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Enhancement of Power Quality in Distribution System Using D-Statcom for Different Faults

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Abstract: ***The main aim of the paper is to improve the voltage sags, harmonic distortion using Distribution Static Compensator (D-STATCOM) with LCL Passive Filter using PI and Fuzzy Controller in distribution system. The model is based on the Voltage Source Converter (VSC) principle. The D-STATCOM is one of the most efficient and modern custom device used in distribution networks The D-STATCOM injects current into the system to mitigate the voltage sags. LCL Passive Filter was then added to D-STATCOM to improve harmonic distortion and low power factor. The D-STATCOM has an additional capability to sustain reactive current at low voltage, and can be developed as a voltage and frequency support by replacing capacitors.***

Keywords: VSC, FACTS, DSTATCOM, FLC

1. Introduction

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. The 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 occur. 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. 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.

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

2. D-STATCOM (Distribution Static Compensator)

A D-STATCOM (Distribution Static Compensator), which is schematically depicted in Figure, consists of a two-level Voltage Source Converter (VSC), a dc energy storage device, a coupling transformer connected in shunt to the distribution network through a coupling transformer. The VSC converts the dc voltage across the storage device into a set of three-phase ac output voltages. These voltages are in phase and coupled with the ac system through the reactance of the coupling transformer. Suitable adjustment of the phase and magnitude of the D-STATCOM output voltages allows effective control of active and reactive power exchanges between the D-STATCOM and the ac system. Such configuration allows the device to absorb or generate controllable active and reactive power.

The VSC connected in shunt with the ac system provides a multifunctional topology which can be used for up to three quite distinct purposes:
1) Voltage regulation and compensation of reactive power;
2) Correction of power factor; and
3) Elimination of current harmonics.

Here, such device is employed to provide continuous voltage regulation using an indirectly controlled converter.

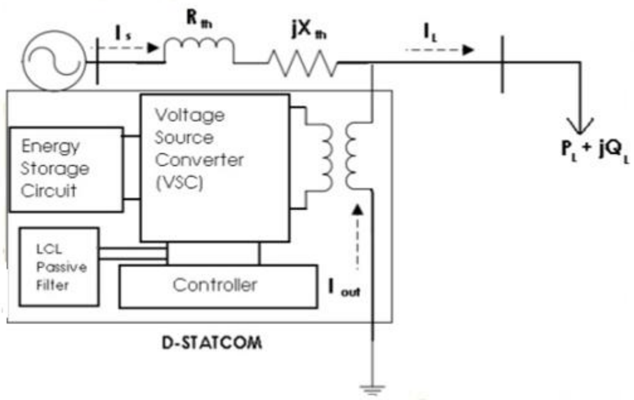

Figure 2.1: Schematic Representation of D-STATCOM

Figure-2.1 the shunt injected current I_{sh} corrects the voltage sag by adjusting the voltage drop across the system impedance Z_{th}. The value of I_{sh} can be controlled by adjusting the output voltage of the converter.

The shunt injected current I_{sh} can be written as,

$$I_{out} = I_L - I_s = I_L - \frac{V_{th} - V_L}{Z_{th}}$$

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

The complex power injection of the D-STATCOM can be expressed as,

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

It may be mentioned that the effectiveness of the D-STATCOM in correcting voltage sag depends on the value of Z_{th} or fault level of the load bus. When the shunt injected current I_{sh} is kept in quadrature with V_L, the desired voltage correction can be achieved without injecting any active power into the system. On the other hand, when the value of I_{sh} is minimized, the same voltage correction can be achieved with minimum apparent power injection into the system. The control scheme for the D-STATCOM follows the same principle as for DVR. The switching frequency is set at 475Hz.

A. Voltage Source Converters (VSC)

A voltage-source converter is a power electronic device that connected in shunt or parallel to the system. It can generate a sinusoidal voltage with any required magnitude, frequency and phase angle. The VSC used to either completely replace the voltage or to inject the „missing voltage". The „missing voltage" is the difference between the nominal voltage and the actual. It also converts the DC voltage across storage devices into a set of three phase AC output voltages. In addition, D-STATCOM is also capable to generate or absorbs reactive power. If the output voltage of the VSC is greater than AC bus terminal voltages, D-STATCOM is said to be in capacitive mode. So, it will compensate the reactive power through AC system and regulates missing voltages. These voltages are in phase and coupled with the AC system through the reactance of coupling transformers. Suitable adjustment of the phase and magnitude of the DSTATCOM output voltages allows effectives control of active and reactive power exchanges between D-STATCOM and AC system. In addition, the converter is normally based on some kind of energy storage, which will supply the converter with a DC voltage.

B. Controller

Figure 2.2 shows the block diagram of Controller system. The controller system is partially part of distribution system.

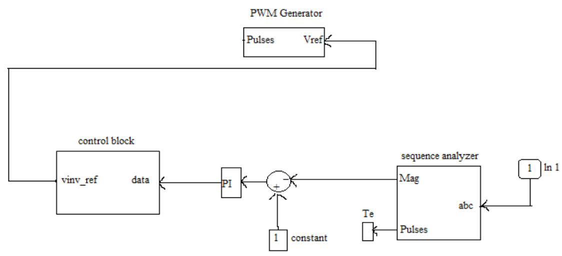

Figure 2.2: Block Diagram of Controller System

1. PI Controller

A proportional control system is a type of linear feedback control system. A proportional-integral (PI) controller drives the plant to be controlled with a weighted sum of the error (difference between the actual sensed output and desired set-point) and the integral of that value. An advantage of a proportional plus integral controller is that its integral term causes the steady-state error to be zero for a step input. The proportional and integral terms is given by:

$$u(t) = K_p e(t) + K_i \int e(t)\, dt$$

Kp and Ki are the tuning knobs, are adjusted to obtain the desired output.

2. Fuzzy Logic Controller

The Fuzzy Logic Controller (FLC) is used as controller in the proposed model. It offers to a soft computing partnership the important concept of computing with words. It provides a technique to deal with imprecision and information granularity. The fuzzy theory provides a mechanism for representing linguistic constructs such as "many", "low","medium","often","few".In fuzzy logic, basic control is determined by a set of linguistic rules which are determined by the system. Since numerical variables are converted into linguistic variables, mathematical modeling of the system is not required. The fuzzy logic control is being proposed for controlling the inverter action. FLC is a new addition to control theory and it incorporates a simple, rule based IF X AND Y THEN Z approach to a solving control problem rather than attempting to model a system mathematically

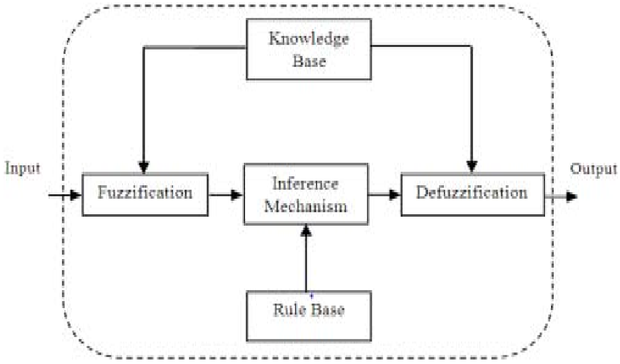

Figure 2.3: Block diagram of proposed control system.

C. Energy Storage Circuit

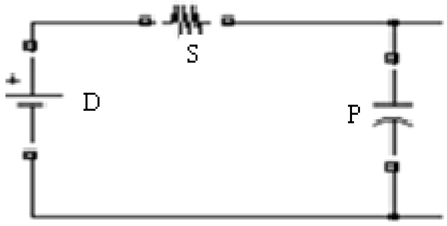

Figure 2.4: Circuit Diagram of DC Storage

DC source is connected in parallel with the DC capacitor. It carries the input ripple current of the converter and it is the main reactive energy storage element. This DC capacitor could be charged by a battery source or could be recharged by the converter itself.

D. LCL Passive Filter

LCL Passive filter is more effective on reducing harmonic distortion. To design it, equation (2.3), (2.4) and (2.5) are used.

$$L_g = \frac{E_n}{2\sqrt{6}\, i_{ripm} f_{sw}} \qquad (2.3)$$

$$L_c = \frac{L_g}{2} \qquad (2.4)$$

$$C_f = \frac{L + L_g}{L L_g (2\pi f_{res})^2} \qquad (2.5)$$

To design an efficient LCL Passive filters make sure that 10, $f_n \leq f_{res} \leq 0.5 f_{sw}$

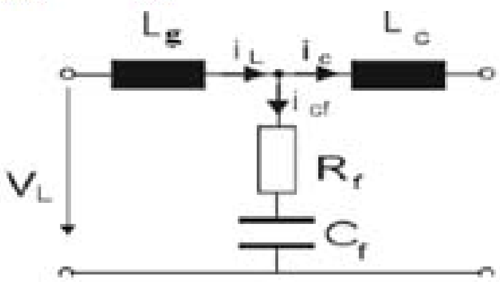

Figure 2.5: Circuit diagram for single phase LCL Passive Filter

3. Methodology

To enhance the performance of distribution system, DSTATCOM was connected to the distribution system. DSTATCOM was designed using MATLAB simulink version R2007b. Figure 3.1 below shows the flowchart for the methodology:

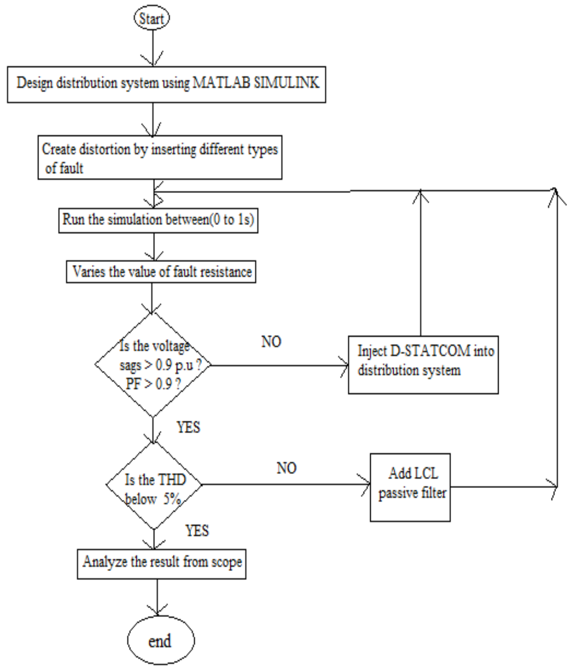

Figure 3.1: Flow chart for the Methodology

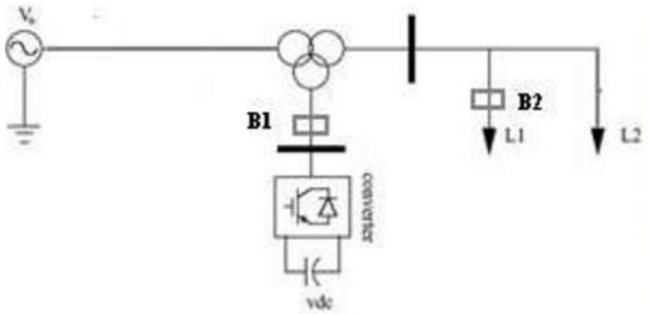

Figure 3.2: Single line diagram of the test system

The test system shown in figure 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.

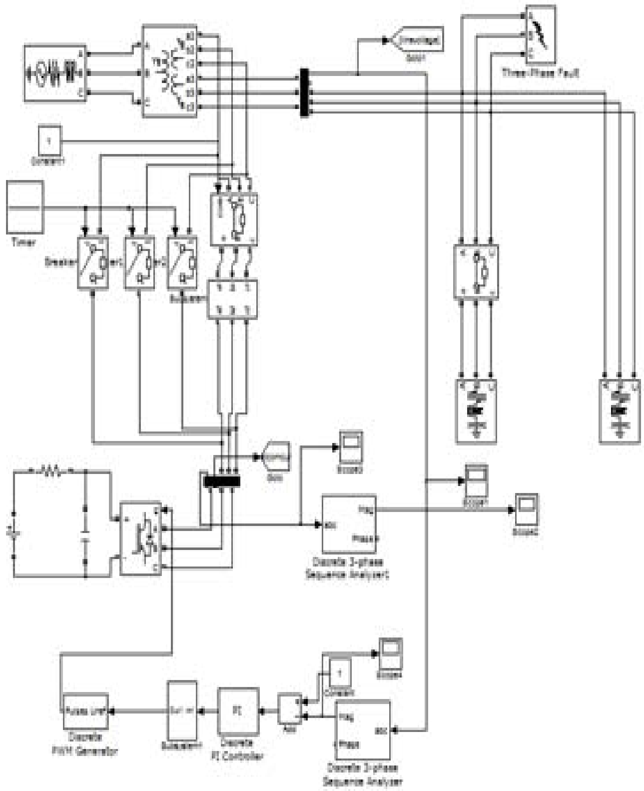

Figure 3.3: Diagram of the test system.

Table 3.1: List and value of parameters used in simulation

Symbol	Name	Quantity Value
En	RMS value of grid voltage	19kV(rms)
Iripm	15% of peak value fundamental harmonic current	793.1mA(rms)
Lg	Gride-side filter inductance	1630mH
Lc	Converter-side filter inductance	815mH
Cf	Filter capacitance	0.0017uF
Rf	Resistance of Converter-side filter	15Ω
Fsw	Switching frequency	20kHz
Fres	Resonance frequency	5.25kHz

4. Results and Discussion

To create distortion in the distribution system, different types of fault such as Three Phase to Ground (TPG), Double Line to Ground (DLG), Line to Line (LL), and Single Line to Ground (SLG) are injected.

A. Without insertion of D-Statcom.

Table 4.1: Results of Voltage Sags for Different Types of Fault.

Fault Resistance R_f, Ω	Voltage sags for TPG fault (p.u)	Voltage sags for DLG fault (p.u)	Voltage sags for LL fault (p.u)	Voltage sags for SLG fault (p.u)
0.66	0.660	0.707	0.758	0.825
0.76	0.710	0.748	0.791	0.848
0.86	0.751	0.783	0.821	0.867

Table 4.1 shows the overall results of voltage sag for different types of faults without insertion of D-Statcom. From the above table it can observe that as the fault resistance increases, the voltage sags is also increased for different types of fault.

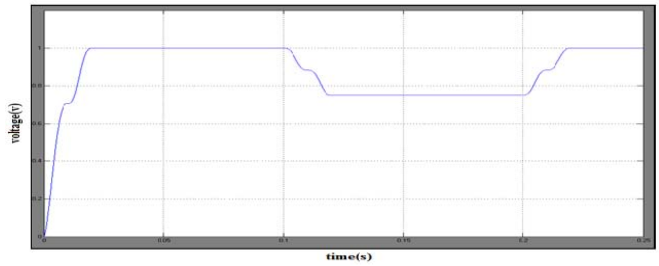

Figure 4.1(a): TPG voltage at load point is 0.751

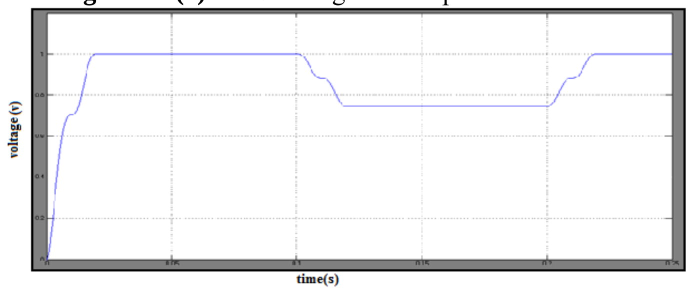

Figure 4.1(b): DLG voltage at load point is 0.748

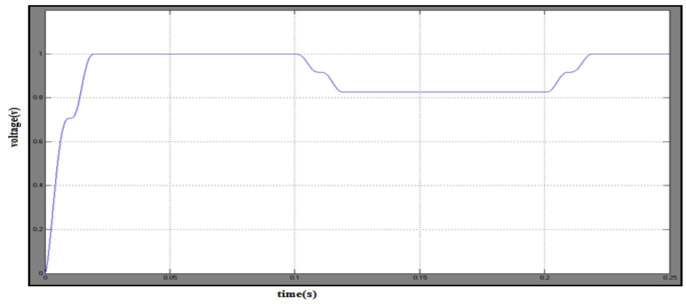

Figure 4.1(c): SLG voltage at load point is 0.825

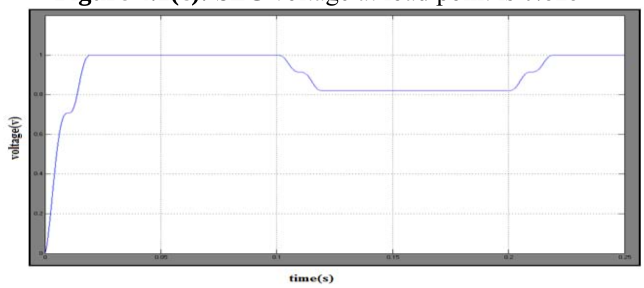

Figure 4.1(d): LL voltage at load point is 0.821

B. With Insertion of D-Statcom With PI Controller.

Table 4.2: Results Of Voltage Sags for Different Types of Fault.

Fault Resistance R_f, Ω	Voltage sags for TPG fault (p.u)	Voltage sags for DLG fault (p.u)	Voltage sags for LL fault (p.u)	Voltage sags for SLG fault (p.u)
0.66	0.936	0.980	1.01	0.983
0.76	0.945	0.980	1.014	0.981
0.86	0.954	0.985	1.015	0.986

Table 4.2 shows the overall results of voltage sag for different types of faults with insertion of D-Statcom with PI controller. From the above table it can observe that as the fault resistance increases, the voltage sags is also increased for different types of fault.

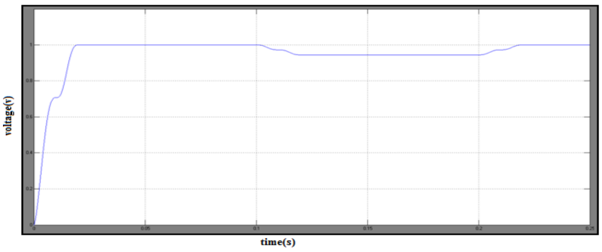

Figure 4.2(a): TPG voltage at load point is 0.945

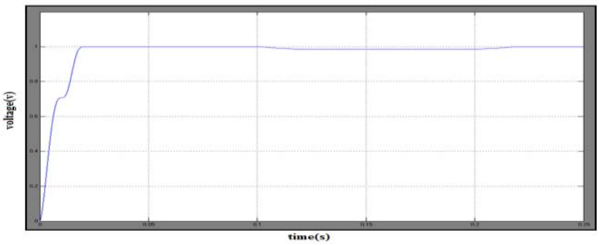

Figure 4.2(b): DLG voltage at load point is 0.985 p.u

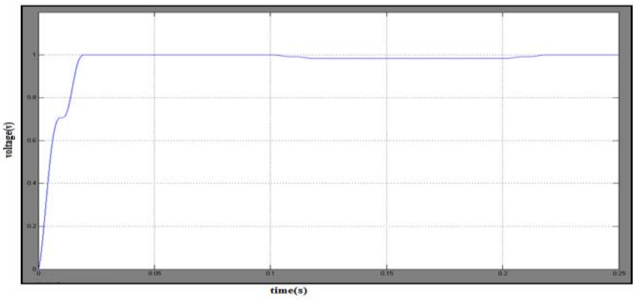

Figure 4.2(c): SLG voltage at load point is 0.983 p.u

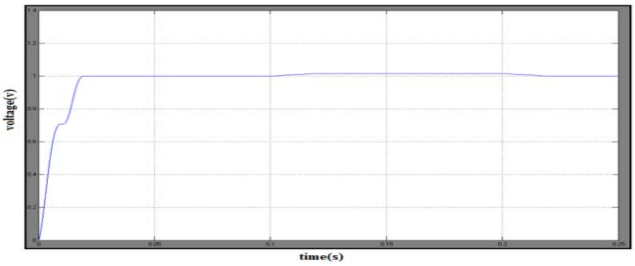

Figure 4.2(d): LL voltage at load point is 0.015 p.u

C. With Insertion of D-Statcom with Fuzzy Controller.

Table 4.3: Results of Voltage Sags for Different Types of Fault

Fault Resistance R_f, Ω	Voltage sags for TPG fault (p.u)	Voltage sags for DLG fault (p.u)	Voltage sags for LL fault (p.u)	Voltage sags for SLG fault (p.u)
0.66	0.945	0.99	1.00	0.991
0.76	0.952	0.991	1.05	0.995
0.86	0.998	0.995	1.13	1.003

Table 4.3 shows the overall results of voltage sag for different types of faults with insertion of D-Statcom with Fuzzy controller. From the above table it can observe that as the fault resistance increases, the voltage sags is also increased for different types of fault.

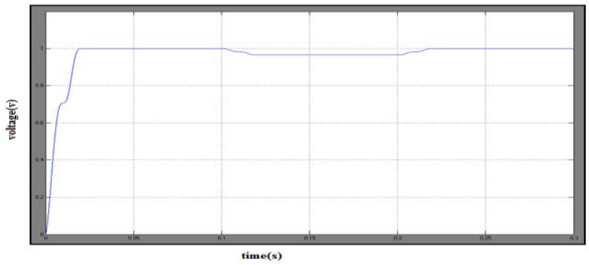

Figure 4.3(a): TPG voltage at load point is 0.914 p.u

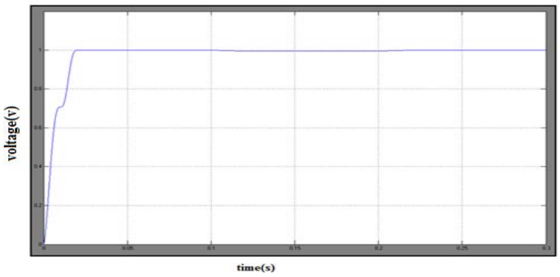

Figure 4.3(b): DLG voltage at load point is 0.995 p.u

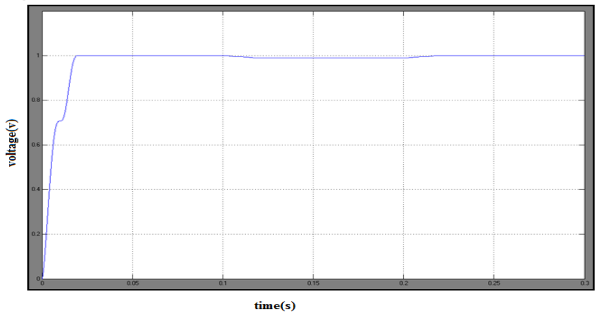

Figure 4.3(c): SLG voltage at load point is 0.997 p.u

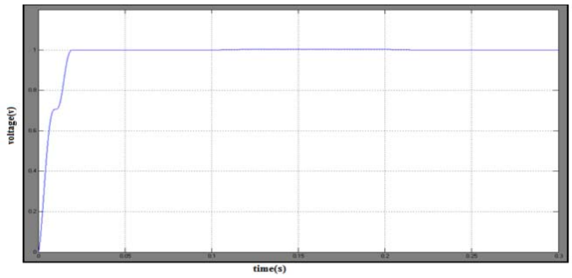

Figure 4.3(d): LL voltage at load point is 1.001 p.u

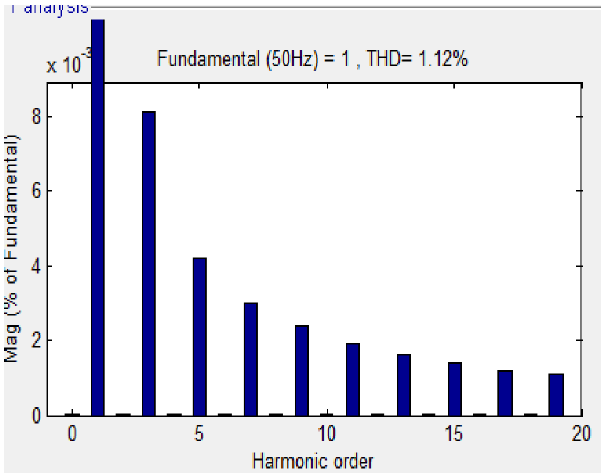

Figure 4.4: Harmonic spectrum of distortion output current with LCL passive filter with PI Controller.

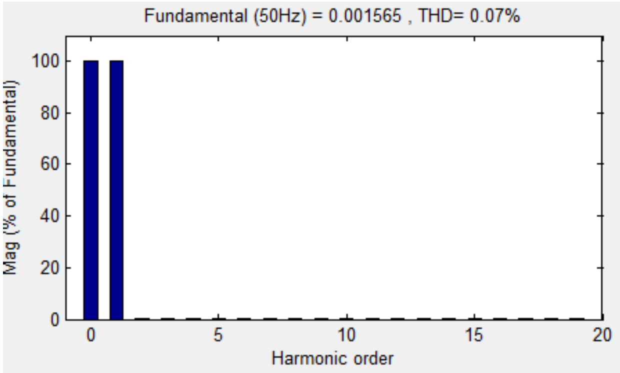

Figure 4.5: Harmonic spectrum of distortion output current with LCL passive filter with Fuzzy Controller.

5. Conclusions

The simulation results show that the voltage sags can be mitigate by inserting D-STATCOM to the distribution system. The simulation used in MATLAB software shows that by using fuzzy controller, performance of D-STsATCOM is more satisfactory than the PI controller. By adding LCL passive filter to D-STATCOM, also % THD reduced within the IEEE STD 519-1992. Thus, it can be concluded that by adding D-STATCOM with LCL filter the power quality is improved and also Fuzzy Controller is more adequate than PI controller.

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