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Power Quality Improvement and Reactive Power Compensation in a Grid Connected System for Non-Linear Loads Using DSTATCOM

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Abstract - Power systems that are conceived to operate at the fundamental frequency (50 or 60 Hz) are more susceptible to erroneous behaviour as more and more non-linear loads are connected to the system. Large fluctuating loads like electric arc furnace, steel rolling mills, electric traction and some non-linear loads like rectifiers, inverters, fax machines, printers, PLCs, refrigerators, TVs, CFLs distort the voltage and current waveform and affect the performance of the grid voltage and currents as well as PCC (Point of Common Coupling) that causes poor power quality and harmonic distortion in power. Due to deteriorate the quality of power, other customers which are connected to the same pcc also experiences the poor quality of power so whole system gets affected by these non-linear loads. D-STATCOM solves these problems more efficiently and reliably. Many application of D-STATCOM is in the power systems at the distribution level. It compensates the reactive power, improves power factor, enhances voltage regulation and compensate at fault condition. Here in my paper the main concern is harmonic distortion due to non-linear loads and mitigation of current harmonics using D-STATCOM and compensation of reactive power for load and maintains the grid reactive power near to zero using MATLAB/SIMULATION.

Keywords:D-STATCOM (Distributed Static Synchronous Compensator); Non-linear loads; PI Controller; Hysteresis Current Control; Harmonic Distortion.

I .Introduction

STATCOM [1, 2] and D-STATCOM have similar strategies but objective of these two are different and covers the different area of objective. When STATCOM is connected to the distribution side then it is called D-STATCOM. DSTATCOM has the additional advantage in the power systems. It has its own applications viz. to improve power factor, to improve voltage regulation, to maintain three-phase balanced voltage and compensate at the fault condition. DSTATCOM is a shunt connected power electronic device which used self-commutated device like IGBT, IGCT etc. Voltage source converter (VSC) is the main part of the STATCOM. It injects the compensated or harmonic component of the current to cancel out the other harmonic frequency component (other than power frequency). So it acts as an active power filter [3]. 2

Power Quality

Power quality deals with maintaining a pure sinusoidal waveform of voltage and frequency. Voltage quality concern with deviation of voltage from ideal voltage (sinusoidal) it is a single frequency sine wave at rated magnitude and frequency with no harmonics. Current quality is a complimentary term of voltage quality concern with a deviation from the ideal current. Current should be in phase with the voltage. According to IEEE standard 1100, "power quality is the concept of powering and

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grounding sensitive equipment in a manner that is suitable to the operation of that equipment".

Power quality problems

There are so many problems related with quality of power. Here the main concern with the poor power quality with nonlinear loads. Non-linear loads can cause voltage and current distortion. That is it changes its shape other than sinusoidal.

Harmonic Distortion

Harmonic components are those waveforms which have the frequency as an integer multiple of the fundamental. Any periodic waveform which is non-sinusoidal can be divided into fundamental and non fundamental components. Every nth harmonic will have a frequency n times that of fundamental frequency [3].

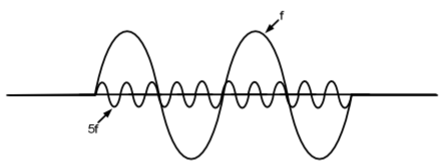

Figure 1: Fundamental component and 5th Harmonic component

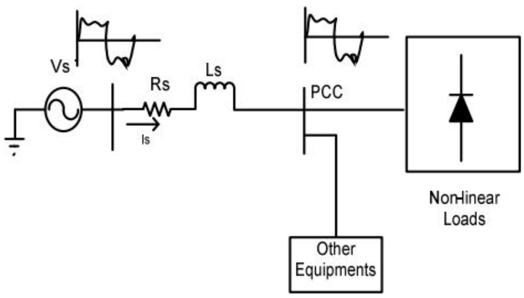

Figure 2: Power system with non linear Loads

Voltage at point of common coupling-

$$V_{pcc} = V_s - L_{s1}\left(\frac{di_s}{dt}\right) \quad (1)$$

$$i_s = i_{s1} + \Sigma i_{sh} \quad (2)$$

$$V_{pcc} = \left(V_{sh} - L_{s1}\left(\frac{di_{s1}}{dt}\right)\right) - \left(L_{s1} - \left(\frac{di_{sh}}{dt}\right)\right) \quad (3)$$

$$V_{pcc} = V_{pcc1} - V_{pcc(distortion)} \quad (4)$$

Where

$$V_{pcc1} = \left(V_{sh} - L_{s1}\left(\frac{di_{s1}}{dt}\right)\right)$$

$$V_{pcc(distortion)} = \left(L_{s1} - \left(\frac{di_{sh}}{dt}\right)\right)$$

Non-linear loads draw reactive power. So input power factor is also get poor. Line current and Total Harmonic Distortion (THD) –

$$v_s = \sqrt{2}V_s \sin \omega t \quad (5)$$

$$i_s = \sqrt{2}I_{s1} \sin(\omega_1 t - \phi_1) + \Sigma\sqrt{2}I_{sh} \sin(\omega_n t - \phi_h) \quad (6)$$

$$i_s = i_{s1}(t) + \Sigma i_{sh}(t) \quad (7)$$

$$I_s = (I_{s1}^2 + \Sigma i_{sh}^2) \quad (8)$$

If we remove fundamental, then only ripple will be left

$$i_{distortion} = (i_s^2 - i_{s1}^2)^{\frac{1}{2}} = (\Sigma i_{sh}^2)^{\frac{1}{2}} \quad (9)$$

$$\%THD = I_{distortion} * \frac{100}{I_{sh}} \quad (10)$$

$$\%THD = \sqrt{I_s^2 - I_{s1}^2} * \frac{100}{I_{s1}} \quad (11)$$

II .Principle of D-STATCOM

It is shunt connected at the distribution side of the power systems. A D-STATCOM 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 D-STATCOM are based on the exact equivalence of the conventional rotating synchronous compensator [5]. 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 Figure 3. The DC side of the converter is connected to capacitor, which carries the input ripple current of the converter and reactive energy storage element. This capacitor could be charged by voltage source or inverter. When AC output voltage of inverter is equal to terminal voltage, then there is no reactive power exchange. It there difference between these voltages the only reactive power exchange occurs. The control strategies studied in this paper are applied with a view to studying the performance of a D-STATCOM for reactive power compensation and harmonic mitigation.

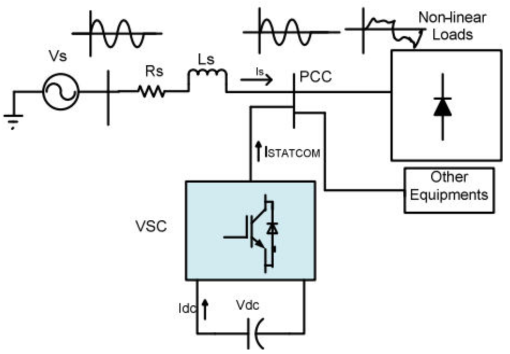

Figure 3: Power system with D-STATCOM

Configuration and operation of D-STATCOM

D-STATCOM has 3-phase voltage source converter, capacitor at DC side of inverter is connected with the electrical system at the PCC. The instantaneous controllable 3-phase output voltage is generated from DC voltage at fundamental frequency. The pulse is generated by the hysteresis current controller which takes the difference of reference current and actual source current and minimise the error and controls the current and generate 3-phase output voltage and injects capacitive or inductive current according to the nature of load [4]

Mathematical Expression for system [3]

Total instantaneous power delivery drawn by non-linear load-

$P_L(\mathbf{t}) = P_{st}(t)+P_r(t)+P_{sh}(t)$ (12)

Real power supplied by source-

$P_s=P_{s1}$ (13)

Reactive power supplied by source-

$Q_s=0$ (14)

Real power drawn by the load-

$P_L=P_{s1}+P_{sh}$(16)

Reactive power drawn by the load-

$Q_L=Q_{s1}+Q_{sh}$(17)

Real power supplied by the D-STATCOM-

$P_{STATCOM}=P_{sh}-P_{loss}$ (18)

Reactive power supplied by D-STATCOM-

$Q_{STATCOM}=Q_{s1}+Q_{sh}$ (19)

Where P_{loss} loss component of STATCOM-

From the single line diagram Figure 2

$i_s(t)=i_l(t)+i_{STATCOM}(t)$ (20)

When the phase of $V_{STATCOM}$ is in quadrature with $i_{STATCOM}$without injecting real power the D-STATCOM can achieve the voltage sag mitigation. The shunt injecting current$i_{STATCOM}$and $V_L$in Figure 3 can be expressed as equation (21 and 22)

$$I_{STATCOM} = I_L - I_s = I_L - \left(\frac{V_{th}-V_L}{Z_{th}}\right) \quad (21)$$

$$V_L = V_{th} + (I_{STATCOM} - I_L)Z_{th} \quad (22)$$

$$I_s = (V_{th} - V_L)/Z_{th}$$

III. Control strategy

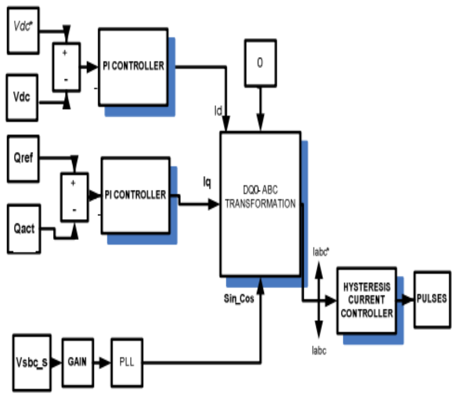

Figure 4: Control strategy to generate pulses

The direct and quadrature axis component of current are:

$$I_d = \left(K_p + \frac{Ki}{s}\right) * (V_{DC}^* - V_{DC}) \quad (23)$$

$$I_q = \left(K_p + \frac{Ki}{s}\right) * (Q_{grid}^* - Q_{grid}) \quad (24)$$

d-q-0 to a-b-c transformation

$$x_{abc} = K^{-1}x_{dq0}$$

$$= \sqrt{\frac{2}{3}} * \begin{bmatrix} \cos(\theta) & -\sin(\theta) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta - \frac{2\pi}{3}\right) & -\sin\left(\theta - \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \\ \cos\left(\theta + \frac{2\pi}{3}\right) & -\sin\left(\theta + \frac{2\pi}{3}\right) & \frac{1}{\sqrt{2}} \end{bmatrix} \begin{bmatrix} x_d \\ x_q \\ x_0 \end{bmatrix} \quad (25)$$

Hysteresis Current Controller

In conventional hysteresis band (HB) current control, the switching signal is sent to the IGBT at the same arm (T1 and T4). The output of the HBC is directly connected to the transistor T1 and reverse is connected to the T4, therefore the transistor in the same leg is not simultaneously ON or OFF. IGBT are self commutated. Hysteresis Current Controller compares the actual and reference current and generates pulses for the inverter [5, 6]

If
$$i \le (i^* - HB), \text{ then T1 in ON} \quad (26)$$
If
$$i \ge (i^* + HB), \text{ then T4 is ON} \quad (27)$$

IV .Mathematical modeling

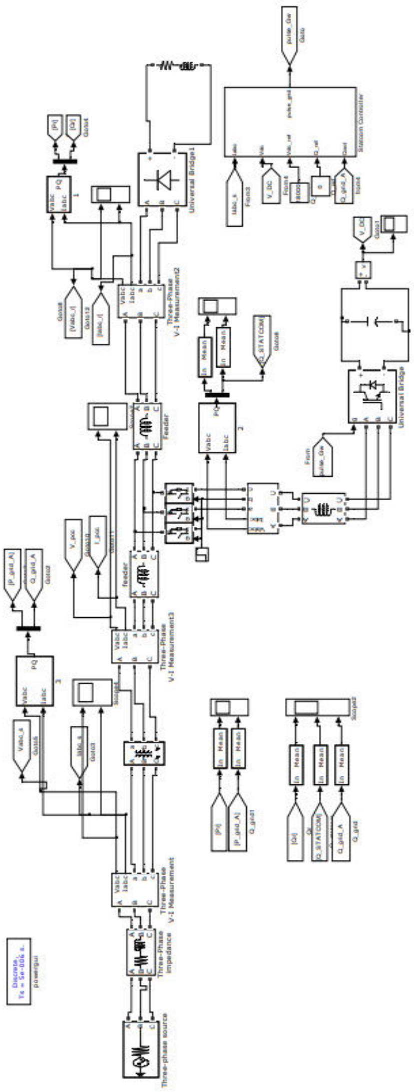

Figure 5:SIMULATION MODEL

System parameter	Symbol	Values
Source voltage	Vs	230 kV L-L
Distribution side voltage	Vr	11 kV L-L
System frequency	f	50 Hz
Line Thevenin equivalent resistance	Rth	0.01 ohm
Line Thevenin equivalent reactance	Xth	0.5 mH
Source resistance	Rs	0.01 ohm
Source reactance	Ls	0
Feeder 1 reactance	Lf1	1.5 mH
Feeder 2 reactance	Lf2	7 mH
Non-linear load parameter	R, L	50 ohm, 100mH
Source reference reactive power	Qref	zero

Table 1: SYSTEM parameter

Parameters	Symbol	Value
DC link voltage	Vdc	18 kV
Capacitance	Cdc	2200e-6 F
Filter reactance	Lf	1.5mH
PI parameter for DC voltage	Kp, Ki	0.05, 5
PI parameter for reactive power	KP, Ki	0.5, 1

Table 2: STATCOM parameter

V .Results and discussion

The D-STATCOM is connected to the system after 0.1 seconds. Before 0.1 seconds the DC link voltage is decreasing. After the D-STATCOM is connected to the system PI controller minimizes the error between actual and reference DC voltage and maintains the DC link voltage constant which injects reactive current to the power systems and compensated for the reactive power to the load. Figure 6 shows DC link voltage. In Figure 7 the first graph shows the reactive power demanded by load this load reactive power is decreased after connecting D-STATCOM. Second graph shows reactive power supplied by D-STATCOM to the load. D-STATCOM generates the sufficient reactive power for the power system which was generated by Grid before connecting the DSTATCOM. So after 0.1 seconds the Grid is

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supplied nearly zero reactive power i.e. grid actual reactive power is equal to grid reactive power.

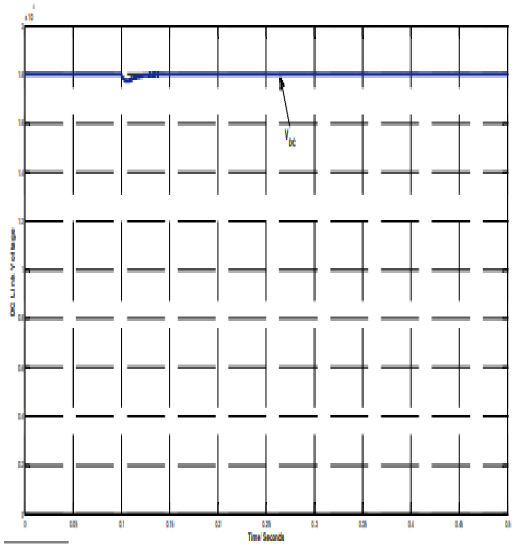

Figure 6: DC link voltage

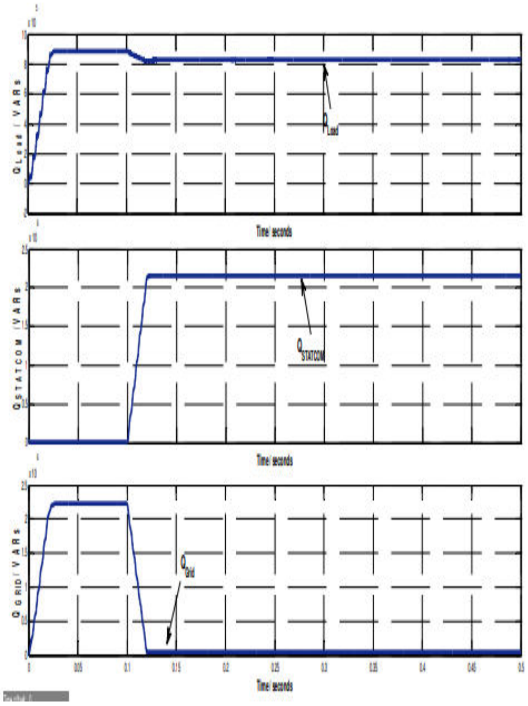

Figure 7: (1) Reactive power demanded by load, (2) Reactive power supplied by D-STATCOM, (3) Reactive power generated by Grid

Figure 8 shows the reference grid current which is pure sinusoidal. The actual current follows the path of reference current and exactly in phase with reference current shown in Figure 9. The source current is distorted due to non linear load so D-STATCOM injects harmonic current to make source purely sinusoidal. STATCOM injects only these harmonics which are presented in the grid current. Figure 10 shows the load voltage and current waveforms which are distorted.

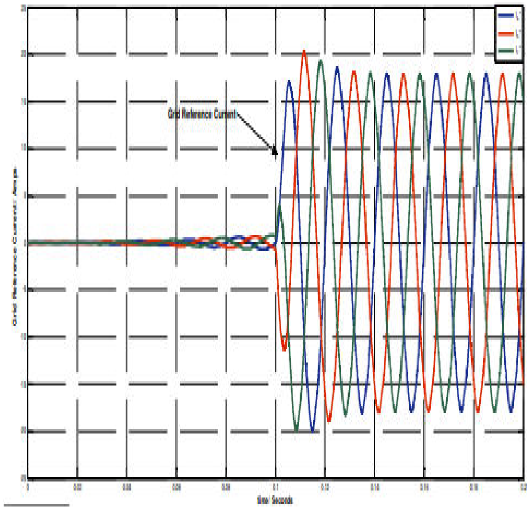

Figure 8: Grid reference current

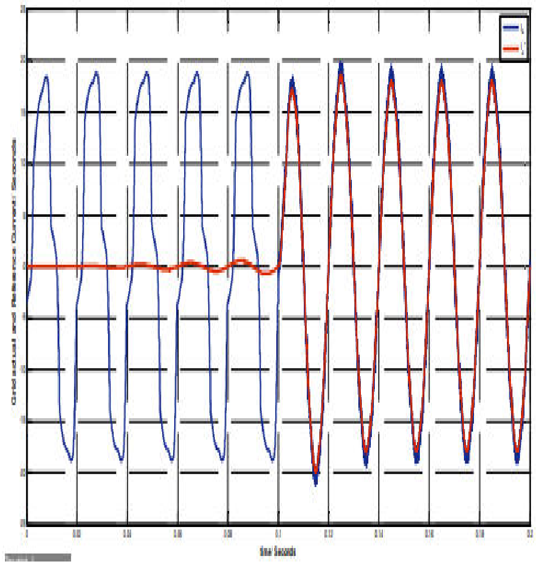

Figure 9: Grid phase and reference currents

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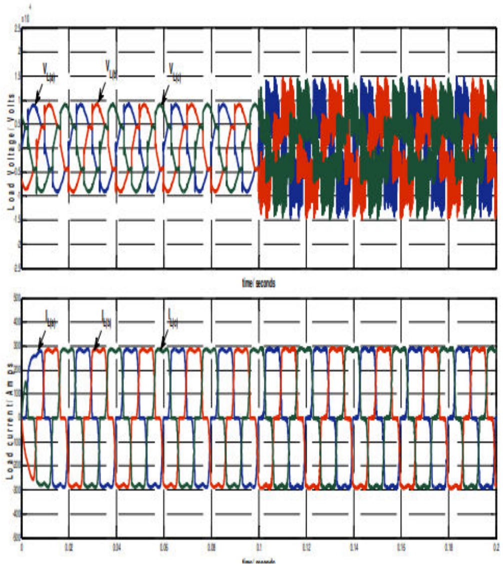

Figure 10: Load voltage waveform, (2) Load current waveform

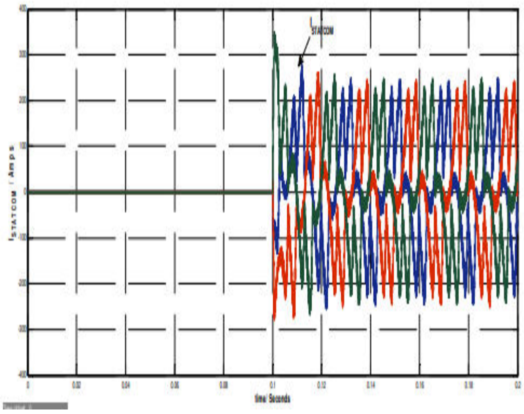

Figure 11: D-STATCOM injected harmonic current

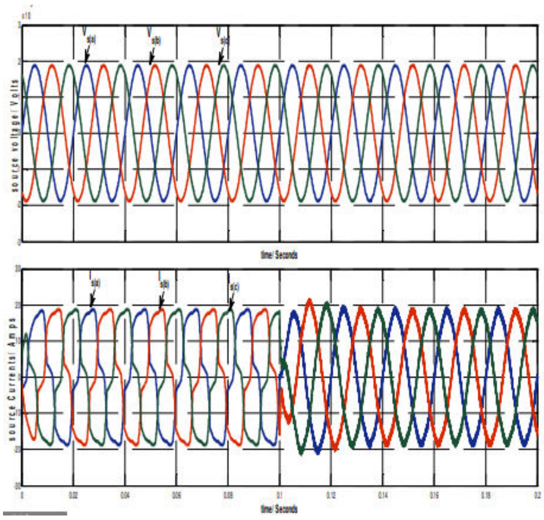

Figure 12: (1) source voltage, (2) source current

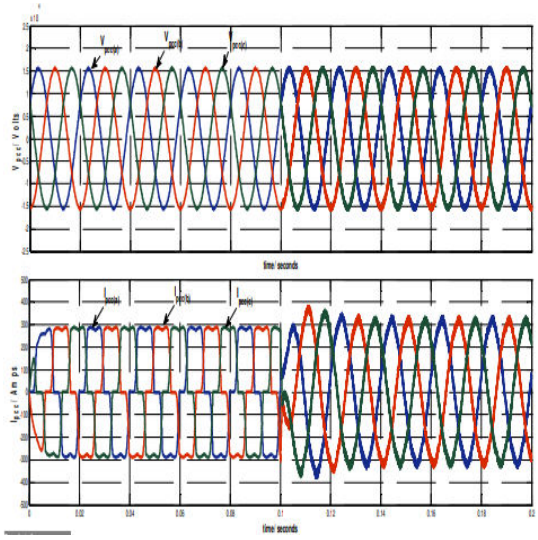

Figure 13: PCC voltage , (2) PCC current

THD Analysis	*Without D-STATCOM*	*With D-STATCOM*
PCC current % THD	21.42 %	3.19 %
Source current % THD	16.32 %	2.62 %

Table 3: Result comparison

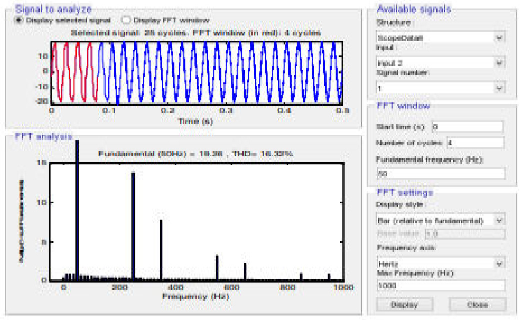

Figure 14: THD in source current without D-STATCOM

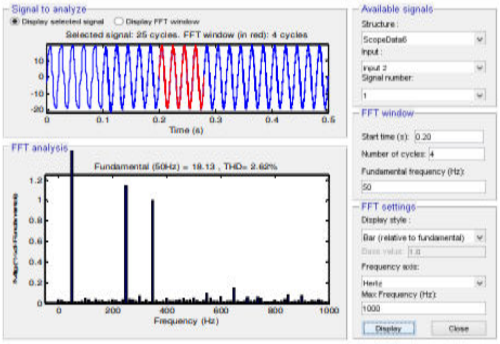

Figure 15: THD in source current with D-STATCOM

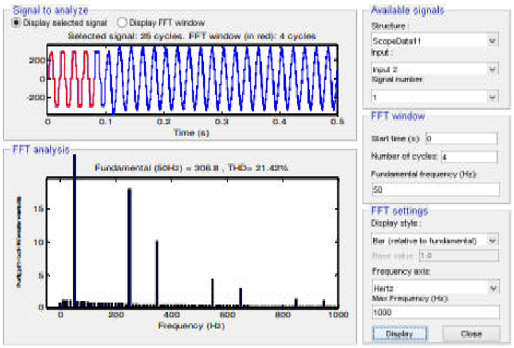

Figure 16: THD in PCC current without D-STATCOM

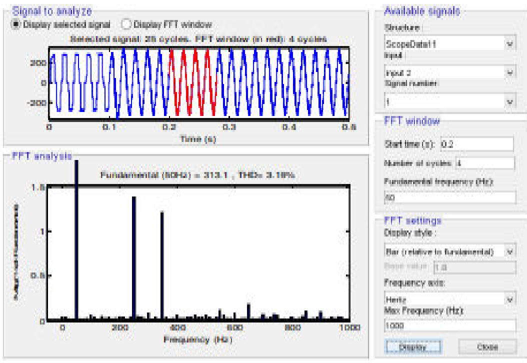

Figure 17: THD in PCC current with D-STATCOM

THD is less than 5% in source and pcc current waveform when system is connected with D-STATCOM which is under IEEE standard. 10

VI .Conclusion

The model is designed and analysed its performance on the basis of reactive power compensation and power quality improvement. In this model, PI controlling technique is best fit.

VII.Acknowledgement

First of all, I am grateful to the personnel at the Department of Electrical Engineering, National Institute of Technology Srinagar. I would like to express my heartfelt gratitude to my friend Neeraj who helped me and support me. And finally I would like to thank my mother, my brothers for their constant support and word of wisdom and belief that kept me driven and focused throughout.

VIII .References

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control scheme utilized to improve power quality of Wind Generation System connected to grid", International Journal of Innovative Research in Advanced Engineering, Volume 1, Issue 6, (2014).
0 0.1 0.2 0.3 0.4 0.5 -20 -10 0 10 Selected signal: 25 cycles. FFT window (in red): 4 cycles Time (s) 0 200 400 600 800 1000 0 0.2 0.4 0.6 0.8 1 1.2 Frequency (Hz) Fundamental (50Hz) = 18.13 , THD= 2.62% Mag (% of Fundamental) 0 0.1 0.2 0.3 0.4 0.5 -200 0 200 Selected signal: 25 cycles. FFT window (in red): 4 cycles Time (s) 0 200 400 600 800 1000 0 5 10 15 Frequency (Hz) Fundamental (50Hz) = 306.8 , THD= 21.42% Mag (% of Fundamental) 0 0.1 0.2 0.3 0.4 0.5 -200 0 200 Selected signal: 25 cycles. FFT window (in red): 4 cycles Time (s) 0 200 400 600 800 1000 0 0.5 1 1.5 Frequency (Hz) Fundamental (50Hz) = 313.1 , THD= 3.19% Mag (% of Fundamental)