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Power Quality Enhancement by DSTATCOM

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Abstract — ***Static Synchronous Compensator (STATCOM) is a device based on a voltage source converter which shunt connected to the grid. The STATCOM goes one step further than SVC and is capable of improving the power quality against even voltage dips and flickers. The advantages of a STATCOM are that the reactive power provision is independent from the actual voltage on the connection point. In this work MATLAB based simulation of STATCOM and its related analysis is done. In this paper the study of various shunt connected FACTS devices and simulation of 11KV transmission line with and without STATCOM is done and different faults are applied to the system and analysis of voltage sag is done. The respected simulations are being shown.***

Keywords- ***Power Quality, DSTATCOM, Voltage sags, VSC, PI controller, MATLAB/SIMULINK***

I. INTRODUCTION

Nowadays, more and more revolutionary power electronics equipment's are used in industries for attaining better & better power controlling ability. Also Power Quality is one of the important issues in power systems has been a problem to both suppliers and consumers. Any small disturbances like voltage dips, voltage swells or any other harmonic disturbances can bring a large amount of financial losses. Moreover power electronics and power quality are indirectly linked together as with the advancement in both broad areas [1]. Flexible AC Transmission Systems (FACTS) which are based on power electronics offer an opportunity to enhance controllability, stability, and power transfer capability of AC transmission systems.

Increased electric power consumption causes transmission lines to be driven close to or even beyond their transfer capacities resulting in overloaded lines. Also some other problems like voltage dip, voltage sag and voltage swell creates a critical problem both technically and economically. As a result of all such problems, Power Quality is affected. Since most loads are inductive and consume lagging reactive power, the compensation required is usually supplied by leading reactive power. As a result Shunt compensation of reactive power is needed STATCOM is such one of the Shunt FACTS Controllers.

II. POWER QUALITY

In present days the AC power distribution system or transmission system is suffering from various power quality problems. The widespread use of power electronics in applications such as adjustable speed drives (ASD), programmable logic controllers (PLC), and energy efficient lighting led to a complete change of electric loads nature. These loads are simultaneously the major causers and the major victims of power quality problems. Due to the non-linearity in loads, all these loads cause disturbances in the voltage waveform [2]. For power engineers the term power quality refers to a certain sufficiently high grade of electric service. The measure of power quality depends upon the needs of the equipment that is being supplied. Usually the term power quality refers to maintaining a sinusoidal waveform of bus voltages at rated voltage and frequency.

III. INTRODUCTION OF SAG

Sags or dips were initially any reduction in rms voltage below a user defined low limit for between one cycle and 2.55 seconds. Sag (dip) a decrease to between 0.1 and 0.9 pu in rms voltage or current at the power frequency for durations of 0.5 cycles to 1 minute.

IV. CAUSES OF SAG

TRANSMISSION SYSTEMS(typically above 65kV):They include the weather, construction accidents, transportation accidents (helicopter or light planes are common culprits), animals or a fault on another part of the system[15].

DISTRIBUTION SYSTEMS(65kV to 12 kV):Similar to the transmission system causes, weather (lightning, wind, ice), animal contact, contamination of insulators, construction accidents, motor vehicle accidents, falling or contact with tree limbs can result in voltage sags.

POINT-OF- UTILIZATION(120-480V):Sudden increases in the current requirement can have the same effect within a facility's wiring as on a utility distribution system.Voltage sags can be caused by fault conditions within the building or the start up of large inductive loads, such as motors that create a temporary in rush current condition.

V. PRINCIPLE OF STATCOM

A STATCOM is comparable to a Synchronous Condenser (or Compensator) which can supply variable reactive power and regulate the voltage of the bus where it is connected. In its most general way, the STATCOM can be modeled as a regulated voltage source Vi connected to a voltage bar Vs through a transformer. It is shown in figure 1 [1] [9] [14] In its most general way, the STATCOM can be modeled as a regulated voltage source Vi connected to a voltage bar Vs through a transformer. The Static Compensator (STATCOM) uses a VSC interfaced in shunt to a transmission line. In most cases the DC voltage support for the VSC will be provided by the DC capacitor of relatively small energy storage capability. Hence, in steady state operation, active power exchanged with the line has to be maintained at zero, as shown symbolically in the figure. With the active power constraint imposed, the control of the STATCOM is reduced to one degree of freedom, which is used to control the amount of reactive power exchanged with the line.

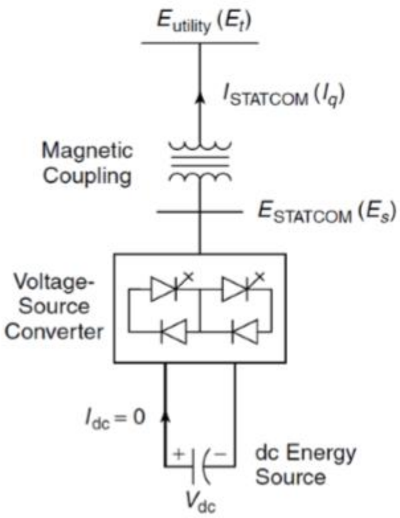

Figure 1 principle of STATCOM

Accordingly, a STATCOM is operated as a functional equivalent of a Static VAR compensator; it provides faster control than an SVC and improved. The figure 2 shows the equivalent circuit of a STATCOM system with its power diagram.

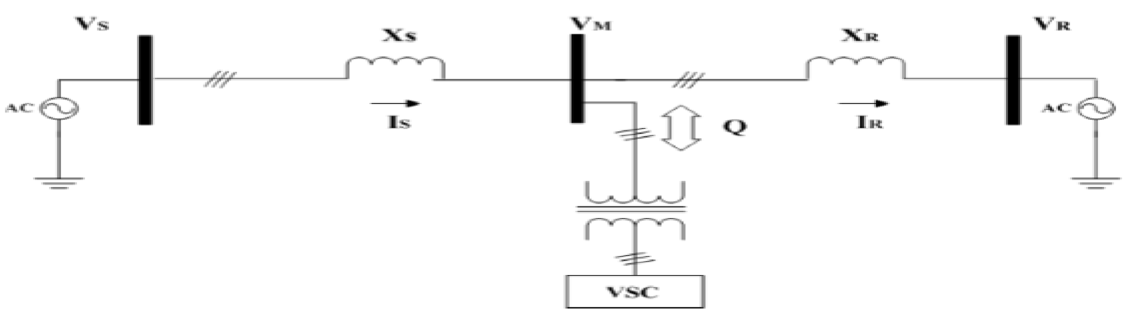

Figure 2 Equivalent circuit of a STATCOM

VI. CONTROLLER ALGORITHM

The main aim of the control scheme is to maintain constant voltage magnitude at the point where a sensitive load is connected, under system disturbances. In this scheme it measures the RMS voltage at the load point, i.e. no requirements of reactive power measurements. Here the sinusoidal PWM technique is used for the switching of Voltage Source Converter as sine PWM offers simplicity and good response compared to other scheme like space vector PWM. The input of the controller is an error signal which is obtained from the reference voltage and the value RMS of the terminal voltage measured. Now PI controller which is shown in figure 3 will process this error signal and then the output is the angle δ, which is provided to the PWM signal generator.

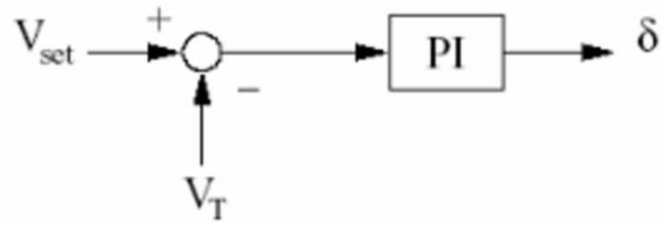

Figure 3 PI controller

In this case it is important to note that in converter, there is active and reactive power exchange with the network simultaneously. Now the error signal is obtained by comparison of the reference voltage with the RMS voltage measured at the load point. The error signal is processed by PI controller which in return generates the required angle to drive the error to zero, i.e., the load RMS voltage is brought back to the reference voltage.

VI PHASE MODULATION OF CONTROL ANGLE

Phase Modulation of control angle shown in figure 4 in which the output of PI controller is delta which is converted in to the radian and sum up with the digital clock.

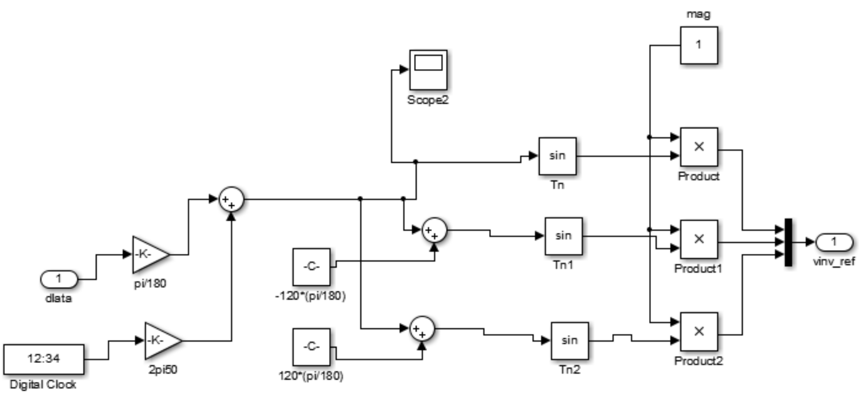

Figure 4 phase modulation of control angle

The sinusoidal signal Vcontrol is phase-modulated by means of the angle δ.

i.e., VA= sin (ωt +δ)

VB= sin (ωt+δ-2π/3)

VC = sin (ωt +δ+2π/3)

Now in order to generate the switching signals for the VSC valves, the modulated signal Vcontrol l is compared against a triangular signal. The amplitude modulation index of signal, and the frequency modulation index of the triangular signal are the main parameters of the sinusoidal PWM scheme.

VII. CALCULATION OF TRANSMISSION LINE PARAMETERS

The assumed parameters are:

Transmission power: 10 MW

Power factor: 0.9

Efficiency: 94%

(1) Calculation of Voltage:

$$V = 5.5\left(L/1.6 + \frac{P}{100}\right)^{0.5}$$
$$V = 5.5\left(5/1.6 + \frac{5KW}{100}\right)^{0.5}$$
$$V = 11KV$$

(2) Calculation of receiving current (Ir):

$$Ir=\frac{10*10^6}{3^{0.5}*11000*0.9}$$

Ir=583.18A

According to current from Appendix A ACSR 30/7/264.40 mm conductor is used in which 30 shows number of Aluminum conductor, 7 shows number of steel conductor and 264.40 shows cross sectional area of Al. conductor.

Line losses are approximately 3 $(Ir)^2$ R Where R is total line resistance per phase.

(3) Calculation of Resistance at 75 degree:

$$\frac{r_{75}}{r_{20}} = \frac{228+75}{228+20}$$

R = 0.6719 ohm

(4) Calculation of Line efficiency=

$$\frac{10*10^6}{10*10^6 + 3*583.18^2*0.6719}$$

Efficiency=93.58%

(5) Calculation of ABCD parameters of Transmission line:

Here π Method is used for parameters.

$$D_{eq=}\sqrt[3]{1.2*1.2*2.4}$$

D_{eq}=1.5119 m

R = 11.72* 10^-3 m

Geometric mean radious =0.7788*11.72* 10^-3

=9.13*10^-3

$$\text{Inductor (L)} = 0.4605\ LOG\frac{1.5119}{9.13*10^{-3}}$$

Inductor (L)=1.02 mH/Km

Calculation of Impedance $(Z) = R + JwL$

$$Z = 0.6719 + j1.6022$$
$$Z = 1.7373\angle 67.24$$
$$C = \frac{0.02412}{\log\frac{1.5119}{11.72*10^{-3}}}$$
$$C = 0.01142\ \mu F/Km$$

Calculation of Admittance(Y)= $jwcl$

$$\text{Admittance(Y)} = j*2\pi*50*0.0114*10^{-6}*5$$
$$\text{Admittance(Y)} = B = 1.7373\angle 67.24$$

Calculation of $A = D = 1 + \frac{Y}{Z}$

$$A = D = 1 + \frac{1}{2}(17.93*10^{-6})$$

$$A = D = 0.9977$$

Calculation of $C = Y(1 + \frac{ZY}{4})$

$$C = 56.93*10^{-6}\angle 161.65$$

VIII. SIMULATION AND RESULTS

The following figure 5 shows the block diagram of the STATCOM scheme implemented and simulated. As shown in the diagram the whole operation of system. There is three phase source

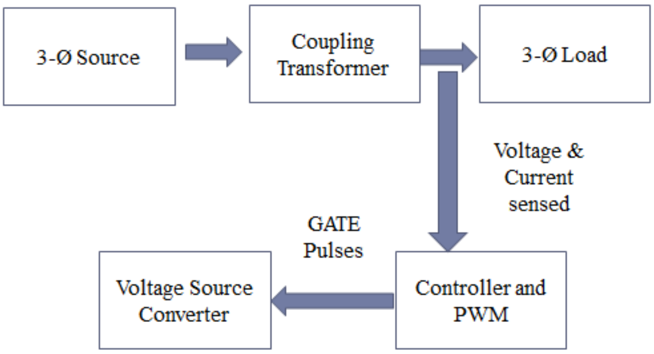

Figure 5 Block diagram of Implemented STATCOM scheme

Which supply of system, coupling transformer which couples the system to the load. Three phase load is there which is load of transmission line.

Controller is there for close loop control which continuously senses the output of the system. PWM (pulse width modulation) will provide the pulses to the GATE terminal of IGBT of VSC. According to the output of VSC the voltage will be absorb or supplied to the system.

[A] SIMULATION OF UNCOMPENSATED 11KV TRANSMISSION LINE

As shown in figure 6 the three phase series RLC line is connected through the three phase transformer and three phase source and three phase fault is connected to the transmission line.

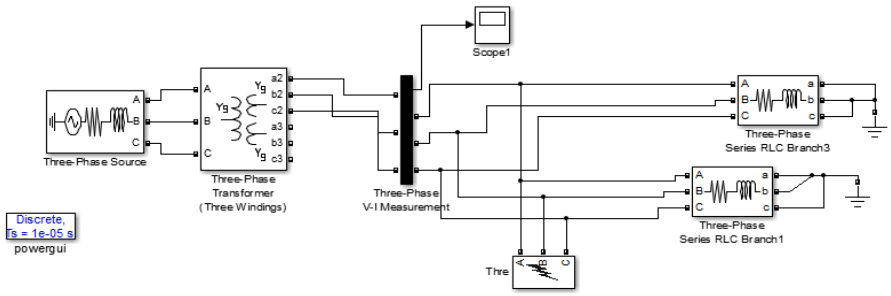

Figure 6 Simulation of uncompensated 11kv transmission line

[B] WAVEFORM BEFORE FAULT CREATED

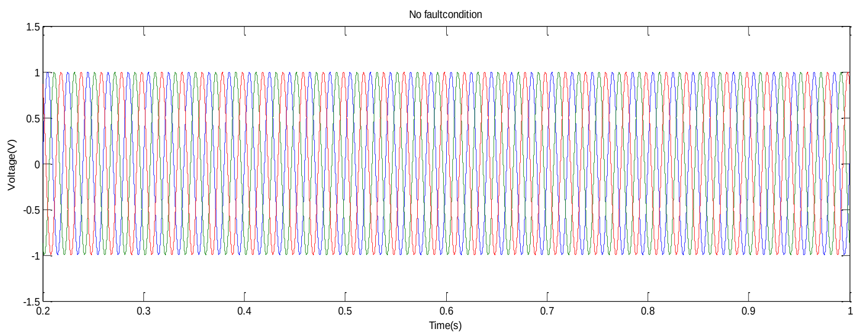

Figure 7 Waveform before fault created

[C] WAVEFORM WHEN SLG (SINGLE LINE TO GROUND) FAULT CREATED

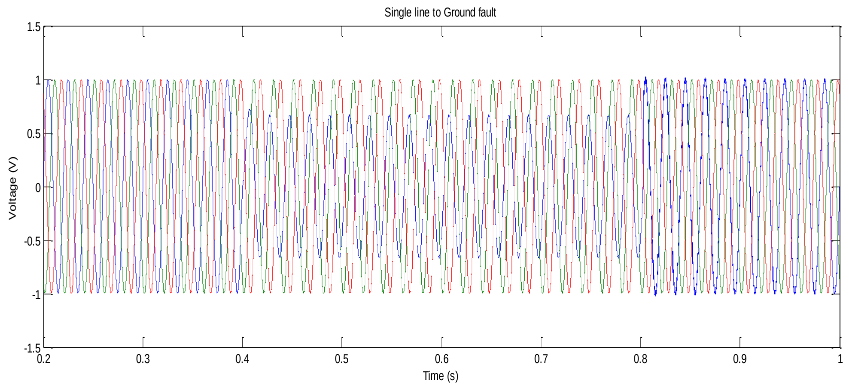

Figure 8 ***Waveform when SLG (single line to ground) fault created***

When SLG fault is created in the system that particular phase voltage will decreases. As shown in figure 8 voltage of phase Y is decreases compared to phase R and phase B.As fault resistance is kept 0.2 ohm the fault voltage (sag) is 0.2608.

[D] WAVEFORM WHEN DLG (DOUBLE LINE TO GROUND) FAULT IS CREATED

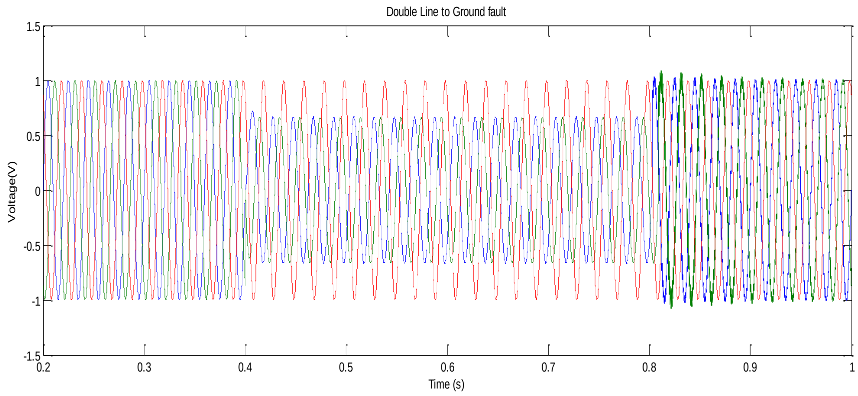

Figure 9 Waveform when DLG (double line to ground) fault is created

As shown in figure 9 when double line to ground fault is created in the system the voltage of two phases (Y and R) will be decreases.

[E] WAVEFORM WHEN TLG (TRIPLE LINE TO GROUND) FAULT IS CREATED

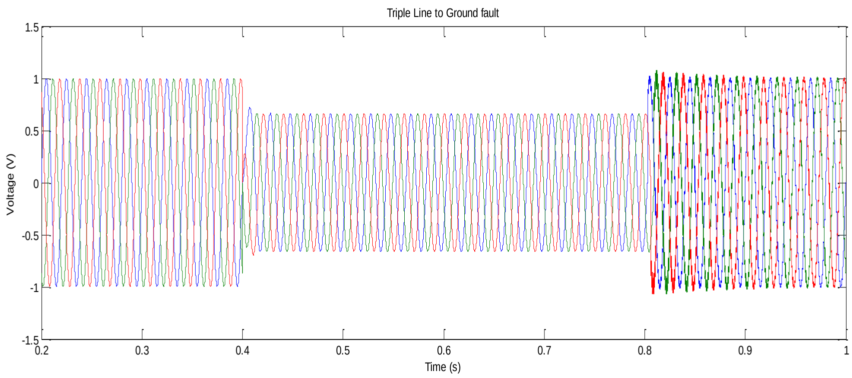

Figure 10 Waveform when TLG (triple line to ground) fault is created

As shown in figure 10 when three phase fault is created the voltage dip is there for all three phases for the time duration of 0.4 to 0.8s.Which will compensate by DSTATCOM.

[F] MATLAB SIMULINK MODEL OF DSTATCOM FOR MITIGATION OF SAG:

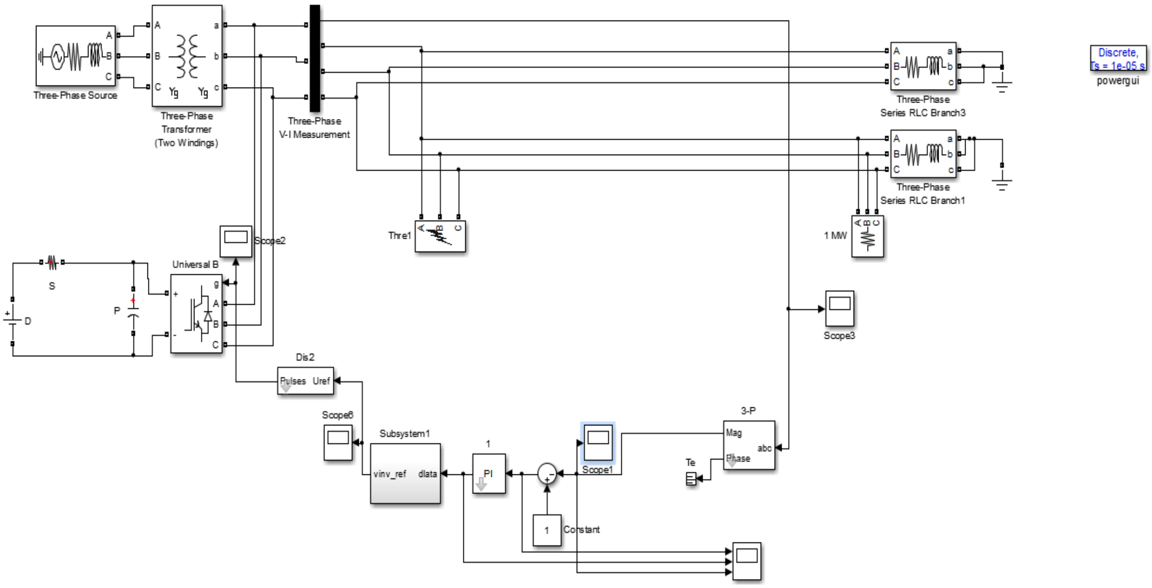

Figure 11 MATLAB Simulink model of DSTATCOM for mitigation of sag

As shown in figure 11 the DSTATCOM model is simulated in MATLAB which will mitigate the sag at the time of different fault.

[G] VOLTAGE DURING NO FAULT CONDITION:

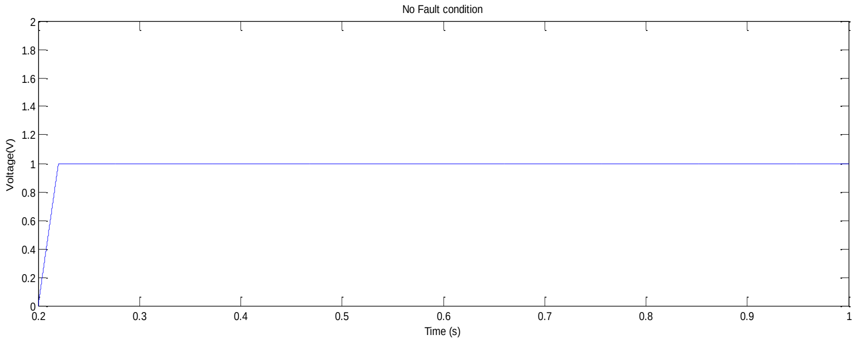

Figure 12 Voltage during no fault condition

[H] VOLTAGE DIP DURING SINGLE L-G FAULT WITHOUT & WITH DSTATCOM:

The first simulation contains no D-STATCOM and single line to ground fault is applied, via a fault resistance of 0.66 Ω, during the period 0.4 TO 0.8 s. It is clearly seen from figure that there is a voltage dip created between 0.4 sec to 0.8 second due to single phase L-G fault. Similarly, a new set of simulations are carried out but now with the D-STATCOM connected to the system. Now as seen from the below figure 14 the dip is almost mitigated.

After having D-STATCOM in the system, the voltage dip is mitigated during that particular interval of time and there is no loss of voltage in the system.

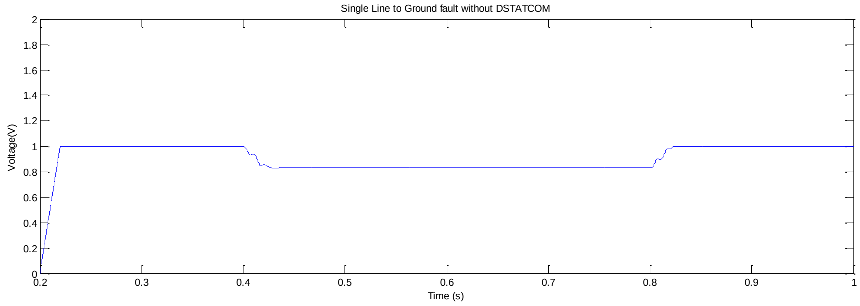

Figure 13 Voltage dip during single L-G fault without DSTATCOM

As shown in figure 13 the voltage sag is there when single line to ground fault is applied.

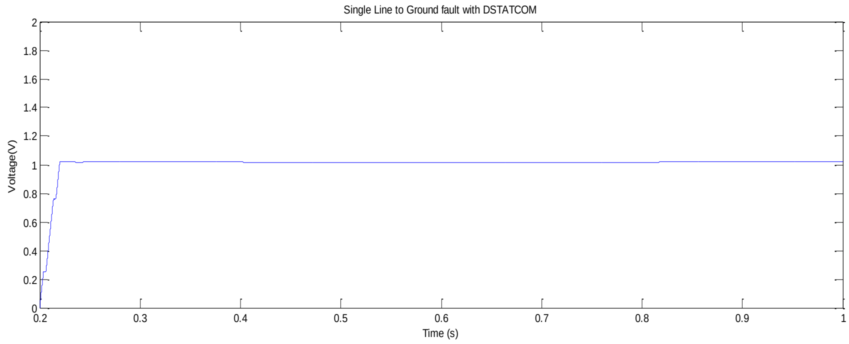

Figure 14 Voltage dip during single L-G fault with DSTATCOM

[I] Voltage Dip During double L-G Fault without & with D STATCOM:

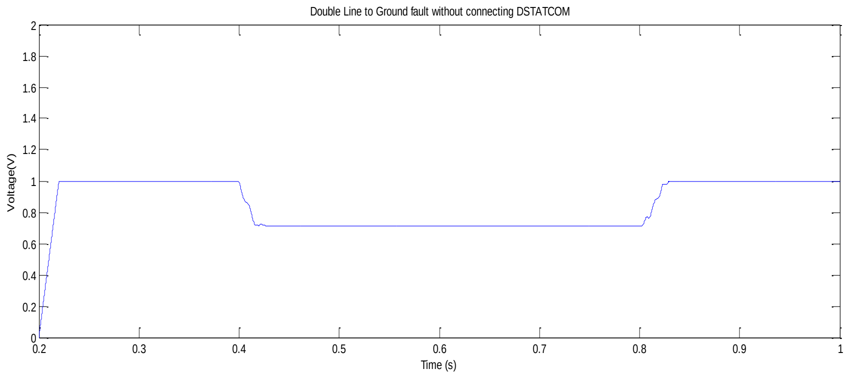

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Figure 15 Voltage Dip During double L-G Fault without D STATCOM

As shown in figure the Double line to ground fault is created without connecting DSTATCOM. By connecting DSTATCOM voltage sag can be mitigated.

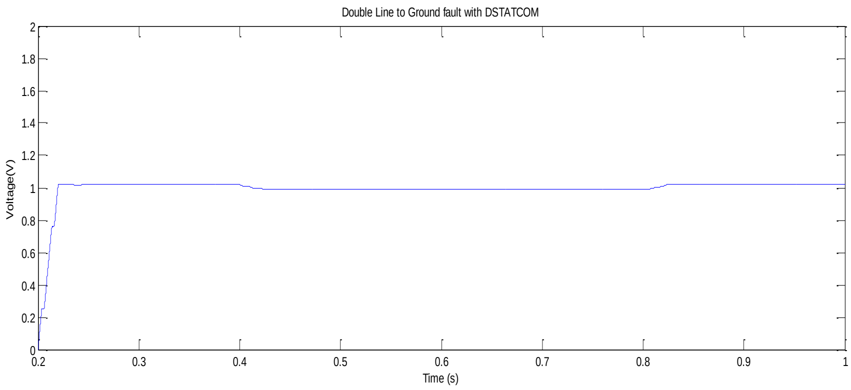

Figure 16 Voltage Dip During double L-G Fault with D STATCOM

[I] Voltage Dip during Triple L-G Fault without & with D STATCOM

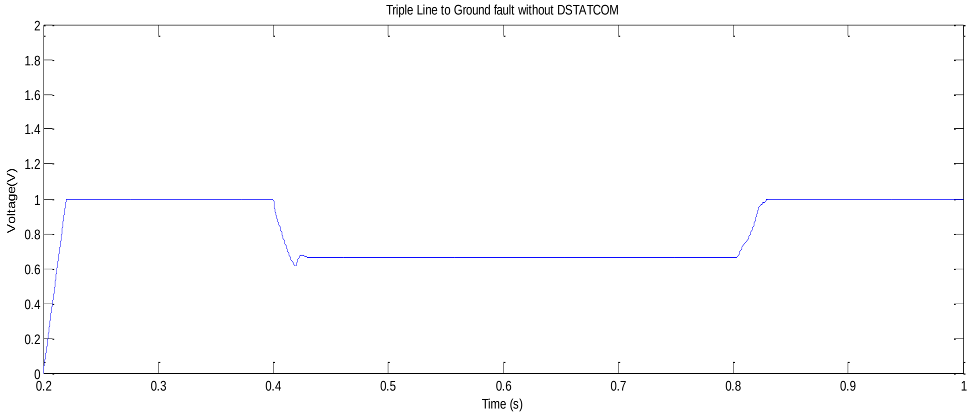

Figure 17 Voltage Dip during Triple L-G Fault without D STATCOM

As shown in figure 17 Triple line to ground fault is created and voltage dip is there which will mitigate by DSTATCOM.

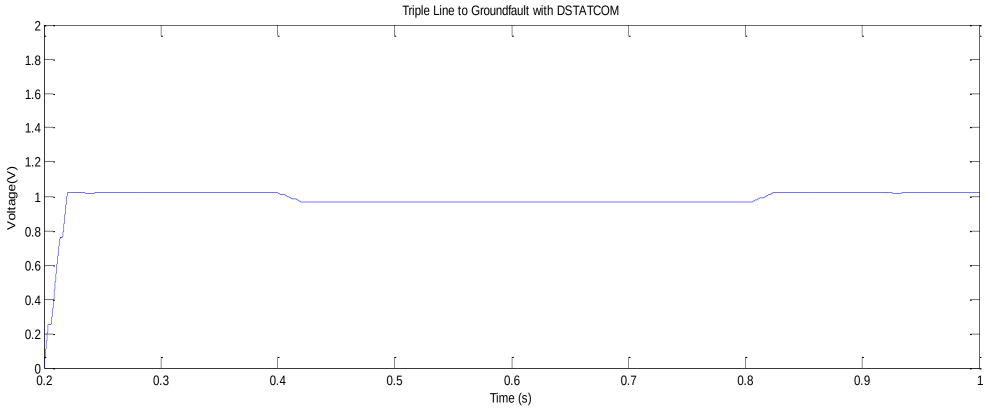

Figure 18 Voltage Dip during Triple L-G Fault with D STATCOM

IX VALUES OF VOLTAGE IN DIFFERENT FAULT CONDITION WITHOUT DSTATCOM AND WITH DSTATCOM:

Sr No.	Type of Fault	Values of voltage without DSTATCOM	Values of voltage with DSTATCOM
1	Normal condition	1.0195	1.0195
2	Single Line to Ground fault	0.83	1.014
3	Double Line to Ground fault	0.70	0.99
4	Triple Line to Ground fault	0.66	0.96

IX. CONCLUSION

According to the Simulink model during different faults L-G, DLG and TLG voltage dip is there in the output which can mitigate by connecting the DSTATCOM in the system. As shown in result voltage sag is almost reduces with DSTATCOM for particular fault period and different values of voltages is shown in the result which proves the advantages of DSTATCOM.

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