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Research Article

Applications of D-STATCOM for Power Quality Improvement in Distribution System

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Abstract

FACTS use Power Electronic devices and methods to control the high-voltage side of the network for improving the power flow. Custom Power is for low-voltage distribution, and improving the poor power quality and reliability of supply affecting factories, offices and homes. Power quality and Reliability are becoming important issues for critical and sensitive loads after introducing the term of Custom Power by Hingorani in early 1980s. Custom Power Devices is classified into three categories by their structures such as Dynamic Voltage Restorer (DVR), Distribution STATCOM (D-STATCOM) and Unified Power Quality Compensator (UPQC). This paper presents the improvement of Voltage Sags, Harmonics Distortions and poor powers factors using Distributions Static Compensator (D-STATCOM) with LCL Passive Filters in distribution system. The model is based on then Voltage Source Converter (VSC) principles and PWM Technique. The D-STATCOM injects a current into the system to mitigate the voltages sags. LCL Passive Filter was then added to D-STATCOM to improve harmonics distortions and poor power factor. The simulations were performed using MATLAB SIMULINK versions R2009b.

Keywords: *D-STATCOM, Voltages Sags, Voltages Source Converter (VSC), LCL Passive Filter, Total Harmonics Distortions (THD).*

1. Introduction

Power quality issues are gaining significant attention due to the increase in the number of sensitive loads. Many of these loads use equipment that is sensitive to distortions or dips in supply voltages. Almost all power quality problems originate from disturbances in the distribution networks. Regulations apply in many places, which limit the distortion and unbalance that a customer can inject to a distribution system. These regulations may require the installation of compensators (filters) on customer premises. It is also expected that a utility will supply a low distortion balanced voltage to its customers, especially those with sensitive loads. An increasing demand for high quality, reliable electrical power and increasing number of distorting loads may leads to an increased awareness of power quality both by customers and utilities. most common power quality problems today are voltage sags, harmonic distortion and low power factor.

Voltage sags is a short time (10 ms to 1 minute) event during which a reduction in r.m.s voltage magnitude occurs. It is often set only by two parameters, depth/magnitude and duration. The voltage sags magnitude is ranged from 10% to 90% of nominal voltage and with duration from half a cycle to 1 min Voltage sags is caused by a fault in the utility system, a fault within the customer's facility or a large increase of the load current, like starting a motor or transformer energizing (Bhim Singh *et al*, 2005).Voltage sags are one of the most occurring power quality problems. For an industry voltage sags occur more often and cause severe problems and economical losses. Utilities often focus on disturbances from end-user equipment as the main power quality problems (Sung-Min *et al*, 2001).

Harmonic currents in distribution system can cause harmonic distortion, low power factor and additional losses as well as heating in the electrical equipment. It also can cause vibration and noise in machines and malfunction of the sensitive equipment. The development of power electronics devices such as Flexible AC Transmission System(FACTS) and customs power devices have introduced and emerging branch of technology providing the power system with versatile new control capabilities (Arindam Ghosh *et al*, 2011).

There are different ways to enhance power quality problems in transmission and distribution systems. Among these, the D-STATCOM is one of the most effective devices. A distribution static compensator (D-STATCOM) is a voltage source Converter (VSC)-based

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power electronic device. Usually, this device is supported by short-term energy stored in a DC capacitor. When a DSTATCOM is associated with a particular load, it can inject compensating current so that the total demand meets the specifications for utility connection. Alternatively, it can also clean up the voltage of a utility bus from any unbalance and harmonic distortion. A new PWM-based control scheme has been implemented to control the electronic valves in the DSTATCOM. 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 (Noramin Ismail *et al*, 2010).

In this paper, the configuration and design of the DSTATCOM with LCL Passive Filter are analyzed. It is connected in shunt or parallel to the 11 kV test distribution system. It also is design to enhance the power quality such as voltage sags, harmonic distortion and poor power factor in distribution system.

2. Custom Power Devices

Custom power is a strategy, which is intended principally to convene the requirement of industrial and commercial consumers. The concept of the custom power is tools of application of power electronics controller devices into power distribution system to supply a quality of power, demanded by the sensitive users. These power electronics controller devices are also called custom power devices because through these valuable powers is applied to the customers. They have good performance at medium distribution levels and most are available as commercial products. For the generation of custom power devices VSI is generally used, due to self-supporting of dc bus voltage with a large dc capacitor. The custom power devices are mainly divided into two groups: network reconfiguring type and compensating type. The complete classification of custom power devices is shown in the Fig 2.1.

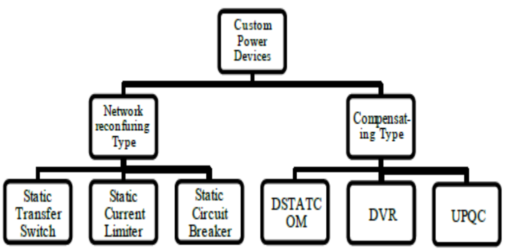

Fig 2.1 Custom power devices

3. D-STATCOM

3.1 Basic Principal of D-STACTOM

A DSTATCOM is a controlled reactive source, which includes a Voltage Source Converter (VSC) and a DC link capacitor connected in shunt, capable of generating and/or absorbing reactive power. The operating principles of a DSTATCOM are based on the exact equivalence of the conventional rotating synchronous compensator.

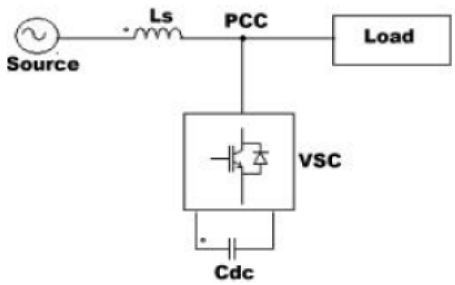

Fig.3.1 Basic structure of D-STATCOM

The AC terminals of the VSC are connected to the Point of Common Coupling (PCC) through an inductance, which could be a filter inductance or the leakage inductance of the coupling transformer, as shown in Fig. 1. The DC side of the converter is connected to a DC capacitor, which carries the input ripple current of the converter and is the main reactive energy storage element. This capacitor could be charged by a battery source, or could be recharged by the converter itself. If the output voltage of the VSC is equal to the AC terminal voltage, no reactive power is delivered to the system. If the output voltage is greater than the AC terminal voltage, the DSTATCOM is in the capacitive mode of operation and vice versa. The quantity of reactive power flow is proportional to the difference in the two voltages. It is to be noted that voltage regulation at PCC and power factor correction cannot be achieved simultaneously. For a DSTATCOM used for voltage regulation at the PCC, the compensation should be such that the supply currents should lead the supply voltages, whereas, for power factor Correction, the supply current should be in phase with the supply voltages. The control strategies studied in this paper are applied with a view to studying the performance of a DSTATCOM for power factor correction and harmonic mitigation.

3.2 Basic Configuration and operation of D-STATCOM

The D-STATCOM is a three-phase and shunt connected power electronics based device. It is connected near the load at the distribution systems. The major components of a D-STATCOM are shown in Fig. 3.2. It consists of a dc capacitor, three-phase inverter (IGBT, thyristor) module, ac filter, coupling transformer and a control strategy. The basic electronic block of the D-STATCOM is the voltage sourced inverter that converts an input dc voltage into a three-phase output voltage at fundamental frequency. The D-STACOM employs an inverter to convert the DC link voltage Vdc on the capacitor to a voltage source of adjustable magnitude and phase. Therefore the DSTATCOM can be treated as a voltage-controlled source. The D-STATCOM can also be seen as a current-controlled source. Fig. 2 shows the inductance L and resistance R which represent the equivalent circuit elements of the step down transformer and the inverter will is the main component of the D-STATCOM.

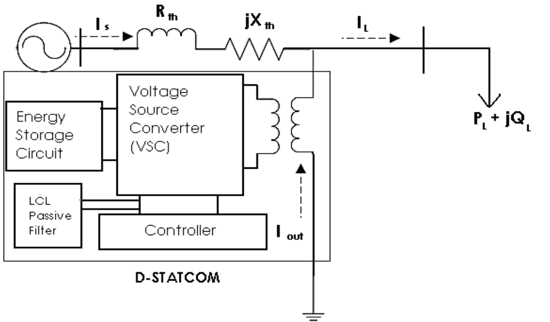

Fig. 3.2 Distribution system with D-STATCOM

The voltage Vi is the effective output voltage of the DSTATCOM and ä is the power angle. The reactive power output of the D-STATCOM inductive or capacitive depending can be either on the operation mode of the DSTATCOM. The construction controller of the DSTATCOM is used to operate the inverter in such a way that the phase angle between the inverter voltage and the line voltage is dynamically adjusted so that the DSTATCOM generates or absorbs the desired VAR at the point of connection. The phase of the output voltage of the thyristor-based inverter, Vi, is controlled in the same way as the distribution system voltage, Vs. A D-STATCOM consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network. Figure 3.2 shows Distribution system with D-STATCOM.

The compensation working principle of the D-STATCOM is in brief as follows:

As shown in the figure 3.2 *D-STATCOM* consists of a two-level VSC, a dc energy storage device, controller and a coupling transformer connected in shunt to the distribution network.

$$I_{sh} = I_{out} = I_L - I_s = I_L - \frac{Vth-VL}{Zth} \qquad (3.1)$$

$$I_{sh} \angle \gamma = I_L \angle -\theta - \frac{Vth}{Z\,th} \angle(\delta-\beta) + \frac{VL}{Zth} \angle -\beta \qquad (3.2)$$

I out = output current $I_{L=}$ load current
I_s = Source Current $V_{th\,=}$ Thevenin Voltage
V_L = load voltage Z_{th} = impedance

Referring to the equation 3.2, output current will correct the voltage sags by adjusting the voltage drop across the system impedance. It may be mention that the effectiveness of D-STATCOM in correcting voltage sags depends on:

- The value of Impedance,
- The fault level of the load bus

By sensing the fault condition, the VSC will produce required current to compensate the fault voltage/ voltage sag. Afterwards by adding filter to combination of VSC and Controller unit, harmonic distortion will be eliminated and power factor will also be improved(Arindam Ghosh *et al*, 2011).Analysis will be done through the simulation using Mat lab Simulink model. After compensation the out-put waveforms are observed, these waveforms show the correction as compared to waveforms without using D-STATCOM. By observing this result, we can compare the results by, with and without using D-STATCOM. And simulation can be continued for different values fault resistances.

4. Case Study

The proposed Simulink model has been successfully run in MATLAB SIMULINK 2009a for analyzing voltage sag, power factor and total harmonic distortion, under different fault conditions on the distribution system by considering different fault resistances.

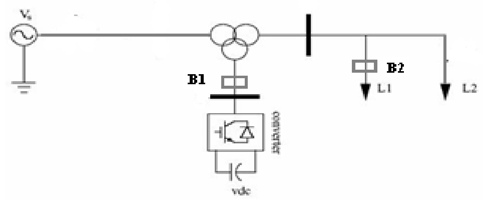

Fig.4.1 Single line diagram for the test system

The test system shown in figure 4.1 comprises a 230kV, 50Hz transmission system, represented by a Thevenin equivalent, feeding into the primary side of a 3-winding transformer connected in Y/Y/Y, 230/11/11 kV. A varying load is connected to the 11 kV secondary side of the transformer. A two-level D-STATCOM is connected to the 11 kV tertiary winding to provide instantaneous voltage support at the load point. A 750 μF capacitor on the dc side provides the D-STATCOM energy storage capabilities. Breaker 1 is used to control the period of operation of the D-STATCOM and breaker 2 is used to control the connection of load 1 to the system.

Table 4.1 List and value of parameters used in simulation

Device	Name of the parameter	Quantity value
Source	RMS value of the source voltage	19kV(rms)
	Resistance	0.8929 ohms
	Inductance	16.58 mH
	Frequency	50hz
Three phase Transformer	Nominal power and frequency	100MVA 60hz
	Phase to phase RMS voltage, inductance and capacitance of winding 1 are	19 kVA, 0.002pu, 0.08pu
	Phase to phase RMS voltage, inductance and capacitance of winding 2 are	11 kVA, 0.002pu, 0.08pu
	Phase to phase RMS voltage, inductance and capacitance of winding 3 are	11kVA, 0.002pu. 0.08pu
Load	Configuration	Star grounded

	Nominal phase to phase voltage	11kV(rms)
	Active power	10kW
	Inductive reactive power	100 +ve var
	Capacitive reactive power	100 –ve var
LCL Passive Filter	Filter inductances L1, L2 and filter capacitance C	1630mH, 815mH, 0.0017e-6 F

4.1 The sequential steps for simulation using matlab Simulink model

Step 1: design Simulink model for test distribution system using matlab Simulink and store the necessary input data for different devices like source data, distribution line data, load data and simulation time etc., used in the test system
Step 2: create a distortion by inserting different types of fault and store the fault resistance of the line.
Step 3: run the simulation between 0 to 1 second
Step 4: vary the value of fault resistance
Step 5: check the limits of voltage sag and power factor. If they exceed limits connect the D-STATCOM in to distribution system, if they do not exceed the limits means, system will check next condition. The limits are voltage sags> 0.9 p.u and power factor>0.9.
Step 6: check the value of total harmonic distortion, if total harmonics distortion is more than 5%, the LCL passive filter will be added to the system. If total harmonic distortion is less than 5%, results can be analyze from the scope.
Repeat the above steps for different values of fault resistances and analyze the results for different fault conditions for with and without using DSTACOM.

4.2 Simulink Model for the Proposed Test System

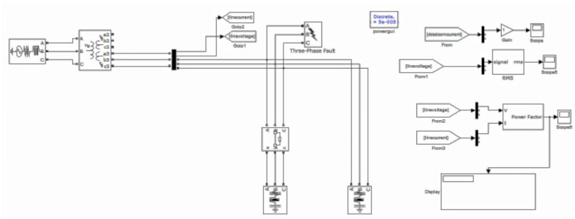

Fig4.3 Simulink model for test system without D-STATCOM

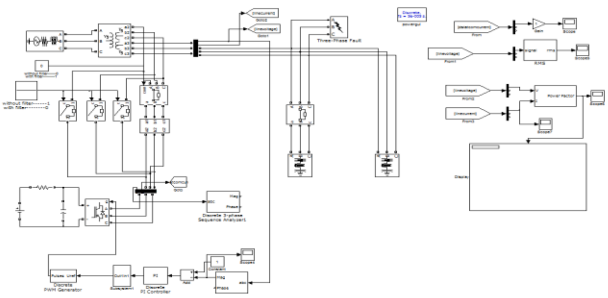

Fig.4.4 Simulink model for test system with D-STATCOM

5. Results and Discussions

To create distortion in the distribution system, different types of faults such as Three Phase to Ground (TPG), Double Line to Ground (DLG), Line to Line (LL), and Single Line to Ground (SLG) are injected. Four different fault conditions and D-STATCOM with and without LCL passive filter are considered for the test system shown in Figure-4.1. The results for each fault condition are as fallows.

5.1 Three Phase to Ground Fault Condition

In this case three phase to ground fault was considerd. The fault was created for the duration of 0.1 to 0.25 seconds. And fault resistance and ground resistance are 0.66ohm and 0.001ohm respectively. The output waveforms for the load voltage without D-STATCOM and with D-STATCOM are shown in Fig 5.1 and 5.2 respectively.

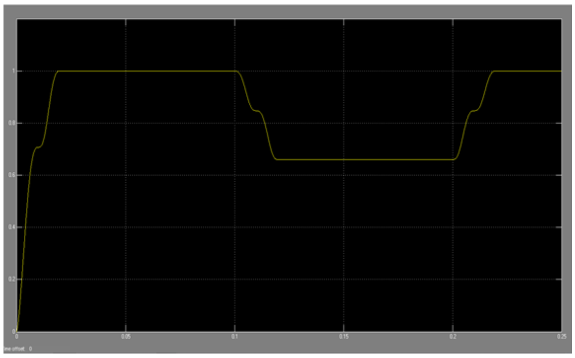

Fig 5.1 TPG fault without D-STATCOM

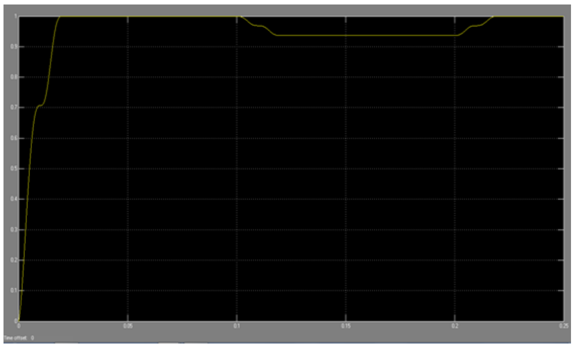

Fig 5.2 TPG fault with D-STATCOM

From the above wave forms shown in fig 7.5 and 7.6, the value of line voltage during the fault without using STATCOM is 0.66 p.u. And the value of of line voltage during the fault with D-STATCOM is 0.9367 p.u . Hence with D-STATCOM the voltage has been improved by 0.2767 p.u when compared to voltge without using D-STATCOM. Here, X-axis represents the time in seconds and Y-axis represents the line voltage in voltage p.u

5.2 Double Line to Ground Fault Condition

In this case double line to ground fault was considered the fault has created for the duration of 0.1 to 0.25

seconds and the fault resistance and ground resistance are 0.66 ohm and 0.001ohm respectively. The output waveform for the line voltage without and with using D-STATCOM are shown in fig 5.3 and fig 5.4 respectively.

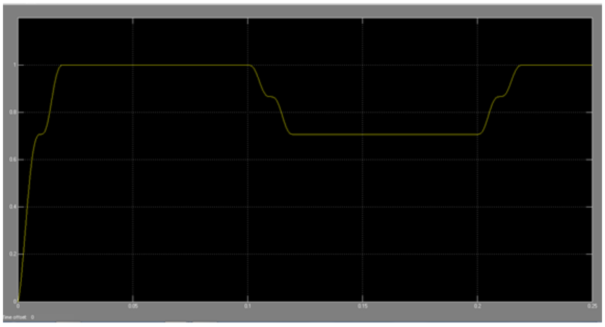

Fig 5.3 DLG fault without D-STATCOM

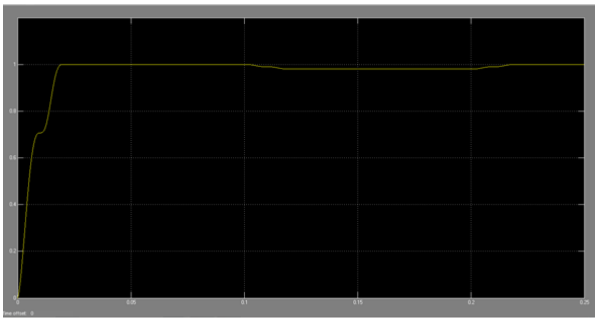

Fig 5.4 DLG fault with D-STATCOM

From the above wave forms shown in fig 5.3 and 5.4, the value of line voltage during the fault without using STATCOM is 0.707 p.u. And the value of of line voltage during the fault with D-STATCOM is 0.9800 p.u . Hence with D-STATCOM the voltage has been improved by 0.273 p.u when compared to the voltge without using D-STATCOM. Here, X-axis represents the time in seconds and Y-axis represents the line voltage in voltage p.u.

5.3 Line to Line Fault Condition

In this case line to line fault was considered. The fault was created for the duration of 0.1 to 0.25 seconds and the fault resistance and ground resistance are 0.66 ohm and 0.001ohm respectively.

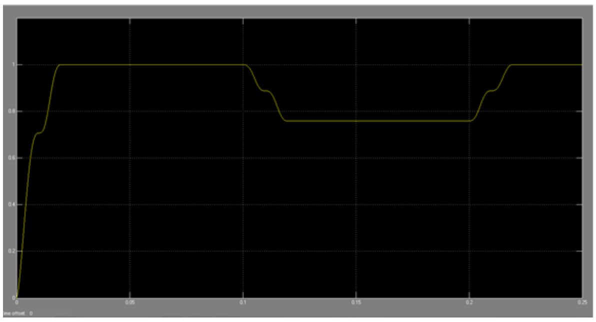

Fig 5.5 L-L fault without D-STATCOM

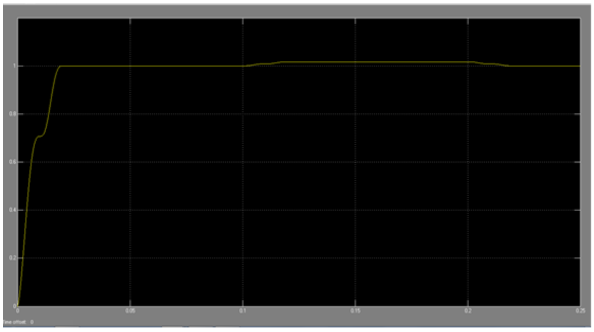

Fig 5.6 L-L fault with D-STATCOM

The output waveforms for the line voltage without and with using D-STATCOM are shown in fig 5.5 and fig 5.6 respectively.

From the above wave forms shown in fig 5.5 and 5.6, the value of line voltage during the fault without using STATCOM is 0.7587 p.u. And the value of line voltage during the fault with D-STATCOM is 1.0116 p.u. Hence with D-STATCOM the voltage has been improved by 0.2529 p.u when compared to the voltage without using D-STATCOM. Here, X-axis represents the time in seconds and Y-axis represents the line voltage in voltage p.u.

5.4 Single Line to Ground Fault Condition

In this case single line to ground fault was considered. The fault was created for the duration of 0.1 to 0.25 seconds and the fault resistance and ground resistance are 0.66 ohm and 0.001ohm respectively. The output waveform for the line voltage without and with using D-STATCOM are shown in fig 5.7 and fig 5.8 respectively.

From the below wave forms shown in fig 5.7 and 5.8, the value of line voltage during the fault without using D-STATCOM is 0.8259 p.u. And the value of line voltage during the fault with D-STATCOM is o.9837 p.u. Hence with D-STATCOM the voltage has been improved by 0.1578 p.u when compared to the voltage without using D-STATCOM. Here, X-axis represents the time in seconds and Y-axis represents the line voltage in voltage p.u.

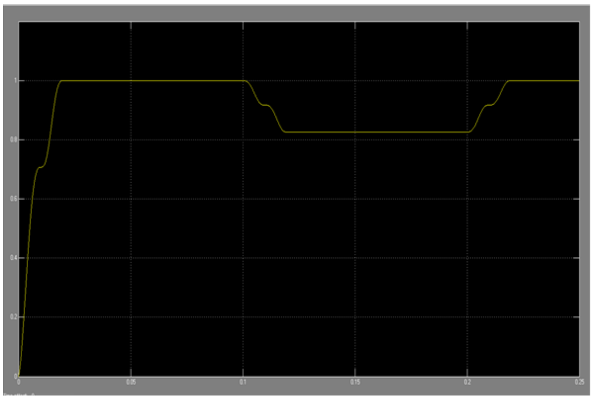

Fig 5.7 SLG fault without D-STATCOM

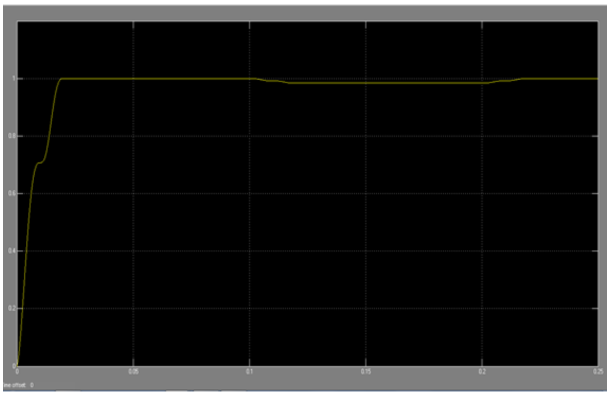

Fig 5.8 SLG fault with D-STATCOM

Table 5.1 Results of voltage sags for different types of fault with and without using D- STATCOM.

Fault resistance R_f in ohms		0.66	0.76	0.86
Voltage sags for TPG fault (P U)	Without D-STATCOM	0.66	0.7107	0.7515
	With D-STATCOM	0.9367	0.945	0.9858
Voltage sags for DLG fault (P U)	Without D-STATCOM	0.707	0.7487	0.7833
	With D-STATCOM	0.98	0.9806	0.9858
Voltage sags for LL fault (P U)	Without D-STATCOM	0.7587	0.7918	0.821
	With D-STATCOM	1.0168	1.0142	1.0152
Voltage sags for SLG fault (P U)	Without D-STATCOM	0.8259	0.8486	0.8659
	With D-STATCOM	0.9837	0.9817	0.9863

Table 5.1 shows the overall results of voltage sags in p.u for different types of fault without and with considering the D-STATCOM. It can be observed that voltage sags improved with insertion of D-STATCOM when compared to without DSTACOM. The value of voltage sags are between 0.9 to 1.02 p.u.

Table 5.2 Results for different types of fault before and after insertion d-statcom when R_f = 0.66 Ω

Types of fault	Without D-STATCOM line voltage in (p.u)	With D-STATCOM line voltage in (p.u)	Percentage of improvement (%)
TPG	0.6600	0.9367	27.67
DLG	0.7070	0.9800	27.30
LL	0.7587	1.0168	25.81
SLG	0.8259	0.9837	15.78

Table 5.2 shows the percentage improvement in line voltage for different fault conditions with and without using D-STATCOM. From the table 5.2 it can be seen that by using D-STATCOM the voltage sags has improved in a better way and the voltage sags are close to 1.0 p.u.

Figure 5.9 shows the input current harmonic spectrum with respect to the IEEE STD 519-1992 harmonic limits.

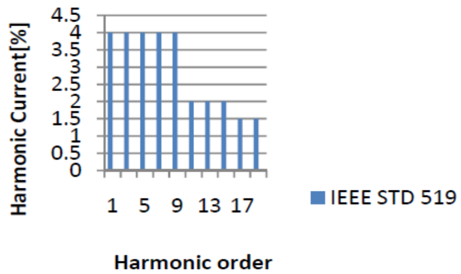

Fig 5.9 EEE STD 519-1992 of Current Harmonic Spectrum

5.5 D-STATCOM without LCL Passive Filter

In this case D-STATCOM without LCL Passive Filter was considered. The fault was created for the duration of 0 to 0.25 seconds and the fault resistance and ground resistance are 0.66 ohm and 0.001ohm respectively. The output waveform of the current distortion and harmonic spectrum of distortion output current for D-STATCOM without LCL Passive Filter are shown in fig 5.10 and fig 5.11 respectively.

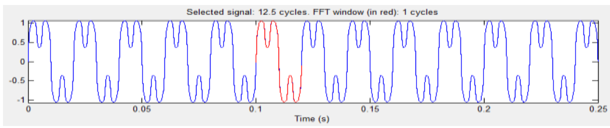

Fig 5.10 Waveform of distortion output current without LCL Passive Filter

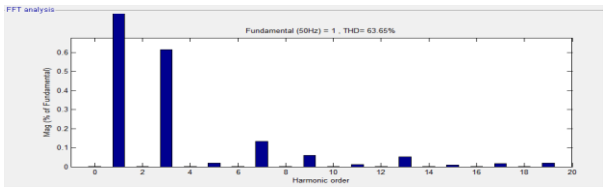

Fig 5.11 Harmonic spectrum of distortion output current without LCL Passive Filter

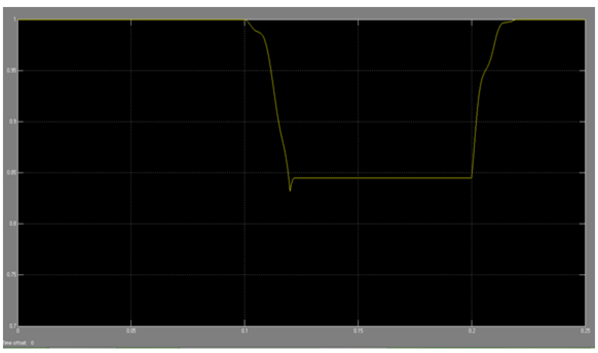

Fig 5.12 Power factor of the system without LCL Passive Filter

Table 5.3 Results of THD and power factors for different types of fault conditions without using LCL passive filter

Factors considered	Harmonic distortion of TPG fault in %	Harmonic distortion of DLG fault in %	Harmonic distortion of LL fault in %	Harmonic distortion of SLG fault in %
THD	63.65	88.66	44.51	48.28
Power Factor	84	75	92	90.05

Table 5.3 shows the percentage values of THD and power factor results obtained from the simulation, before using LCL passive filter with D-STATCOM. From the table we can see that the THD values obtained from the simulation results are not within the range of IEEE-STD 519-1992.

5.6 D-STATCOM with LCL Passive Filter

In this case D-STATCOM with LCL Passive Filter was considered. The fault was created for the duration of 0 to 0.25 seconds and the fault resistance and ground resistance are 0.66 ohm and 0.001ohm respectively. The output waveform of the current distortion and harmonic spectrum of distortion output current for D-STATCOM with LCL Passive Filter are shown in fig 5.13 and fig 5.14 respectively.

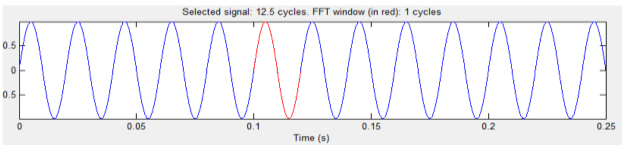

Fig 5.13 Waveform of distortion output current without LCL Passive Filter

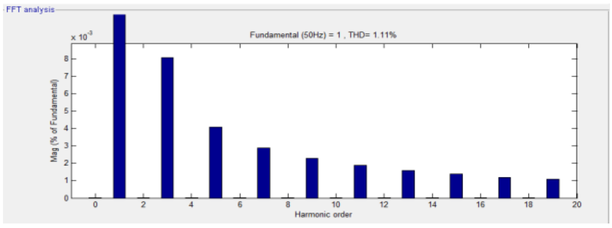

Fig 5.14 Harmonic spectrum of distortion output current with LCL Passive Filter

From the fig 5.14 it can be seen that the percentage value of Total Harmonic Distortion (THD) has been reduced compared to the previous case. Now the value of THD (1.1%) obtained from the simulation result is within the IEEE STD 519-1992. According to IEEE STD 519-1992 the value of the THD should be below 5%.

Fig 5.15 represents the power factor of the system with STATCOM & LCL passive filter. From fig it can be seen that the value of power factor is 0.99, compare this value with case without passive filter the power factor has been improved considerably.

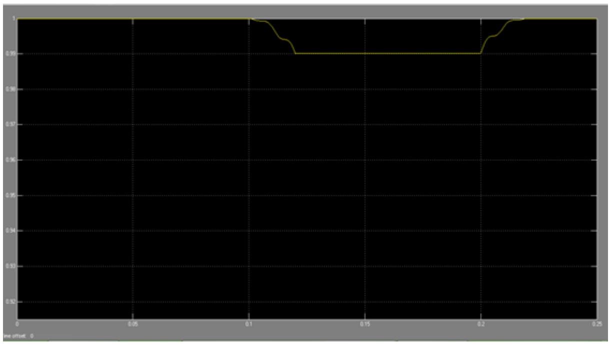

Fig 5.15 power factor of the system with LCL Passive Filter

Table 5.4 Results of THD and power factors for different types of fault conditions with LCL passive filter

Factors	Harmonic distortion of TPG fault in %	Harmonic distortion of DLG fault in %	Harmonic distortion of LL fault in %	Harmonic distortion of SLG fault in %
THD	1.11	1.12	0.65	1.15
Power Factor	99	99	99	99

Table 5.4 shows the percentage values of THD and power factor results obtained from the simulation, after using LCL passive filter with D-STATCOM. From the table 5.4 we can see that the THD values obtained from the simulation results are within the range of IEEE-STD 519-1992. And also we can see the better improvement in power factor.

Conclusion

DSTATCOM Simulink model has been designed for the test system and analyzed the simulation results for different types of faults before and after the insertion of DSTATCOM. The simulation results show the improvement in line voltage magnitude after using DSTACOM. And harmonics are also eliminated by using LCL filter with the DSTATCOM. The value of THD (1.11%) obtained from the simulation result is within the IEEE STD 519-1992, after using D-STATCOM with LCL filter. And power factor has also improved considerably. PI controller is used with the D-STATCOM to enhance its performance. By observing the above results we can conclude that the DSTATCOM can effectively improves the power quality in distribution networks.

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