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A D-STATCOM Control Scheme for Mitigation of Voltage Sags and Improvement in Reduction of Total Harmonic Distortion in Electrical Distribution System

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Abstract: A power quality problem at any point of an electrical distribution system causes disoperation of end user equipments, failures of power supply and the damaging of sensitive machine parts .For proper functioning of an electrical distribution power system there is a need to maintain power quality in whole electrical system. This paper presents the mitigation of voltage dips and the improvement in reduction of harmonic distortion in the distribution system. The simulations were performed using MATLAB SIMULINK version R2011b.

Index Terms—D-STATCOM, Voltage Sagging, Voltage source converter, LCL filter, Total harmonic distortion. Electrical Distribution System . *(key words)*

1. INTRODUCTION:

Electricity distribution is the final stage in the delivery of electricity to end Customers. A distribution system network carries electricity from the transmission system and delivers it to consumers. Typically, the network operate with medium-voltage ranges between 2kV to 34.5 kV power lines , substations and pole-mounted transformers, low-voltage (less than 1 kV) distribution wiring such as a Service Drop and sometimes meters[5][6]. An electrical distribution system comprises of bulk power sources, Transformers and various interconnected grid lines and the system ends at the load side that is Consumer side . In modern age due to heavy load demanding at the consumer side there is a demand for high quality, reliable electrical power with economic consideration kept in mind. Today the whole world facing the power quality problem are Voltage Fluctuation, THD Variation, Unbalancing of Active & Reactive Power and Low power factor. Voltage Sags is a short time event during which a reduction in RMS voltage magnitude occurs [1][2] .The voltage sags magnitude is ranged from 10% to 90% of nominal voltage.

Voltage sags is caused by the fault due to lightning phenomenon, fault in the utility system, fault in the consumer's side or a sudden large increase of load current like starting a motor or transformer energizing. In industries load demand is varying so voltage sags occur more often and causes severe physical and economic losses.[1]

Harmonic currents in distribution system can causes harmonic distortion, Low power factor and also causes heating in electrical equipment. It also can causes vibration and noise in machines and so the damaging of sensitive machine parts[1].

There are different ways to improve power quality problems in electrical power system. Among these the Fact controller D-STATCOM is one of the most effective devices. A pulse width modulation scheme has been implemented to control the gates circuit of the D-STATCOM Controller[4]. The LCL Passive filter was then added to improve harmonic distortion. The D-STATCOM has additional capability to sustain reactive current at low voltage and can be developed as a voltage and frequency support by replacing capacitors with batteries as energy storage.

2. DISTRIBUTION STATIC COMPENSATOR (D-STATCOM).

A capacitor is an AC device that stores energy in the form of an electric field. When current is passing through a capacitor, it takes a period of time for a charge to stored up to produce the full voltage difference. On an AC system the voltage across a capacitor is continuously changing so the capacitor will oppose this change causing the voltage to lag behind the current. So the current leads the voltage in phase hence these devices are said to be sources of storage power[3]. A D-STATCOM consist of two level voltage source converter, Controller circuit and a coupling transformer connected in shunt to the distribution network.fig shows the schematic diagram of a D-STATCOM.

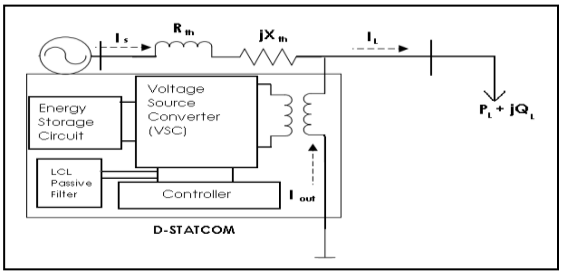

Fig 1: POWER CONTROLLER

Here I s + I out = I load
So , I out = I load – Is
=I load – V th –V load /Z th
Then V out = I out * Z th.

By above equation, The output current I out will compensate the voltage deviation by adjusting the voltage drop across the system impedance, Z th = R + j X . The effectiveness of D-STATCOM in correcting voltage sags depends on[1][4]:

1. The value of impedance, Z th = R + j X
2. The fault level of load bus.

A. *Voltage Source Converter (VSC):*

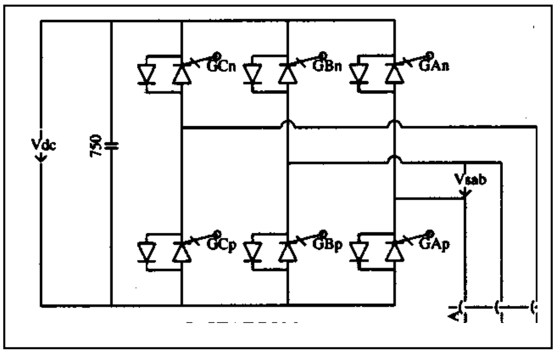

Fig 2: IGBT CONVERTER

A voltage source controller[2][5] is a power electronic device that connected in shunt or parallel to the system. It can generate a basic mathematical voltage with any required magnitude, frequency and phase angle. The controller will completely replace the voltage or to provide the sagging voltage. It also converts the dc voltage across reactive device into a set of three phase Ac output voltages. If the output voltage of the power controller is greater than the Ac bus terminal voltage then, D-STATCOM is working in capacitive mode. So it will compensate the storage power through Ac system so voltage dips become reduced to approximately ideal conditions and if the output voltage of VSC is less than the source voltage so D-STATCOM will work in inductive mode. Properly controlling of the phase and magnitude of the Power Controller output voltages allows effective exchanges of active and reactive power between the D-STATCOM and the Ac system[3].

B. Controller Circuitry Working:

The controller circuitry compares the load side RMS voltage with the reference voltage and generates an error signal. The error signal is processed by the PI controller. Proportional integral controller is a feedback controller which forces the system to be controlled with a measured sum of the error signal and the integral of that value. The PI controller operates the error signal generates the required angle to drive the error to zero that is the load voltage is brought back to the reference voltage. The angle delta which is the output of the PI controller is summed with the phase angle of balanced supply voltages equally at 120 Degree. The phase modulated signal is compared against a triangular signal in order to generate the pulses for the gates terminals of the voltage source converter.[2]

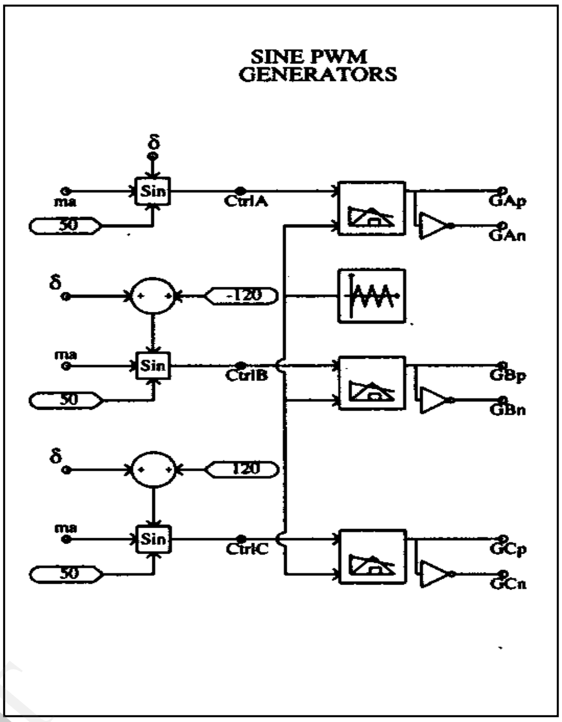

FIG 3: CONTROLLER CIRCUITRY

C. Energy Storage Circuit:

DC source is connected in parallel with the dc capacitor. It carries the input current of the controller and it is the main reactive energy storage element. This DC capacitor could be charged by battery source or could be recharged by the converter operation in D-STATCOM.

D. LCL Passive Filter:

LCL passive filter is introduced in simulation model [1][3],for reducing harmonic distortion. The design equations are stated:

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} f_{sw}}, \quad C_f = \frac{L+L_g}{LL_g\left(2\pi f_{res}\right)^2}, \quad L_c = \frac{L_g}{2}$$

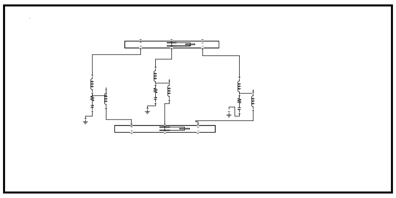

Fig 4: SIMULINK MODEL OF FILTER

3. METHODOLOGY:

A. Test system for Electrical distribution system :[1]

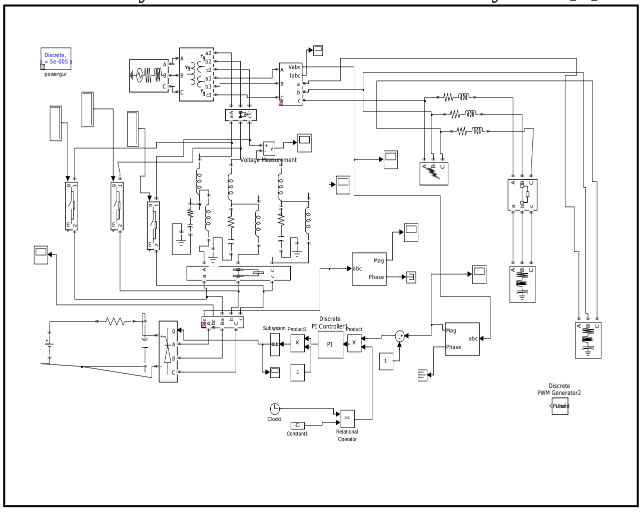

FIG 5: SIMULINK MODEL OF EDS

It comprises a 230kv,50 Hz transmission system feeding into the primary side of a 3 Phase winding transformer connected in Star Pattern ,230/11/11 KV. A varying load is connected to the 11 KV secondary side of the transformer. A Filter & D-STATCOM is connected to the tertiary side of the transformer by means of circuit breaker. The voltage at the load point is calculated from the VI measurement block[4][5]. The output current is also measured from the VI measurement block, from which we get the Total Harmonic Distortion by the use of FFT Analysis. Waveforms below shows the simulation results of the test system for different types of fault. The fault occur during 200-700 ms when the fault resistance is Rf = 0.10 ohm.

B. Results Of Simulation Model:

a. Voltage sags for different types of fault without D-STATCOM:

Tab 1: VOLTAGE SAG VALUES

Fault Resistance	*Voltage sags for TPG fault*	*V sag for DLG fault*	*V sag for LL fault*	*V sag for SLG fault*
.1	.85	.92	.83	.98
.3	.95	.97	.91	1
.5	.961	.981	.94	1

1. Voltage sags for TPG fault:

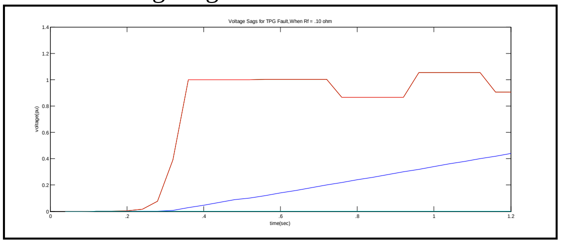

FIG 6: TPG FAULT WAVEFORM

2. Voltage sags for DLG fault:

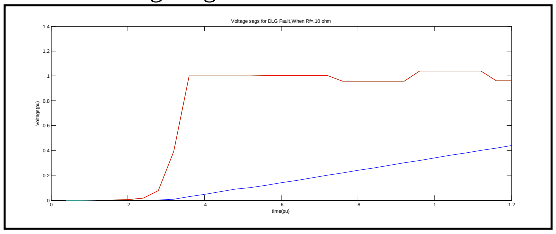

FIG 7: DLG FAULT WAVEFORM

3. Voltage sags for Line to Line fault:

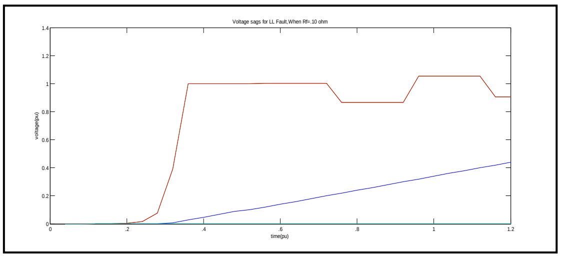

FIG 8: LL FAULT WAVEFORM

4. Voltage sags for Single Line To Ground Fault:

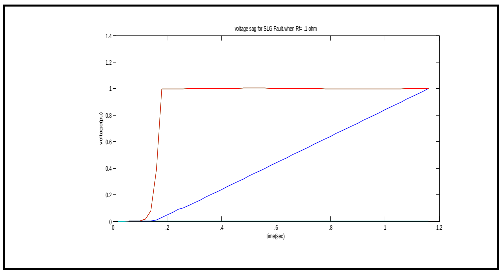

FIG 9: SLG FAULT WAVEFORM

b. Voltage sags for different types of fault with D-STATCOM:[3],[4]

Tab 2: VOLTAGE SAG TABLE WITH D-STATCOM

Fault resistance	***V sag for TPG fault***	***V sag for DLG fault***	***V sag for LL fault***	***V sag for SLG fault***
.1	.9	.96	.92	.99
.3	.96	.98	.98	1
.5	.97	.99	.98	.99

1. Voltage sags for TPG Fault :

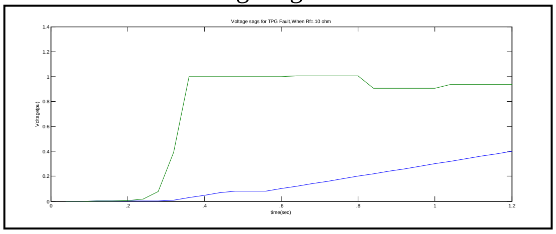

FIG 10: TPG FAULT COMPENSATION

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2. *Voltage sags for DLG Fault :*

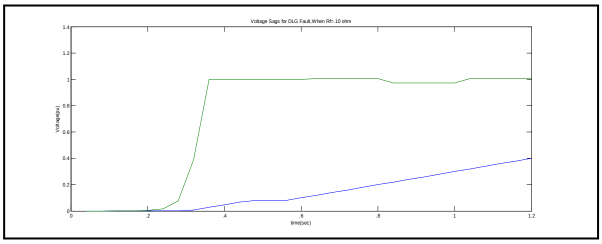

FIG 11: DLG FAULT COMPENSATION

3. *Voltage sags for LL Fault:*

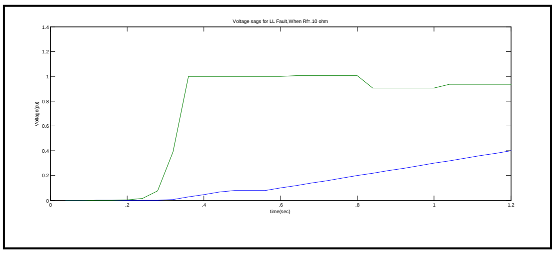

FIG 12: LL FAULT COMPENSATION

4. Voltage sags for SLG Fault:

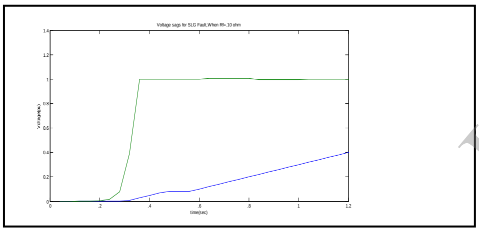

FIG 13: SLG FAULT COMPENSATION

c. Waveform of Distortion output current with D-STATCOM and its Harmonic Spectrum:[1]

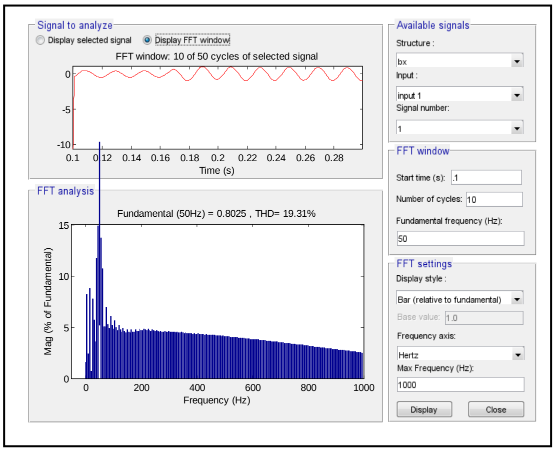

FIG 14: OUTPUT CURRENT THD WAVEFORM

RESULT: The THD of output current without LCL passive filter is 19.31 %.

d. Figure below shows the waveform of distortion output current with D-STATCOM & LCL Passive filter and the harmonic spectrum of output current:[1]

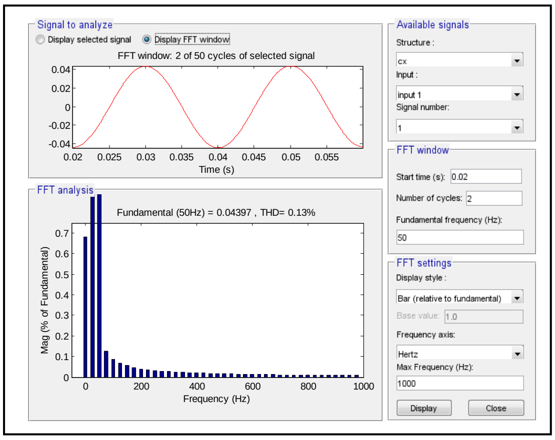

FIG 15: HARMONIC DISTORTION WAVEFORM WITH FILTER

RESULT: Total Harmonic Distortion of distortion current with filter is .13 %.

e. Comparison Of Results Of Voltage Sags For Different Types Of Fault,When R f = 0.10 ohm:

Tab 3: VOLTAGE SAG COMPARISION TABLE

Types of Fault	V sag (PU) Without D-STATCOM	V sag (PU) With D-SATCOM
TPG	.8	.9
DLG	.91	.96
LL	.83	.92
SLG	.96	.99

f. Comparison Of Results For Total Harmonic Distortion For Different Types Of Fault, When R f = 0.10 ohm:

Tab 4: THD COMPARISION TABLE

Types of Fault	THD(%)Without D-STATCOM	THD(%)With D-STATCOM	THD(%)WITH FILTER
TPG	11.61	19.31	.13
DLG	11.61	19.31	.21
LL	11.61	19.34	.21
SLG	11.61	19.36	.31

4. LIST & VALUES OF PARAMETERS USED IN SIMULATION:

Tab 5: SIMULATION PARAMETER TABLE

Symbol	***Name***	***Quantity***
En	Rms value of grid voltage	19kv(rms)
Iripm	15% of peak value fundamental harmonic current	793.1mA(rms)
Lg	Grid side filter inductance	1630mH
Lc	Converter side filter inductance	815mH
Cf	Filter Capacitance	.0017uf
Rf	Resistance of converter side filter	15ohm
Fsw	Switching Frequency	20 khz
Fres	Resonance Frequency	5.25 khz
Vph-ph rms	Phase to Phase source Rms voltage	2.1MV
X/R	Impedance ratio	10
Pnomi	Nominal power (VA)	200MVA
Vph-ph Nomi	Nominal voltage used for P.U Measurement	50 KV(rms)
VLnomi ph-ph	Nominal load voltage	100 KV(rms)
Pactive	Active Power	190 KW
QL	Inductive Reactive Power	100 Mvar
QC	Capacitive Reactive Power	10 Mvar

The simulation results & Table shows that the voltage sags can be mitigated by inserting D-STATCOM to the distribution system. By adding D-STATCOM THD will increase due to switching losses. By adding LCL Passive filter to D-STATCOM, The Total Harmonic Distortion reduced up to .13% which is approximate to ideal condition. Thus, it can be concluded that by adding D-STATCOM and LCL Passive filter power quality is improved. In this paper work, it is shown that the Power Converter can mitigate the voltage sag and swell conditions. The work can be proceed to decrement the source voltage and source current harmonics supplied due to the industrial induction motor load. This paper can also be extended for multilevel power Converter to reduce the harmonic current at the supply side due to industrial load. This paper is done for only single generators and can be extended to Grid connected main station generators with multi level power Converters for Semiconductor Devices.

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