Simulation and Comparison of DVR and D-STATCOM for Voltage Sag Mitigation

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***Abstract*:- In this paper the detail description of Flexible AC Transmission devices in distribution network are presented so as to mitigate the voltage sag at the network buses. Two FACTS devices are implemented in this paper namely Distributed Static Compensator (DSTATCOM) and Dynamic Voltage restorer (DVR). DSTATCOM provides injection of shunt current into the system and DVR provides injection of series voltage into the system to solve the problem of short term reduction in the root mean square voltage of the system. These two devices are very effectual devices working on the principle of Voltage Source Inverter. This paper elaborates the performance of the DVR and DSTATCOM during voltage sag problems. Simulation studies have been carried out to affirm the consequences. DVR and DSTATCOM are modeled and simulated using the MATLAB/ Simulink and simpower system toolboxes.**

Keywords: *- Distributed Static Compensator; Dynamic Voltage Restorer; Voltage Sag; Voltage Source Inverter*

I.INTRODUCTION

Recently the demand of power has risen substantially while the power generation and transmission expansion has been severely restricted because of limited sources and restrictions on environmental conditions. In electrical power system, voltage control performs an essential function to ensure the voltage interruptions [3] like sag, swell and harmonics can be minimized and then increase the power quality, reliability and availability. According to IEC (International Electro-technical commissions) the voltage standard should be in the range of ±6% of the specified value of voltage. Methods of voltage control are: (a) By using FACTS devices [1], (b) By reactive power injection, (c) By using tap changing transformer. If the provided reactive power is introduced into the system, the system voltage will increase and if the reactive power is taken from the system i.e. absorbed by the source then voltage will decrease so voltage and reactive power are related with each other. To utilize the existing power system in better way the advanced technologies are introduced for the reliable and secure operation of the system. Recent advancement in power electronics innovate the use of FACTS controller [1] in power system. Basically the FACTS devices [2] have the capability of solving the problems of voltage stability [1, 9].

To determine the progress resulting from the application of FACTS devices, a basic understanding of voltage sag is important which is explained in section II.

II. VOLTAGE SAG

Previously, mechanical equipment was used to control industrial processes, which was less sensitive to voltage disturbances. But now a days more sensitive equipment are used which are electronically controlled such as PLC, adjustable speed drive(ASD) they require a pure supply voltage without any ripple or disturbance. So due to the high sensitivity of these devices typical disturbances that cause problems for electronic equipment is voltage sag [3]. A momentary diminution in r.m.s. (root mean square) voltage is termed as voltage sag. According to IEEE Std. 1159 (1995), sag magnitudes ranges from 10% to 90% of nominal voltage and sag durations from half- cycle to 1 minute. Furthermore, sags may be classified by their duration as shown in Table-1.

TABLE I. Classification of voltage sag according to IEEE

Type of Sag	Time Duration	Voltage Magnitude
Instantaneous	0.5 – 30 cycles	0.1 – 0.9 per unit
Momentary	30 cycles – 3 seconds	0.1 – 0.9 per unit
Temporary	3 seconds – 1 minute	0.1 – 0.9 per unit

There are various causes of voltage sag, some of them are short circuit fault in transmission lines, opening and closing of circuit breakers, due to motor starting, due to transformer energizing, pollution, bad weather condition etc. Voltage sag causes a great impact on various sensitive equipment such as

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PLC, Adjustable Speed Drives etc. so, to avoid these problems we use FACTS devices which are classified as series and shunt controllers [10].

III. CONTROLLER ALGORITHM

Under system disturbances, the basic objective of the control strategy is to keep voltage amplitude constant where the responsive equipment is coupled. The actual voltage at PCC, where the load is connected determined by the control strategy; it means reactive power measurement is not needed. Voltage Source Inverter based control strategy is used here. A Pulse Width Modulation based switching strategy technique has been implemented for the purpose of controlling the electronic valves in the three level voltage source converter which gives simple and better response. PWM technique has low switching losses. This technique can also be used to regulate the phase angle of injected voltage.

The error signal which is obtained from the difference of desired voltage and root mean square voltage at the load point is input to the controller. PI controller is used to process this error signal and then generate the phase angle δ as the output which is then given to the PWM generator. It is essential to observe that this is the case in which, the exchange of active and reactive power takes place in converter. To make the error zero, the Proportional Integral controller is used for processing. In processing the load root mean square voltage i.e. the actual voltage or true voltage and reference voltage i.e. desired voltage becomes equal.

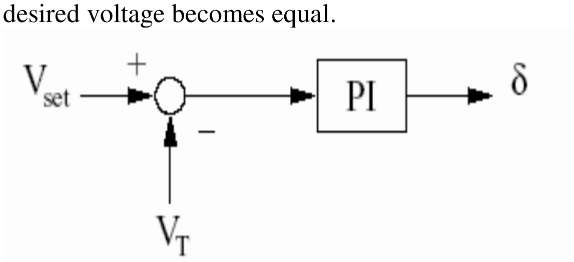

Fig. 1. Proportional Integral controller

The sinusoidal voltage controlled signal $V_{control}$ is then phase-modulated through the angle δ. To operate the PWM generator the angle δ is added with the phase angle of the balanced supply voltages and is pretended to be uniformly separated by 120° to generate the required synchronizing signal i.e.,

$$V_a = \sin(\omega t + \delta)$$
$$V_b = \sin(\omega t + \delta - 2\pi/3)$$
$$V_c = \sin(\omega t + \delta + 2\pi/3)$$

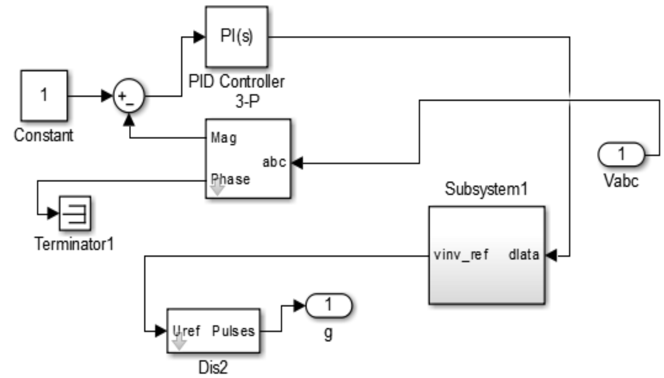

Fig. 2. Phase-Modulation of the control angle δ.

The modulated signal $V_{control}$ is compared against a triangular signal so as to generate the switching signals for the valves of the Voltage Source Converter. The essential elements of PWM technique by which its performance is determined are amplitude and frequency modulation index of signal.

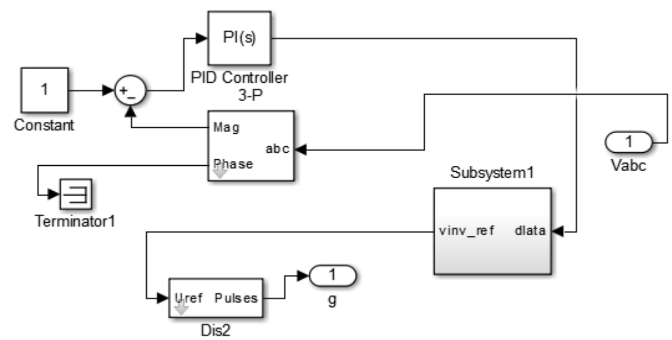

Fig. 3. Simulink model of Controller

With the target of getting the utmost basic voltage element at the controller output the amplitude index should be kept constant at 1pu.

$$m_a = \frac{Vcontrol^{\wedge}}{Vtriangular^{\wedge}} = 1 \text{ p. u.}$$

Where,

$Vcontrol^{\wedge}$ represents the extremum magnitude of the control signal.

$Vtriangular^{\wedge}$ Represents the extremum magnitude of the triangular signal.

The switching frequency is kept fixed at 1080 Hz. Here, Modulation Index = $\frac{\text{Switching frequency}}{\text{Fundamental frequency}}$

= 1080/50 = 21.6

In PWM generators modulated angle is applied in phase a. The modulated angle for phase b is shifted by 240̊ and then for phase c is shifted by120̊.

IV. VOLTAGE SOURCE INVERTERS (VSI)

Voltage Source inverter is an essential electronic block of DVR and DSTATCOM used to supply a sinusoidal voltage with desired amplitude, frequency, and phase angle. VSI principle can be utilized for several purposes such as adjustable speed drives, voltage dips mitigation etc. Voltage Source Converter consists of capacitor, inverter, resistor and a dc source. Usually, Voltage Source Converter used for several other mitigations like flickers, harmonics etc.

V. DYNAMIC VOLTAGE RESTORER

DVR [4] is a voltage controlled device coupled in series with the three phase distribution system by using injection transformer as displayed in Fig. 4. The voltage (i.e. equivalent voltage) at the load side now becomes adequately similar to the voltage obtained by the addition of the power system voltage and the voltage obtained from the DVR via injection transformer [5, 6]. The reactive power requirement of the load is fulfilled by converter while the energy storage device provides the active power as per the requirement.

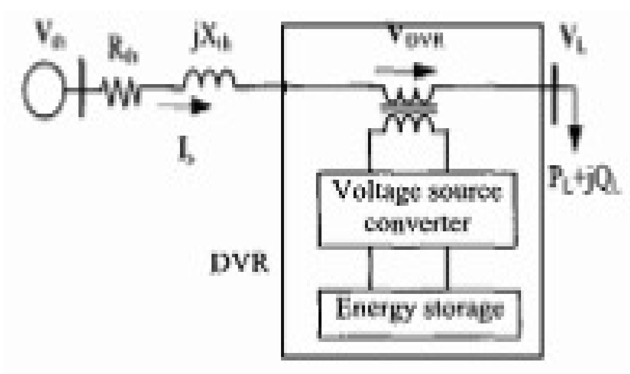

Fig. 4. . Conventional representation of Dynamic Voltage Restorer

In The above figure, thevenin equivalent circuit of the system associated with DVR is shown. The DVR provides injection of a voltage ($\mathbf{V}_{\mathbf{DVR}}$) in series via the coupling transformer when system voltage (V_{th}) drops, so as to obtain the required voltage magnitude at the load side. The voltage provided by DVR in terms of equation expressed as,

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

Here,

V_L represents the required voltage at the load side
Z_{th} represents the impedance of the load
I_L represents the current at the load side
V_{th} represents the voltage of the system during fault condition

The load current I_L of the system can be expressed as,

$$I_L = \left(\frac{P_L + J^* Q_L}{V_L}\right)^*$$

When V_L is considered as a reference voltage so as to express the above equation in another form as shown below,

$$V_{DVR}\angle\alpha = V_L\angle 0 + Z_{th} I_L \angle(\beta\text{-}\theta)\text{-}V_{th}\angle\delta$$

Here θ is the load power factor angle and,

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

The basic governing equation of the DVR can be represented as,

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

By above equation we can see that when the voltage obtained from the DVR is in quadrature with the current at the load side, then correction is accomplish by introduction of reactive power only and so as to improve the voltage, the active power given by the DVR is not required. As DVR is well supported by the dc bus of its own, it is able to supply the reactive power by itself. DVR can be maintain in quadrature with the current at load side I_L only up to a limited amount of voltage drop and after that this relationship cannot be kept constant to compensate the voltage droop. So this is the case, when requirement of active power becomes important for the system then this active power is provided by the energy storage device of the DVR .If the voltage obtained from the DVR is in phase with the current at the load side, then DVR provides real power and therefore capacitor is needed at the dc side of the Voltage Source Converter.

VI. DISTRIBUTED STATIC COMPENSATOR

A D-STATCOM is a current controlled device coupled with three phase distribution system in shunt by using injection transformer [7] as shown in Fig 5. It comprises a three phase inverter module, capacitor, ac filter, injection transformer and a control technique. VSI is the essential electronic block of the D-STATCOM [7]. VSI changes DC voltage into three-phase AC voltage at fundamental frequency. Through the reactance of the coupling transformer these in phase voltages are paired with the AC system.

The Voltage Source Converter coupled in shunt with the AC system can perform multiple functions. The three basic functions performed by it are as follows:

1. Voltage regulation and remuneration of reactive power;
2. Improvement of power factor; and
3. Minimization of current harmonics.

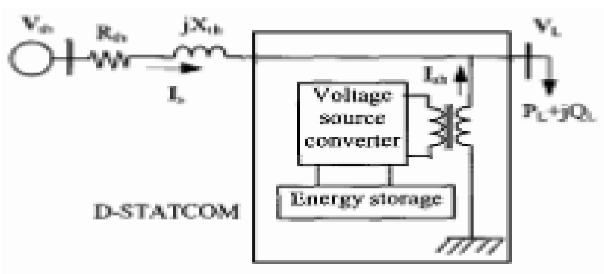

Fig. 5. Conventional representation of D-STATCOM.

In the above figure shunt current I_{sh} which is injected by the DSTATCOM overcomes the short term reduction of voltage by regulating the voltage drops across Z_{th}.Now I_{sh} perchance adjusted by modifying the voltage obtained at the output of the converter. I_{sh} which is obtained by compensator can be expressed as,

$$I_{sh}=I_L-I_S$$

$$I_{sh}\angle\eta = I_L\angle -\theta - \frac{V_{th}}{Z_{th}}\angle(\delta-\beta) + \frac{V_L}{Z_{th}}\angle -\beta$$

The relation by which D-STATCOM injects complex power in the system can be represented as,

$$S_{sh} = V_L I_{sh}^{*}$$

The effectuality of the shunt compensator to counterbalance the voltage droop rely upon the amount of Z_{th}. The Required voltage compensation can be achieved without introducing active power into the system until the shunt current I_{sh} remains in quadrature with load voltage V_L.If the amount of I_{sh} is reduced, the similar voltage compensation may be obtained by injection of minimal apparent power to a point on the system.

The controller strategy for the Distributed Static Compensator accompanies the similar precept as for Dynamic Voltage Restorer. The switching frequency is fixed at 1080 Hz

VII. MATLAB MODELING AND SIMULATION

A. Simulink Model of DVR

The Simulink model of the DVR connected system is represented in Fig. 6 is modeled in MATLAB/Simulink environment with the help of sim power system toolbox. The three-phase ac voltage source is associated to the three-phase load through Dynamic Voltage Restorer with the objective of improving the performance of voltage. DVR [8] comprises three phase inverter module, capacitor, ac filter, injection transformer and a control technique. PWM switching technique has been implemented for the purpose of controlling the electronic valves in the three level voltage source inverter. The battery on the dc side is used to determine the amount of energy required to supply by the capacitor i.e. the energy storage device.

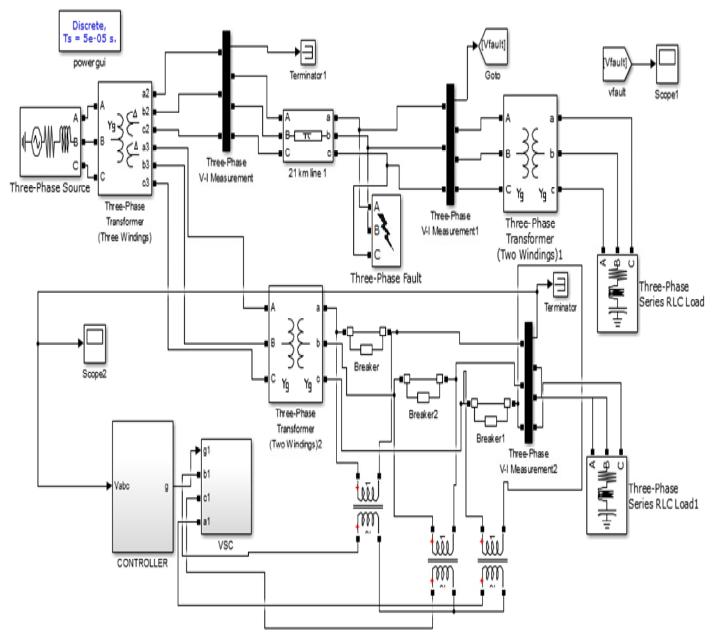

Fig. 6. Simulink model of DVR

B. Simulink Model of DSTATCOM

The Simulink model of the DSTATCOM connected system shown in Fig.7. is modeled in MATLAB/Simulink environment with the help of sim power system toolbox. The three-phase ac voltage source is associated to the three-phase load through D-STATCOM with the objective of improving the performance of voltage. Voltage sag mitigation is done on a 25-kV distribution network by using DSTATCOM. It consists of 21 km feeder- line which transmits power to loads. Power factor can be improved by using shunt capacitor. The system data are given in the Parameters.

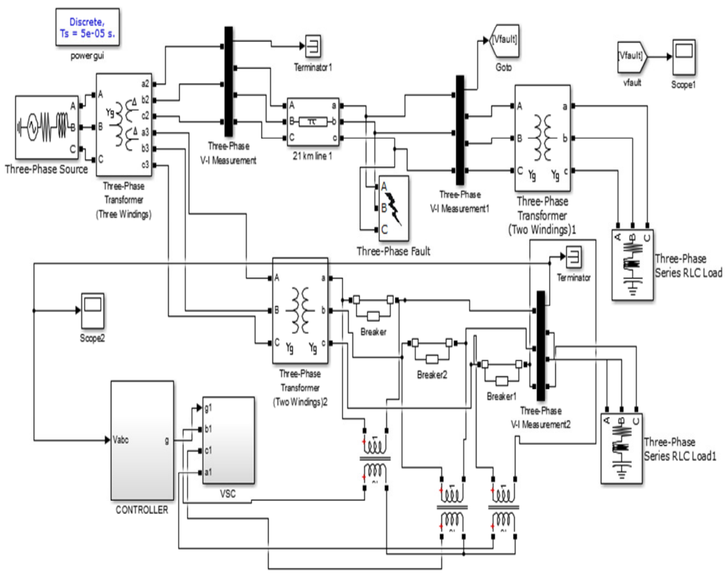

Fig. 7. Simulink model of DSTATCOM

VIII. RESULTAND DISCUSSION

A. Result of DVR

An uncompensated line [10] with three phase fault and fault resistance of 0.66 is simulated. Waveform of uncompensated line is displayed in Fig. 8. The voltage at the load side of an uncompensated line is nearly 10% in terms of actual voltage. So with the help of Simulink the DVR is designed to operate during the fault.

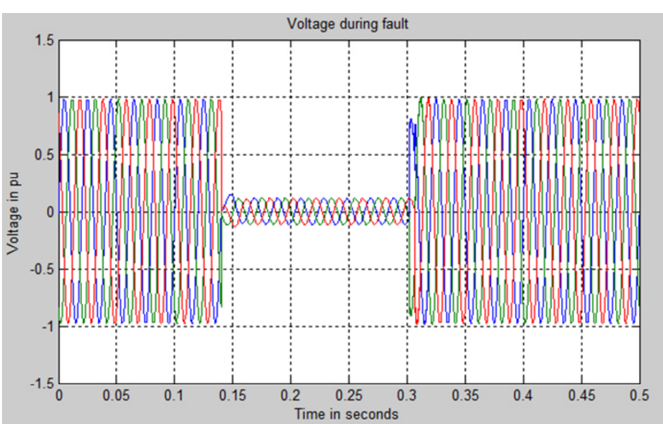

Fig. 8. Voltage waveform of an uncompensated line during fault

The simulation of compensated line is now accomplished by employing the similar condition as that of an uncompensated line in addition with the DVR. At the load side the voltage dip is now become nearly 95% in terms of the actual voltage. The DVR is simulated by using MATLAB.

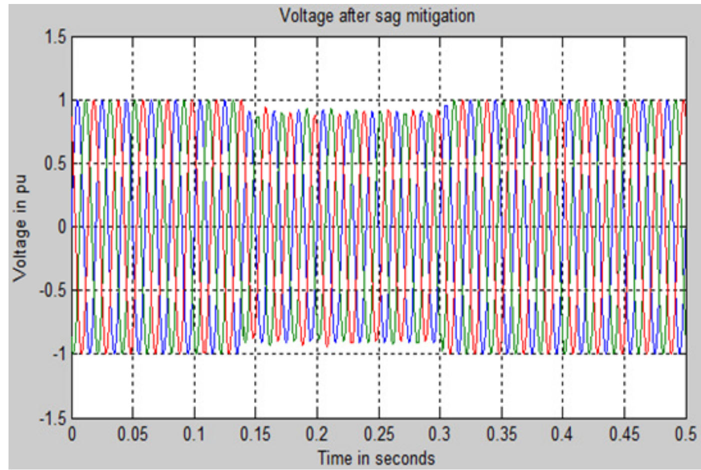

Fig. 9 . Voltage waveform of compensated line with DVR

B. Result of DSTATCOM

An uncompensated line with three phase fault and fault resistance of 0.66 is simulated. Waveform of uncompensated line is displayed in Fig. 10.

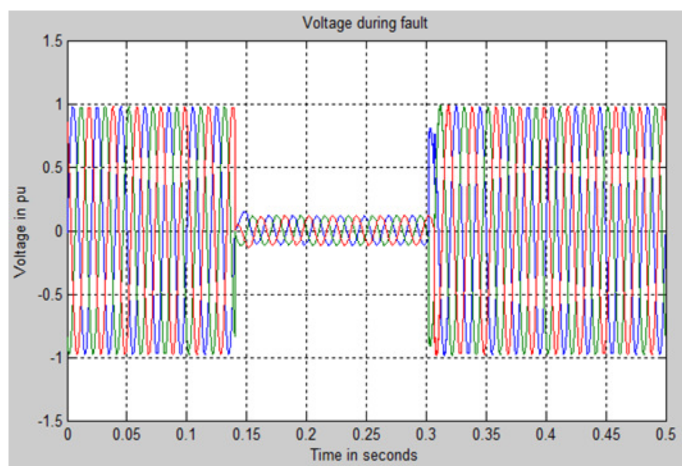

Fig. 10. Voltage waveform of an uncompensated line during fault

The simulation of compensated line is now accomplished by employing the similar condition as that of an uncompensated line in addition with the DSTATCOM. At the load side the voltage dip is now become nearly 85% in terms of the actual voltage. The DSTATCOM is simulated by using MATLAB.

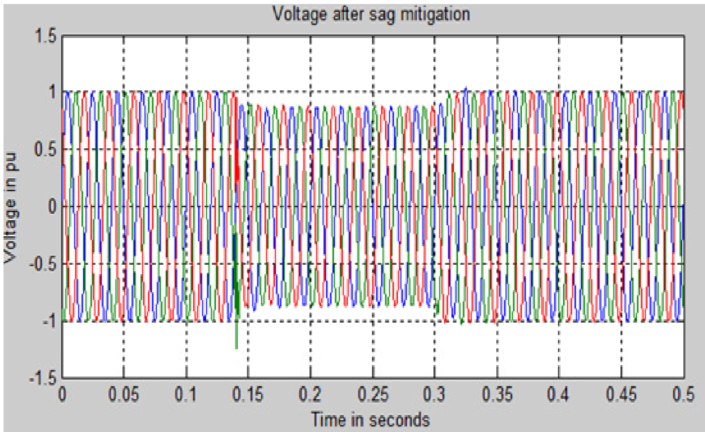

Fig. 11. Voltage waveform of compensated line with DSTATCOM

IX. PARAMETERS

AC voltage source: 25 kV, 50 Hz
Load: 10KVA, 0.80 pf lag
Proportional Integral Controller: Kp =0.5 Ki=100
DC voltage: 20V
Switching Frequency of PWM: 1080Hz
Sample Time= 5µs
Inverter: MOSFET based 3 arms, 6 Pulse.
Capacitance at DC side: 950µF

X. CONCLUSION

Power electronics based mitigation devices give successful response to voltage dip problems. In this paper, the comparison of DVR and D-STATCOM is made using the MATLAB/ Simulink and simpower system toolboxes. The controlling of DVR and DSTATCOM is done by using PI controller. The simulation results clearly represent the performance of the Distributed Static Compensator and Dynamic Voltage Restorer for voltage sag mitigation, caused by the occurrence of fault in distribution systems. From this simulation results we can analyze that the Dynamic Voltage Restorer gives superior result than the Distributed Static Compensator and also it can reduce the harmonics which is produced in the transmission line. DVR is one of the very fast and effectual Flexible AC Transmission devices.

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