - Vd)}\right]$ Go to step (6)

Step 6: Set the necessary control action to inject the voltage of calculated magnitude and angle.

Step 7: Stop.

Procedure for phase advance restoration scheme:

Step 1: Initially, get the values of $V_L, V_S, I, \theta_L, \theta_S, V_{inj}$ for the power system under study. Calculate the value of $Pf_L = \cos\theta_L$

Step 2: Ask the user, if there is any drop in the voltage. If there is no drop in the voltage, no injection will be required go to step (7)

Step 3: If $V_{inj} \geq V_L$ **and** $V_S < V_L Pf_L$ **Calculate**

$$V_i = \sqrt{V_L^2 + V_S^2 - 2V_L V_S Pf_L}$$

Step 4: If $V_{inj} \geq V_L$ **and** $V_S \geq V_L Pf_L$ **Calculate**

$$V_i = V_L \sin\theta_L - \sqrt{V_S^2 - V_L^2 \cos^2\theta_L}$$

and

$$\beta = 90 - \cos^{-1}\left(\frac{V_L Pf_L}{V_S}\right)$$

Step 5: Else if $V_{inj} < V_L$ **and** $V_S < (V_L - V_{inj})$ **The data is unavailable. Go to step (7)**

Step 6: If $V_{inj} < V_L$ **and** $V_S \geq (V_L - V_{inj})$

Calculate $V_i = V_{inj}$ **and**

Calculate

$$\beta = 180 - \cos^{-1}\left[\frac{V_S^2 + V_i^2 - V_L^2}{2V_S V_i}\right]$$

Step 7: Stop.

V. RESULTS AND DISCUSSION

It is seen in the compensation method, that when the voltage drop in the line is less than $(1 - Pf_L)$, no active power injection is required. The expression for magnitude and phase of injected voltage has been derived. The value of angle between supply voltage and line current has also been derived to avoid the reversal of power flow. In this region of voltage drop both the injected voltage magnitude and the angle increases with the increase in the voltage drop. When the voltage drop reaches $(1 - Pf_L)$, the magnitude and angle of injected voltage becomes, $\sqrt{1 - Pf_L^2}$ and 90⁰ respectively. For higher voltage drops, the active power injection is essential and it can be minimized by drawing power from the supply at unity power factor. In this region the injected active power increases linearly with increase in voltage drop and depends upon load power factor. The injected voltage magnitude increases while the phase angle decreases with increase in the voltage drop.

In the *phase advance voltage restoration* scheme, it is observed that energy consumption is reduced as compared to the in-phase injection. When the voltage injection limit of the DVR is greater than the load voltage, i.e. $V_{inj} > V_L$ and load voltage is taken to be 1 p. u. then as the value of Vs is increased, Vi decreases. However, the value of β depends on Vs and load power factor. For the case when Vs and pfL are equal the value of β is maximum i.e. 90 degrees. However as Vs goes on increasing further the value of β goes on decreasing. Graphs have been plotted showing the variation of the injected voltage magnitude and angle for various conditions for the two methods.

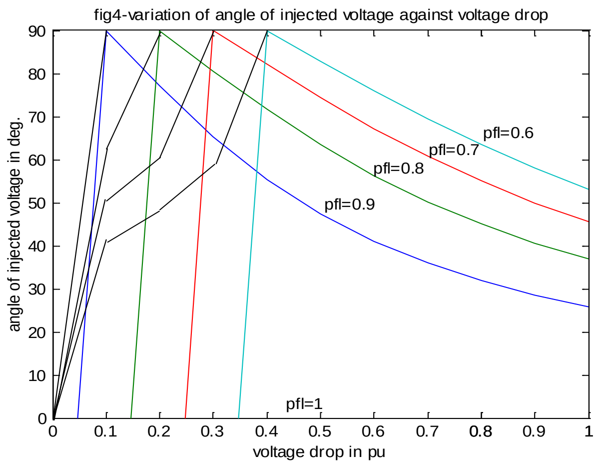

Figure 5 : Variation of angle of injected voltage against voltage drop

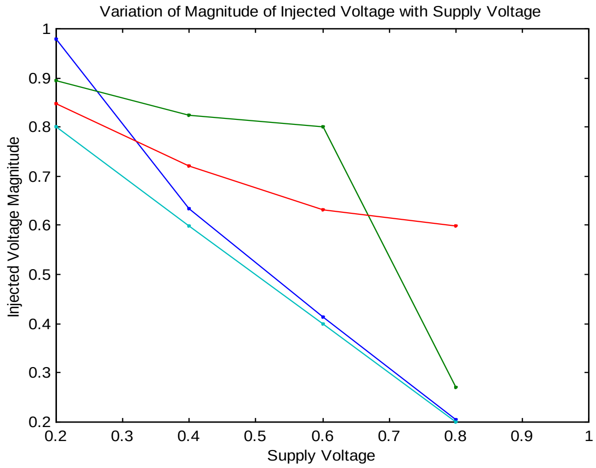

Figure 6 : variation of angle of injected voltage against supply voltage

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