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Voltage Sag Mitigation in Distribution Line Using D-STATCOM

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Abstract

This paper demonstrates the power electronics-based device to recover the better-quality using power custom devices such as D-STATCOM. Mitigation of voltage sag using custom power devices in 3-phase lines is presented in this work. Utmost, AC loads absorb reactive power that causes poor quality in the transmission system. D-STATCOM compensates the reactive power in the transmission line. It is a three-phase voltage source converter that can absorb and generate the reactive power and supplies the power to the sensitive load. It mitigates power interruption, improves harmonics distortion, voltage sag and low power factor. This paper focuses on mitigation of voltage sag with the help of D-STATCOM which demonstrates the power electronics-based device to recover the better quality. Different types of faults to the transmission line such as SLG fault, LLG fault and LLLG faults have been analyzed in this work. As expected, fault causes voltage sag to the distribution system and by inserting the D-STATCOM, the voltage sag improves and the power factor reach above 0.9 pu.

Keywords— *D-STATCOM, Voltage sag, voltage source converter.*

I. INTRODUCTION

In the nineteenth century due to unstable reactive power, a problem like voltage fluctuation throughout load variations and power transfer constraints were observed. Due to the existence of reactance, utmost AC loads absorb reactive power. These days in power system, power quality problem has become major issue in order to maintain quality of supply. Equipment like computer, electronic motors, fan, inverter, air-conditioner, fridge etc. cannot run without electricity. In industry and household electrical load maybe sensitive and non-sensitive type. The performance of these equipment depends on the quality of power supply. Sensitive load may damage easily as any disturbance occur in supply. Power Quality can be reduced due to exploitation of reactive power. On Reliable and protected supply of electricity, these issues have a higher impact in the world of denationalization of electrical system [1]. voltage sag, small power factor, and harmonic distortion are the most frequent power quality issues today. The decrease in RMS voltage size arises due to Voltage sag which is a short duration incident. The voltage sag weight is from 10% to 90% of minimal voltage. Voltage stability is an important issue of power quality problem. voltage sag and swell are the most common occurring disturbance in distribution network for plants or industries, voltage sag and swell appear more frequently and create so many problems due to which the economy suffers. Sensitive loads are less tolerable to distorted voltages D-STATCOM is one of the most common disturbance in distribution network. D-STATCOM is one of the most common procedure for mitigating voltage sag and swell problem at sensitive load terminal [2].

The advancement of power electronics devices like customs power devices and FACTS devices (Flexible AC Transmission System) are announced and innovative branches of technology providing the power system with versatile new control capabilities [3]. The FACTS devices offer a quick and stable control over the transmission parameters, i.e. phase angle, line impedance, and Voltage between the receiving end voltage and sending end voltage. On the other side the custom power device is for small voltage supply, and refining the bad condition and trustworthiness of supply poignantly sensitive loads. By using power electronics-based devices such as DSTATCOM, a certain extent of voltage and power may be inserted into the distribution system and voltage sag and other imbalanced conditions can be minimized. various custom power devices such as UPQC (Unified power quality conditioner), DSTATCOM (Distribution static compensator), and dynamic voltage restorer (DVR). D-STATCOM is one of the best approaches to mitigate the voltage dips complications and can provide a low-cost solution for the repayment of reactive power and destabilize loading in distribution arrangement [4]. In transmission and distribution systems there are distinct ways to better power quality problems.

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The sources of power quality issues are complex and hard to detect. The ideal AC line should be an unpolluted sinusoidal wave of frequency (50/60 Hz) [1].

The electrical power supplied to the end consumer should be of high quality. Poor quality of supply affects the performance of equipment. Factors like voltage and frequency variation, harmonic contents, short circuit, surge, flickers etc. results in poor power quality of supply. Voltage variation is one of the most frequent disturbances occurring in the power system network. For improving the quality of supply such disturbances is compensated effectively. Recently developed power electronic devices help in compensating such kind of problems. Many custom devices such as DVR, D-STATCOM and Unified Power Quality Conditioner (UPQC) are proposed. Several research papers have addressed the enhancement of voltage and current quality by use of custom devices. In modern power system, reactive power support, voltage instability issues (Voltage fluctuations) and power oscillations because of faults and abrupt load disturbances are key issues. One more challenge in front of engineers is to improve reliability and efficiency of the existing systems. To get both financial profitability and operational reliability, the existing power system requires the infrastructure for more efficient utilization and control [5-8].

II. REACTIVE POWER COMPENSATION IN A SYSTEM

The motive for reactive power compensation in a system may be classified as:

- voltage regulation can be improved.
- The stability of the system can be increased.
- Efficient use of elect. machines connected to system.
- Losses can be reduced associated with the system.
- Voltage sag and voltage drop can be avoided [5].
-

III. DISTRIBUTION STATIC COMPENSATOR

STATCOM means Static Compensator. It is one of the FACTS family devices to improve power. FACTS devices mean Flexible AC Transmission Systems. It has some electronic devices such as GTO, IGBT, and transistor. The working of the FACTS device is the same as other as other power system controllers such as phase shifting, transformer tap changing, passive reactor compensator and synchronous condenser [6].

STATCOM can be used on AC transmission networks. STATCOM uses a power electronics device. It is used to improve electricity network performance that has poor factors and poor voltage regulation. STATCOM can also be used for voltage balance and harmonic filtering. The everyday use of STATCOM is for voltage stability and it is given in fig.1(a).

The arrangement of STATCOM is the same as the static VAR compensator (SVC). STATCOM and SVC both use Voltage source converter for shunt compensation. STATCOM works on the principle of generation of controllable AC voltage [7]. There are different types of devices in a D-STATCOM such as coupling transformer connected in the shunt of the distribution system, a VSC to produce sinusoidal voltage, an energy storage device and a controller [1].

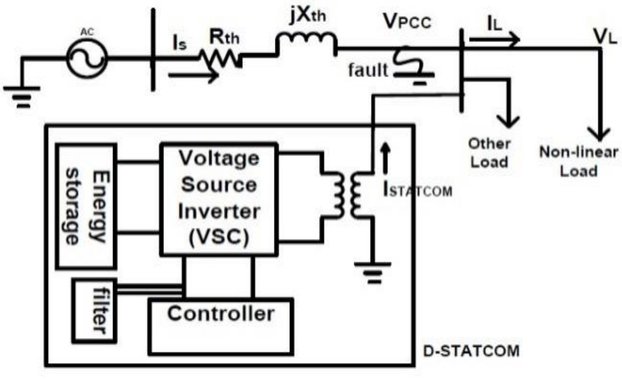

Fig. 1(a) Schematic Diagram of D-STATCOM [8]

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A. Voltage Source Converter

A VSC is a power electronic based device includes a storing device and switching devices that may generate a sinusoidal voltage at any required frequency, phase angle and magnitude. It can convert DC voltage connected across the storage device into three-phase AC voltage D-STATCOM is efficient to generate and absorb the reactive power. In capacitive mode the output of D-STATCOM is more than the terminal voltage, then the D-STATCOM will transfer the reactive power. And in reactive mode output of D-STATCOM is less than terminal voltage then the D-STATCOM absorb the reactive power. Voltage is coupled with the AC system through a coupling transformer. There are four primary varieties of switching devices: metal oxide semiconductor field effect transistors (MOSFET), gate turn-off thyristors (GTO), insulated gate bipolar transistors (IGBT), and integrated gate commutated thyristors (IGCT). Every type has its own particular advantages and disadvantages [1,9].

Typically pulse-width modulation voltage source inverter (PWMVSI) is utilized in DVR. To convert dc voltage into an AC voltage a voltage supply inverter is used. To be able to increase the magnitude value of voltage under the condition of voltage sag, in DVR energy circuit a step-up voltage injection transformer is used. In this way a VSI with a low voltage value is enough.

B. Transformers

The primary side of transformer is connected in shunt to the distribution line bus, at the same time as the secondary side is attached with the D-STATCOM power circuit. Three single phase transformers or three phase transformers can be utilized for three phase D-STATCOM, whereas in case of l- phase may be utilized for single phase Essentially the injection transformer is a step-up transformer which increased the voltage furnished by way of filtered voltage source inverter output to a desired degree and it additionally isolates the D-STATCOM circuit from the distribution network. Winding ratios are very vital and it is predetermined in line with desired voltage on the secondary. Excessive winding ratios could imply excessive currents at the number one facet which may affect the component of inverter circuit. while finding out the enactment of D-SATCOM, the evaluation value or rating of the transformer is a significant component. The winding arrangement of the injection transformer may be very vital and it particularly depends at the upstream distribution transformer[10-11].

C. Energy Storage Unit

DC source and DC capacitor are parallelly connected. In D-STATCOM energy storage circuit is the reactive power storing device. DC capacitors can be charged with the help of battery or by the converter itself [12]. Different type devices which include flywheels, superconducting magnetic energy storage (SMES), lead acid batteries and super-capacitors can be utilized as power storing devices. The primary function of these power storage units is to offer the desired actual real power throughout voltage sag. The measure amount of active power produced through the energy storage device is a key component, as it makes a decision the reimbursement capacity of DVR. Amongst all others, lead batteries are famous due to their high response value at some point of charging and discharging. But the discharge rate is depending on the chemical response rate of the battery so that the accessible power in the battery is determined by its discharge rate. A dc-storage unit is given in fig. 1(b).

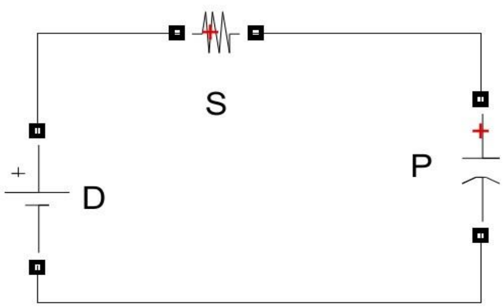

Fig. 1 (b) Circuit Diagram of DC Storage

D. Controller

PI (Proportional Integral) controller is a feedback controller that calculates error value (the difference between required value and measured value) and integrates that value. In this condition, the PI controller

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will compensate the error value to a level ‘0’. PI controller also handles reactive power flowing from the DC capacitor storage circuit. The Simulink model of control system of D-STATCOM is given fig. 2(a-b).

PWM (Pulse width modulation) generates the sinusoidal PWM wave. For the function of the PWM generator, the angle of PWM generator is sum with the phase angle voltage equally at 120 degrees. Therefore, PWM can produce the required phase angle [9].

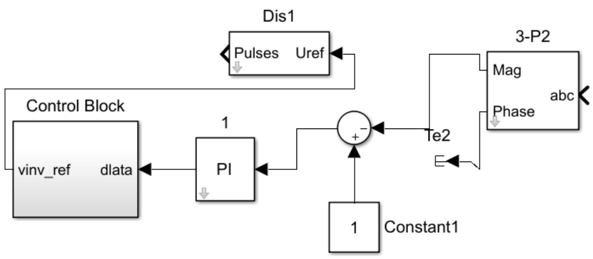

Fig. 2 (a) Control System of D-STATCOM

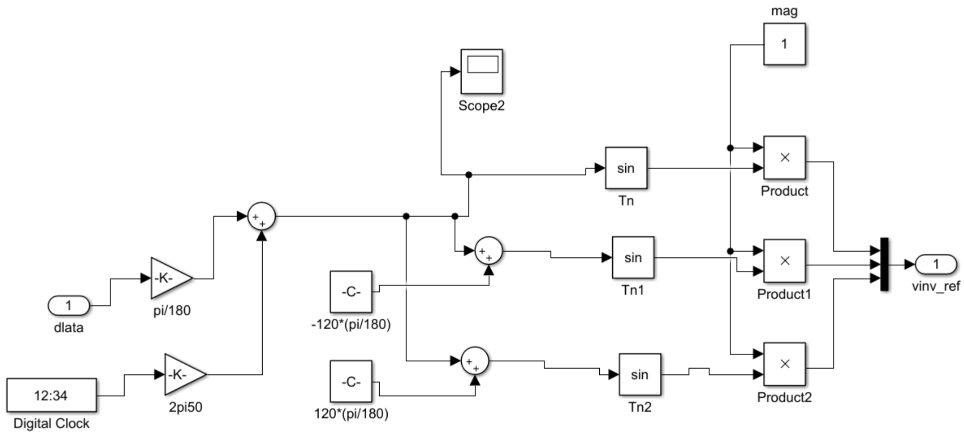

Fig. 2(b) The control Block - component of the control system (phase modulationm of control angle).

IV. MODELING OF D-STATCOM

Total instantaneous power delivery drawn by load-

$$P_L = P_{S1}(t) + P_R(t) + P_{SH}(t) \qquad (1)$$

Where,

$P_{S1}(t)$=Real power drawn by load at fundamental frequency,

$P_{SH}(t)$=Real power harmonics drawn by load,

$P_R(t)$=reactive power drawn by load.

Real power supplied by source-

$$P_S = P_{S1} \qquad (2)$$

Reactive power supplied by source-

$$Q_S = 0 \qquad (3)$$

Real power drawn by the load-

$$P_L = P_{S1} + P_{SH} \qquad (4)$$

Reactive power drawn by the load-

$$Q_L = Q_{S1} + Q_{SH} \qquad (5)$$

Real power provided by the D-STATCOM-

$$P_{STATCOM} = P_{SH} - P_{LOSS} \qquad (6)$$

Reactive power provided by D-STATCOM-

$$Q_{STATCOM} = Q_{S1} + Q_{SH} \qquad (7)$$

Where P_{LOSS} component of STATCOM

Voltage sag can be minimized due to shunt injecting current $I_{STATCOM}$ by changing the voltage drop as Z_{TH} impedance. The Output voltage of the converter frequently adjusts the shunt current.
The equation of I_{SH} is:

$$I_{STATCOM} = I_L - I_S \quad (8)$$

$$I_S = \frac{V_{TH}\text{-}V_L}{Z_{TH}} \quad (9)$$

$$I_{STATCOM} = I_L - I_S = I_L - \frac{V_{TH}-V_L}{Z_{TH}} \quad (10)$$

$$V_L = V_{TH} + (I_{STATCOM} - I_L)Z_{TH} \quad (11)$$

I_S =Source current,
I_L =Load current,
V_{TH} =Thevenin
equivalent voltage,
Z_{TH} = Thevenin equivalent impedance

V. PRINCIPLE OF VOLTAGE REGULATION OF D-STATCOM

A. Without compensator

Voltage E is source voltage & Voltage V is PCC voltage. The PCC voltage decreases in absence of voltage compensator due to load current I_L.

$$I_S = I_L + I_R \quad (1)$$

here I_R is compensating current.

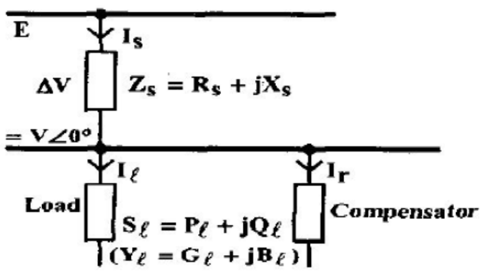

Fig. 3(a) circuit diagram of supply &load system

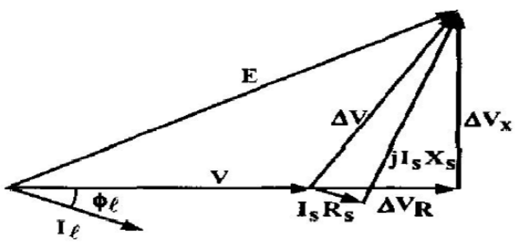

Fig. 3 (b) uncompensated Phasor diagram

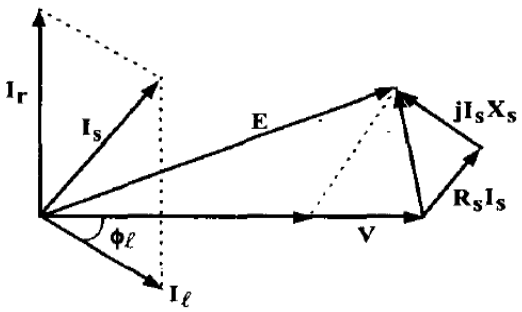

Fig. 3 (c) compensated Phasor diagram

$\Delta V = E - V = Z_S I_L$ (2)
$S = VI^*$ (3)
$S = V^* I$
From above equation
$I_L = \frac{P_L - jQ_L}{V}$ (4)
So that
$\Delta V = (R_S - jX_S)(\frac{P_L - jQ_L}{V})$ (5)
$\Delta V = \left(\frac{R_S P_L - X_S Q_L}{V}\right) + J\left(\frac{X_S P_L + R_S Q_L}{V}\right)$ (6)
$\Delta V = \Delta V_R + V_X$ (7)
as shown in phasor diagram fig (b) change in voltage ΔV has ΔVR with V in same phase and ΔV_X in quadrature with V. The source voltage E is relative to magnitude and phase of V. increase or decrease of voltage depends on active and reactive power of the load. ΔV can be written as

$$\Delta V = I_S R_S - J I_S X_S$$

B. Voltage regulation with DSTATCOM

As shown in phasor diagram fig. (a) Compensator is added in parallel with the load for voltage compensation. If compensating current is controlled, then |V| = |E| is possible.
$I_S = I_L + I_R$
here I_R is compensating current.

VI. POWER QUALITY PROBLEMS

A. Interruption

Interruption term is used to describe as the complete loss of voltage and current in power system or 0.9 per unit decrease in voltage magnitude for duration less than 1 minute.
Three types of interruptions which are classified as their duration.

a) Momentary Interruption- An interruption can be defined as the interruption of supply voltage for a very short period Complete loss of supply voltage and current having duration between 0.5 cycles and 3 second.
   Protection devices open and close automatically due to which interruption mostly occur
b) Temporary interruption- Complete loss of supply voltage and load current for lasting between 3 second and 1 minute.
c) Long term interruption- Interruptions that are larger than 1 minute are called long interruptions. Long interruptions are mainly occurred due to the failure of electrical equipment. [10]

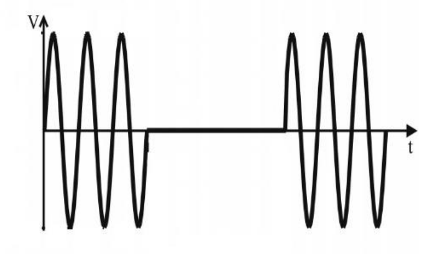

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Fig.4(a) Very short interruption [3]

B. Sag

The drop of RMS voltage for a short time is voltage sag which is due to the increase of current for a short time. Voltage sag most commonly occurred due to the fault, starting of large motor, leading current are transformer energizing. In day today life voltage sag largely occurs due to short circuit events [9].

Voltage sag is classified as based on time duration and voltage magnitude

(a) Instantaneous sag- Instantaneous sag occurs when r.m.s voltage decrease to between 0.1and 0.9 per unit for time period of 0.008333 to 0.5 second.

(b) Momentary sag- Decrease of r.m.s voltage between 0.1 and 0.9 per unit for time period 0.5 second to 3 seconds.

(c) Temporary sag- In this type sag the r.m.s voltage value decrease to between 0.1 and 0.9 per unit for time period of 3 to 60 second.

The main effects of voltage sag on the system AC contactor drop-out, tripping of loads, digital clocks reset, Computers and PLCs reset, Product outside acceptable manufacturing tolerance, Tripping of generators (Thermal Power Plants), Incorrect deposition in manufacturing Variable Speed Drives (VSDs) stopping[10-14]

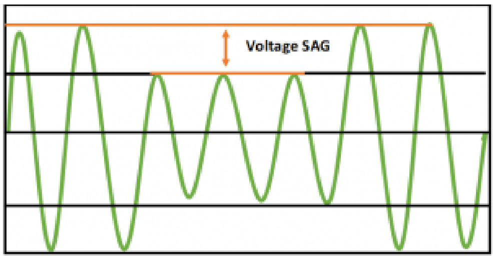

Fig. 4(b) Voltage sag [9]

C. Swells

An increase in RMS voltage for the time of more than one cycle to a few seconds is called swell. They are mainly caused due to start or stop of heavy loads, regulated transformers in poor condition, reduction large loads or switch off large loads and single phase fault on a three phase system are common sources, Capacitor switching, because capacitor is charging device and when it is ON, in this case it adds voltage to the utility system. Voltage swell not frequently happen only represent 2 to 3% of all power problems [8].

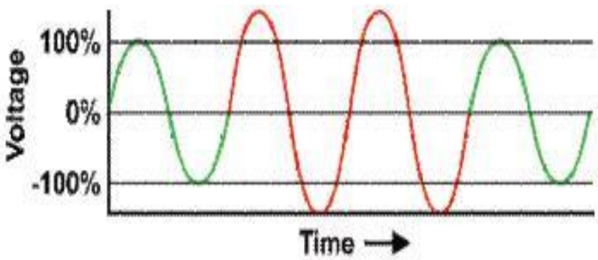

Fig.4(c) Voltage Swell [8]

D. Harmonics Distortion

In the power system, a nonlinear device causes the harmonic distortion. The impedance of the nonlinear device changes with applied voltage. That's why the current drawn the load never be sinusoidal [11].

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Any distortion due to the generation of harmonics in the output waveforms can be described as harmonics distortion. Harmonics are the integer multiples of the fundamental frequency.

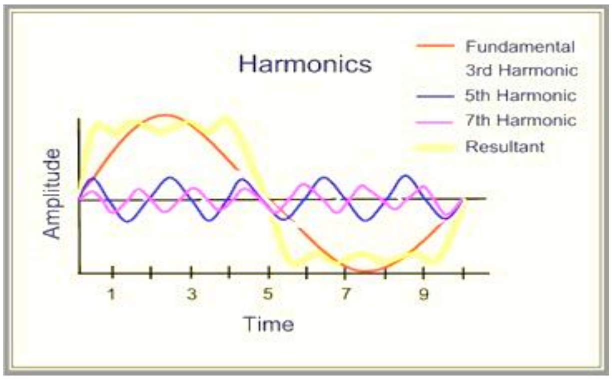
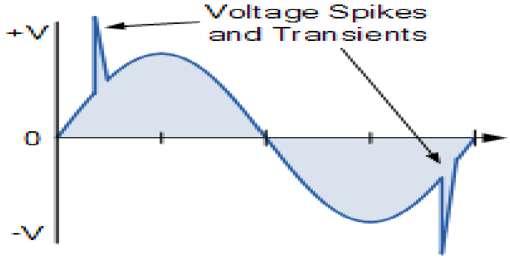


Fig. 4 (d) Harmonics Distortion [9]

E. Voltage Spikes

Rapid variation of voltage for the interval of few microseconds to milliseconds is called voltage spike. Due to the variation, voltage can range up to the thousand times. Due to power factor improvement, removing of heavy loads and lighting voltage spikes happen.



F. Voltage Imbalance

Voltage imbalance is described as the phase angle difference and voltage magnitudes deviation of every phase from the common voltage of all of the three phases is not equal that is one-of-a-kind from each other in three phases.

Voltage imbalance due to massive single-phase loads which includes induction arc furnaces, traction loads, and wrong distribution of all single segment loads through three phase supply.

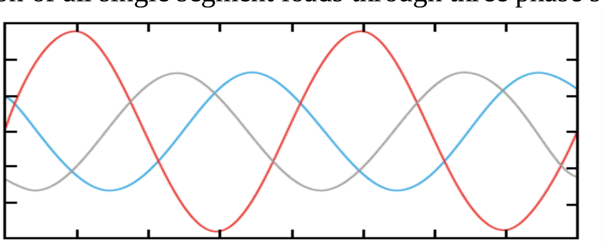


Fig.4 (f)Voltage Imbalance [9]

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VII. FLOWCHART-PROPOSED METHOD

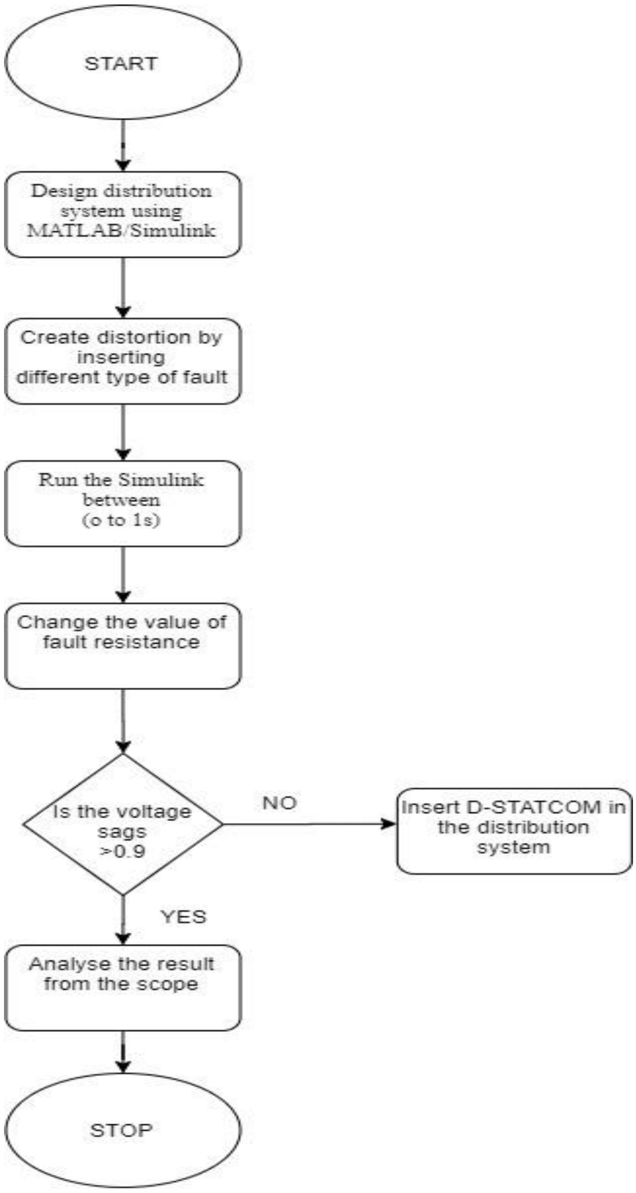

Fig. 5 Flowchart of simulation process

Fig.4 (e) Voltage Spikes [9]

VIII. RESULTS AND DISCUSSION

A. Simulation Model Without Insertion of D-STATCOM

TABLE I. SYSTEM PARAMETERS

S.No.	Parameters	Standards
1	Source	3 phase,230kv,50 Hz
2	Three phase transformer	Y/Y/Y,230/11/11kv
3	Fault resistance	0.66 ohm
4	RL load	R=0.05, L=0.4806H

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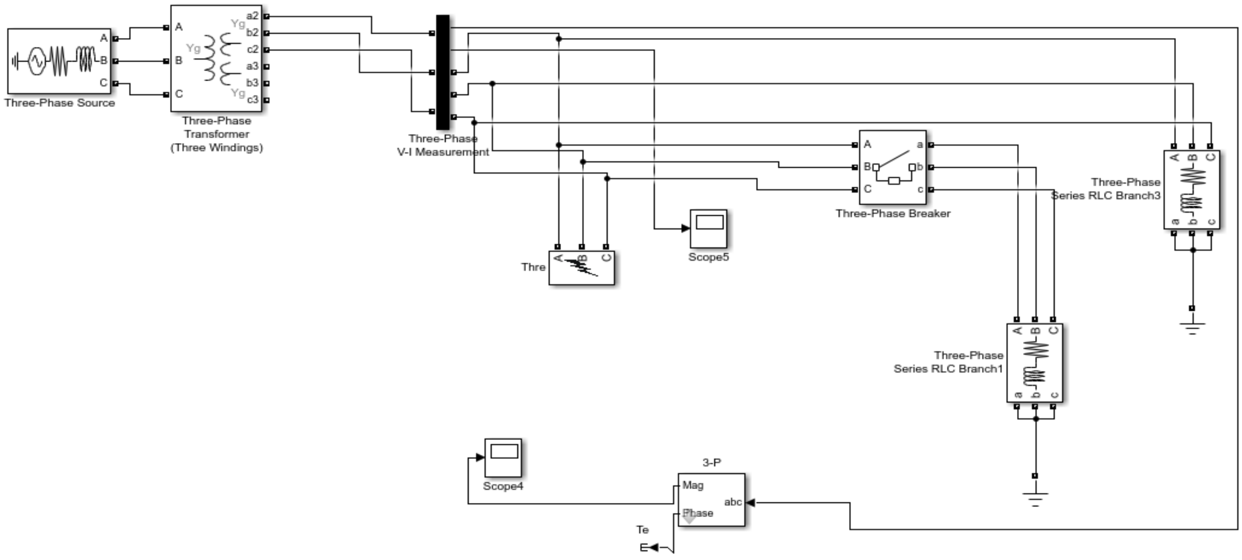
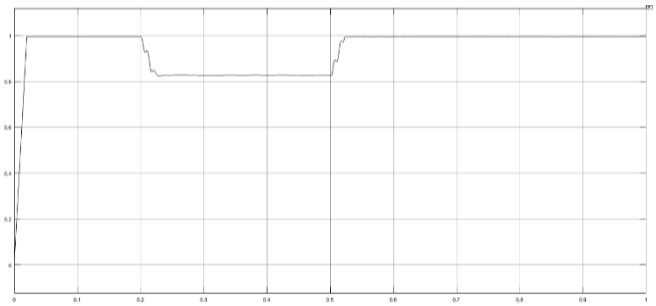
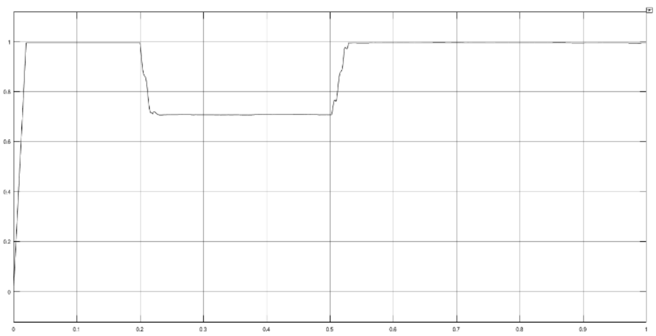


Fig.6 Main circuit of the distribution system without D-STATCOM



Time(s)

Fig. 6 (a) SLG Fault



Time(s)

Fig. 6 (b) DLG Fault

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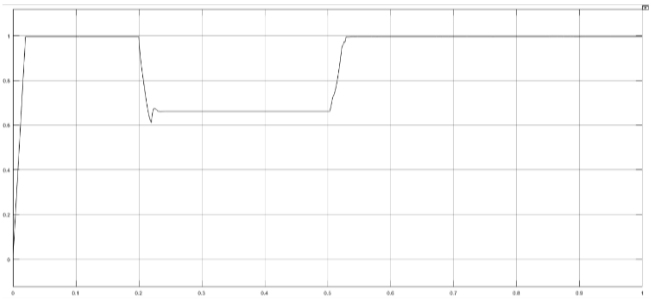


Fig. 6 (c) TLG Fault

A simple distribution network is simulated using MATLAB/Simulink software as shown in fig. 6. The main parameters of network are listed in table I. We applied different types of fault to make voltage sag and as seen from fig. 6 (a), Single line to ground fault (SLG Fault), fig. 6 (b) Double line to ground fault (DLG Fault), fig. 6 (c) Three-line to the ground (TLG Fault). Fault resistance s 0.66ohm. The total fault duration is 0.2s to 0.5s and voltage sag happens during this duration.

B. Simulation With Insertion of D-STATCOM

TABLE II. SYSTEM PARAMETERS

S.No.	Parameters	Standards
1	Source	3 phase,230kv,50 Hz
2	Three phase transformer	Y/Y/Y,230/11/11kv
3	Fault resistance	0.66 ohm
4	RL load	R=0.05, L=0.4806H
5	Universal Bridge	IGBT based, 3arms, 6pulse
6	DC voltage source	19KV
7	Resistor	0.05
8	Capacitor	750µF

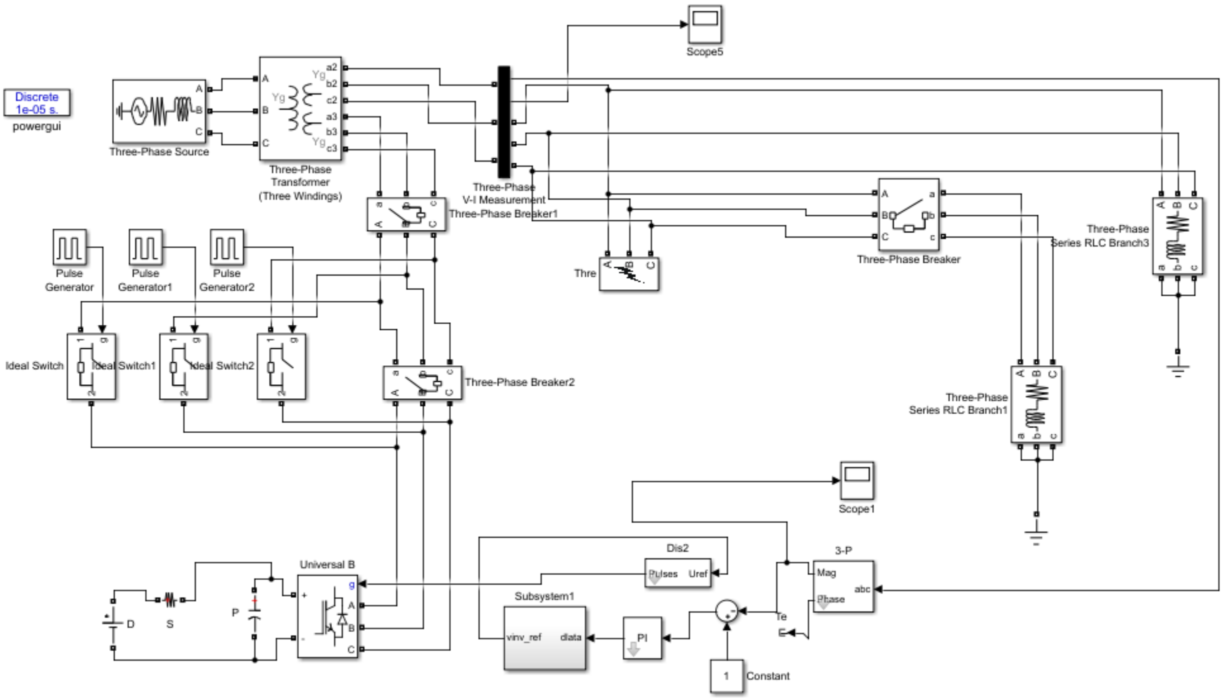
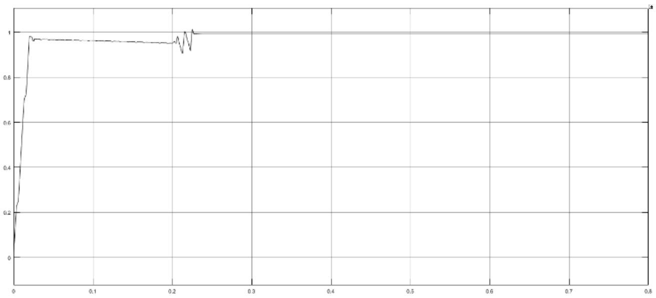
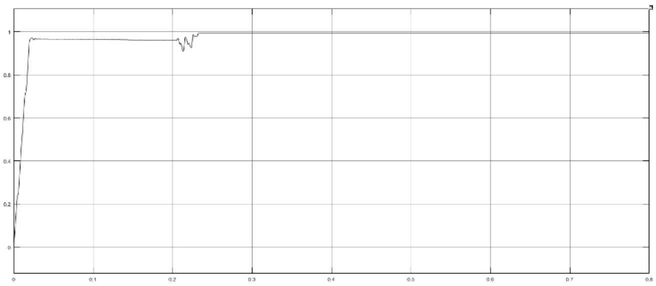


Fig. 7 Main circuit of the distribution system with the D-STATCOM system.



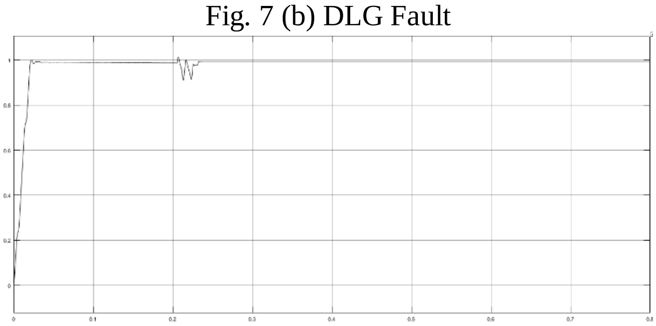
Time(s)

Fig. 7 (a) SLG Fault



Time(s)

Fig. 7 (b) DLG Fault



Time(s)
Fig. 7 (c) TLG Fault

D-STATCOM is connected in shunt in distribution network simulated using MATALB/Simulink as shown in fig. 7. The main parameters are listed in table II. Due to fault, there is a sag occurred between 0.2s to 0.5s in the distribution line. So, we need a custom power device to mitigate the sag. Here we use a D-STATCOM to compensate. The controller is designed to detect sag and generate a control signal which operate the inverter and the stored DC voltage is converted into required AC voltage which inject into line by shunt transformer After using the D-STATCOM, the RMS value of voltage in the distribution line is above 0.9 per unit.

IX. CONCLUSION

In power system networks, voltage sag and swell occur frequently due to starting of large motor or increase of load suddenly or due to birds or tress make the short circuit for small period of time, at that instant, power quality complications like voltage sag and swell occur in system and harmonic distortions are introduced in the distribution system. We have discussed above that voltage sag is a very common problem for consumers and industries. So, we modelled a D-STATCOM on Simulink in this work and we observed that D-STATCOM can compensate the voltage sag to its nominal value or RMS value of voltage above 0.9 pu.

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