SAG MITIGATION AND CONTROL OF DYNAMIC VOLTAGE RESTORER WITH VARIOUS STORAGE SCHEMES

Keren Persis P, Suvitha V, Devi S, Yuvaleela M

Abstract— **Dynamic voltage restorers (DVR) can provide the most commercial solution to mitigate voltage sag by injecting voltage as well as power into the system. Nowadays, a lot of devices have been developed to mitigate voltage sag such as Dynamic Voltage Restorer (DVR), Distribution Static Compensator (D-Statcom) and Uninterruptible Power Supply (UPS). The efficiency of the DVR depends on the performance of the efficiency control technique involved in switching the inverters. This paper deals with the mitigation of voltage sag, performance of DVR under various DC storage devices and the control techniques of DVR**

Index Terms— **DC Energy Storage, Dynamic Voltage Restorer, Voltage Sag mitigation.**

I. INTRODUCTION

Voltage sag is a momentary decrease in rms voltage magnitude in the range of 0.1 to 0.9 per unit (p.u)[2]They are caused by abrupt increases in loads such as short circuits or faults, motors starting, or electric heaters turning on or they are caused by abrupt increases in source impedance, typically caused by a loose connection[1]. Voltage sag mitigation devices are classified into three categories; (i) Traditional Solutions (ii) Uninterruptible Power Supplies (UPS) (iii)DynamicVoltageRestorer(DVR).Active solutions can be produced by Static compensator and DVR. The DVR Supplies the active power with help of DC energy storage and required reactive power is generated internally without any means dc storage. The DVR is connected in series between the load and the supply voltage [3].It basically supplies the voltage difference (difference between the pre sag and sag voltage) to transmission line and maintains the pre sag values condition in the load sides [4]. Voltage sag and swell can be defined as given in the following Table 1.

TABLE 1

Disturbance	Duration in cps	Voltage in p.u
Voltage Swell	0.5-30 cycles	1.1-1.8 p.u
Voltage Sag	0.5-30 cycles	0.1-0.9 p.u.

Voltage sag is an rms variation with a magnitude between 10%and 90% of nominal voltage and duration between 0.5 cycles and 1 minute.There are many ways in order to mitigate voltage sag problem. One of them is minimizing short circuits caused by utility directly which can be done such as with avoid feeder or cable overloading by correct configuration. Another alternative is using the flexible ac technology (FACTS) devices which have been used widely in power system nowadays because of the reliability to maintain power quality condition includes for voltage sag mitigation.

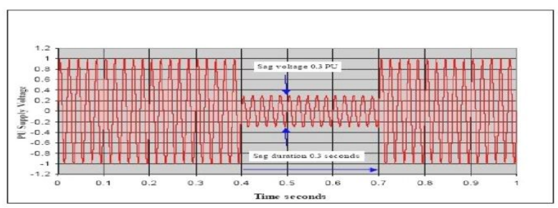

Figure 1. Voltage sag waveform

This paper deals with the one of the facts device DVR along with its position in sag mitigation, comparison of DVR with different DC energy storage accompanied by the techniques to improve DVR efficiency.

DVR STRUCTURE

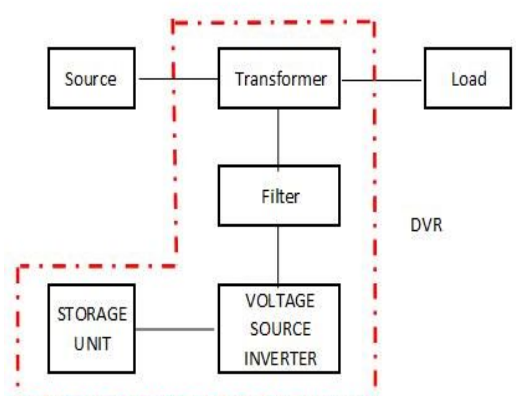

Figure 2 Structure Of DVR

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A. Structure Of DVR

The DVR device consists of five main sections: Energy Storage Unit, Inverter, Passive Filters, By-Pass Switch, and Voltage Injection Transformers. Energy storage unit is responsible for energy storage in DC form. Inverter is used to convert DC power to AC power. Passive Filters clear that higher order harmonic components distort the compensated output voltage. Filter is used to convert the PWM inverted pulse waveform into a sinusoidal waveform. This is achieved by removing the unnecessary higher order harmonic components generated from the DC to AC conversion in the VSI. By-Pass Switch is used to protect the inverter from high currents. In case of a fault or a short circuit on downstream, the DVR changes into the bypass condition where the VSI inverter is protected against over current flowing through the power semiconductor switches Voltage Injection Transformers: In a three-phase system, three Single-phase transformer units or one three phase transformer unit can be used for voltage injection purpose

B. Storage Schemes

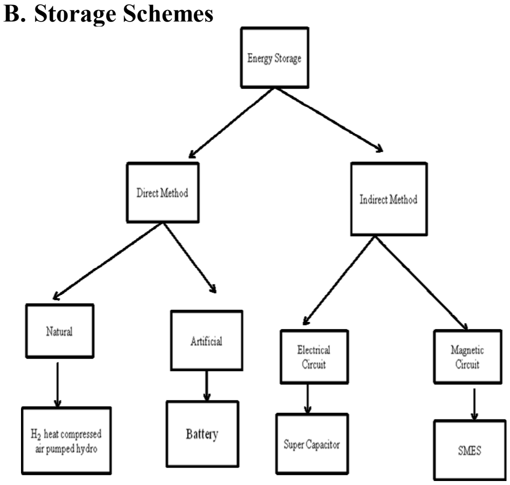

Figure 3 Classification Of Storage Schemes

All the energy storage devices are classified into two categories direct energy storage and indirect energy storage as shown in Fig.3 [5].Electrical energy storage devices come under indirect energy storage categories. The stored energy is reconverted back to electrical energy, when a supply of electrical energy is required, it is difficult to store and reconvert large amount of energy. Various energy storage devices are presently used for voltage sag compensation in the DVR system. Electrical energy storage devices are super capacitor, superconducting magnetic energy storage (SMES) etc. Flywheel energy storage is used as a mechanical energy storage system. In the advance development fuel cell conservation technique is used in place of dc energy storage system.

Energy storage devices are divided into three categories:

1. Small Level(<10MW): Flywheels batteries, capacitors, ultra capacitors (combined with DG devices) are comes in small categories
2. Medium Level (10MW < energy < 100 MW): Large-scale batteries, lead-acid, NAS and Va Red ox are come in medium categories.
3. Large Level (≥100MW). Pumpedstorage, compressed air energy storage (CAES) are comes in large categories.

Various Energy Schemes and its comparison is presented in the below table

TABLE 2

S. No.	Scheme	Efficiency %	Sizes (MW-h)
1	Pumped hydro	75	5k-20k
2	Batteries	74-84	7-40
3	Ultra capacitors	90 +	0.1K-0.5K
4	SMES	90 +	20

II. SAG DETECTION & MITIGATION

Whenever a Voltage sag is created at load terminals, load voltage is sensed and passed through a sequence analyzer.The sag voltage magnitude is compared with the reference voltage which is normally 1 pu and the difference is applied to the PI controller for the better control action . The transfer function of the PI controller is Kp(1+1/TiS), where Kp is the proportional gain constant and Ti is the integral time the schematic of controller is shown below.

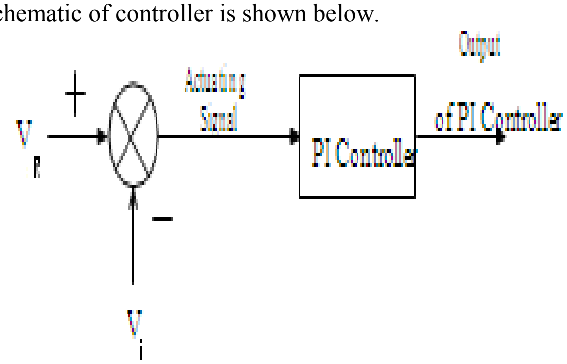

Figure 4 Schematic Of PI

Let Vr be reference voltage, Vr=1pu.Let Vi be voltage at the output load terminals which is the feedback obtained from load side. Actuating signal is nothing but the error signal which gives the difference between the Vr and Vi. Output of the controller block is of the form of an angle δ, which introduces additional phase-lag/lead in the three-phase voltages.When Vi<Vr PWM generates the triggering sequence as a result of it inverter operation of IGBT begins and the power flows from DVR to load and maintaining the load at rated KW. When Vr=Vi, error detector produces zero voltage to the controller, thereby converter operation begins and the source energy storage scheme begins to charge till Vi<Vr.

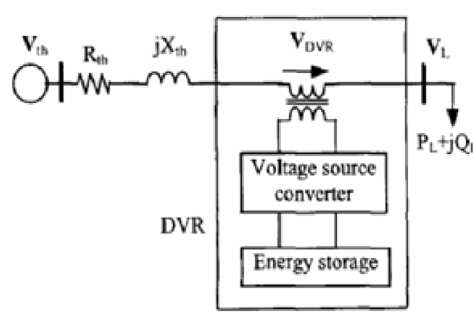

Figure 4 Injection Of Power.

When dropped voltage happened at V_L, DVR will inject a series voltage V_{DVR} through the injection transformer so that the desired load voltage magnitude V_L can be maintained

$V_{DVR} = V_L + Z_{th}I_L - V_{th}$-------(1)
$S_{DVR} = V_{DVR}\ I_L$------------------(2)

V_{DVR}, DVR voltage, S_{DVR}, Power injected from DVR
Below figure depicts the voltage sag with and without DVR.

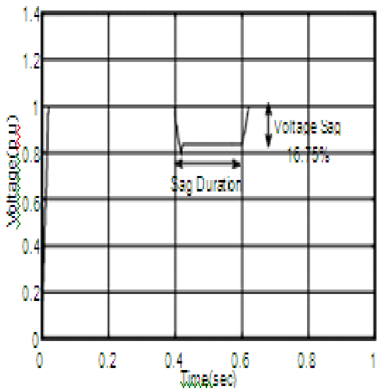

Figure 5 Without DVR

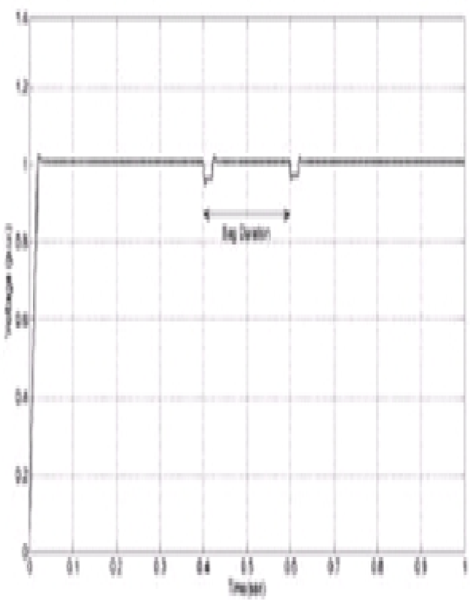

Figure 5 Without DVR

A.PERFORMANCE OF DVR

In a DVR, there are two main considerations in its working performance: the compensation capability and the output voltage quality. In a STATCOM, there is some influence of the capacitor size on its performance, including distortion [6]. Whereas in DVR there are two main factors relating to the capability and performance of DVR working against voltage sags in a certain power system : the sag severity level and the total harmonic distortion (THD). According to IEEE Std 519-1992, "the objective of the current limit is to limit the maximum individual frequency voltage harmonic to 3% of the fundamental and the voltage THD to 5% for the system without a major parallel resonance at one of the injected harmonic "frequency"[8](p.76).In this work, it is simply considered a THD of 5% as a threshold for the analysis whether or not the harmonics injected is acceptable

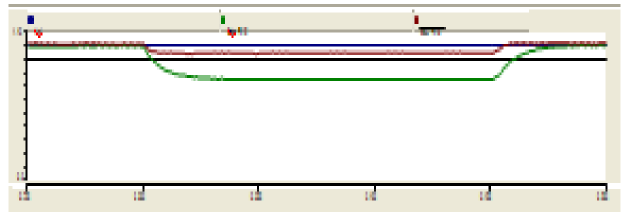

Figure 6 Simulated result of Sag Mitigation

TABLE 3

S.No	DC Voltage in KV	Load Voltage Drops by	THD in %
1	5	60%	8
2	15	30%	9
3	25	9%	3
4	35	5%	5

By definition [1], a value of rms voltage recovery greater than 90% nominal value is acceptable. The issue of how much improvement in rms voltage after compensation is also dependent on the DC voltage value. For example, the sag in the above case is corresponding to a new curve of load voltage is presented above.The table presents the details about the severity of voltage sag and the variation in total harmonic distortion with respect to the different energy storing schemes in DVR. . In this table, the first column shows variation of DC source. The second and the third columns record the values of voltage after compensation and THD according to this DC source variation. It is noted that for comparison purposes, the definition of voltage sag by 10% percent is now applied. Moreover, THD in percentage is a constant for each case. This is because the average value of THD is applied.

B.CONTROL OF DVR

Several control techniques have been proposed for voltage sag compensation such as pre-sag method, in-phase method and minimal energy control method but the hysteresis voltage control opens the door of better controlling

Hysteresis Voltage Control:

Hysteresis voltage control is used to improve the load voltage and determine switching signals for inverters gates.

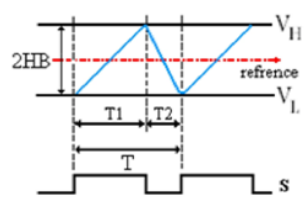

Figure 7 Hystersis Voltage Control

A basic of the hysteresis voltage control is based on an error signal between an injection voltage (V_{inj}) and a reference voltage of DVR (V_{ref}) which produces proper control signals. There is Hysteresis Band (HB) above and under the reference voltage and when the difference between the reference and inverter voltage reaches to the upper (lower) limit, the voltage is force to decrease(increase) as shown in Fig.9 ,

$$T_1 + T_2 = T_c = 1/f_c$$

Where HB and f_c are Hysteresis Band and switching frequency respectively. The HB that has inversely proportional relation to switching frequency is defined as the difference between V_H and V_L ($HB=V_H-V_L$) In comparison with the other PWM methods, the hysteresis voltage control has a very fast response, a simple operation and a variable switching frequency. This efficient upcoming method to inject without harmonic content.

CONCULSION

In this paper, different storage schemes are discussed and efficiency is tabulated .It is came to known that the efficiency depends on DC storage and on the loads employed. Special attention is given to the principle behind the sag mitigation and performance of the DVR along with control strategy. Here we conclude lesser the harmonic better the DVR performance

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