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Comparative Analysis of Grid Power Quality using DVR, DSTATcom, Open UPQC and SVC Light In Grid Wind Energy System

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ABSTRACT: Wind power injection into an electric grid affects power quality due to fluctuating nature of wind. The power arising out of the wind turbine connected to grid concerning power quality measurements are active power, reactive power, voltage sag, voltage swell, flicker and harmonics. Dynamic Voltage Restorer (DVR) is a series compensator that can compensate power quality problems for instance voltage harmonics, voltage sags, voltage swells, voltage flickers, voltage unbalance. Distribution Static Compensator (DSTATCOM) is a shunt compensator that can compensate power quality problems like harmonics in current, reactive current, unbalancing of current and so on. SVC Light is a flicker mitigating device that attacks the root of the problem, i.e., the erratic flow of reactive power through the supply grid to the furnace. It does this by measuring the reactive power consumption and generating a corresponding amount for injection into the system, thereby reducing the net reactive power flow to an absolute minimum. As an immediate consequence, voltage flicker is also minimized. Unified Power Quality Conditioner (UPQC) is a device that consists of series and shunt converters which are in back to back connection and deals with the defects of supply voltage and load current. Open UPQC consists of DVR and DSTATCOM without common DC link. The key objective of this paper is to build up models of DVR, DSTATCOM, SVC Light and OPEN-UPQC for development of power quality under a variety of operating conditions. An open UPQC to compensate for high power load consisting of non linear load is used. It is then simulated to lessen voltage sag/swells and harmonic currents. In order to examine the performance of compensators such as series, shunt and combination of series-shunt the traditional dq-theory is used with PI controller. The open UPQC separates the utility from problems in current quality of load and simultaneously separates the load from problems in voltage quality of utility. The THD of DVR, DSTATCOM, SVC light and Open UPQC are compared in this paper for a 3-phase wind connected distribution network with nonlinear load using Matlab Simulink in power system block set.

Keywords: DSTATCOM, DVR, Power quality, SVC LIGHT, OPEN UPQC

I. INTRODUCTION

The main purpose of a utility system is to deliver electric power in sinusoidal form, currents with proper magnitudes and frequency to the customers at the point of common coupling (PCC). Even though the voltage generated by synchronous machines are nearly sinusoidal in power plants, a few unsighted conditions like lightning and short circuit faults, also non linear loads account steady state error or else transient current and voltage disturbances. For example, electric arc furnaces results in voltage fluctuations whereas harmonics in current and distort voltage waveforms are generated by power electronic converters, and short circuits faults cause voltage sags/swells [1-4]. Alternatively the majority of customer loads like computers, microcontrollers, hospital equipment etc are sensitive to power quality conflicts and their appropriate operation is dependent on the supplied voltage quality.

This is achievable only if the continuous power flow is ensured at proper levels of voltage and frequency. Thus FACTS devices and Custom power devices came into existence in electrical system to enhance the quality of the electrical power by reducing the problems associated with power quality. The different types of Custom Power devices are Active Power Filters (APF), Battery Energy Storage Systems (BESS), Surge Arresters (SA), Static Electronic Tap Changers (SETC), Super conducting Magnetic Energy Systems (SMES), Solid State Fault Current Limiter (SSFCL), Static VAR Compensator (SVC), Solid-State Transfer Switches (SSTS), Distribution Series Capacitors (DSC), Distribution Static synchronous Compensators

(DSTATCOM) Dynamic Voltage Restorer (DVR), Uninterruptible Power Supplies (UPS) , and Unified power quality conditioner (UPQC). The main focus of this paper is on DVR, DSTATCOM ,OPEN UPQC and SVC light..

Wind Energy Generating System

Wind generations are based on constant speed topologies with pitch control turbine. The induction generator is used in the proposed scheme because of its simplicity, it does not require a separate field circuit, it can accept constant and variable loads, and has natural protection against short circuit. The available power of wind energy system is presented as under in (2.1).

$$P_{wind} = \frac{1}{2}\rho A V_{wind}^{3} \tag{2.1}$$

where ρ(kg/m^3) is the air density and A (m^2) is the area swept out by turbine blade, V_{wind} is the wind speed in m/s. It is not possible to extract all kinetic energy of wind, thus it extract a fraction of power in wind, called power coefficient *Cp* of the wind turbine, and is given in (2.2).

$$P_{mech} = C_p P_{wind} \tag{2.2}$$

where *Cp* is the power coefficient, depends on type and operating condition of wind turbine. This coefficient can be expressed as a function of tip speed ratio λ and pitch angle θ. The mechanical power produce by wind turbine is given in (2.3)

$$P_{mech} = \frac{1}{2}\rho\pi R^2 V_{wind}^{3} C_p \tag{2.3}$$

where R is the radius of the blade (m).

II. POWER QUALITY PROBLEMS

Power quality has various meanings to different people. According to the IEEE Std. 1100, the power quality is defined as "*Power quality is the concept of powering and grounding sensitive equipment in a matter that is suitable to the operation of that equipment*." The most commonly occurring power quality problems are current harmonics, voltage sags and voltage swells as shown in Figure-2.1. Altogether they comprise high proportion of the power quality disorders affecting the most commercial and industrial customers.

2.1. Voltage Sag

Voltage sag is considered as a decrease in rms voltage between 0.1 and 0.9 per unit (pu) at the power frequency for the durations from 0.5 cycle to 1 min. The term sag is described as decrease in voltage. The occurrence of voltage sags is generally by system faults but the energization of heavy loads, overloaded wiring and starting of large motors can also cause voltage sag.

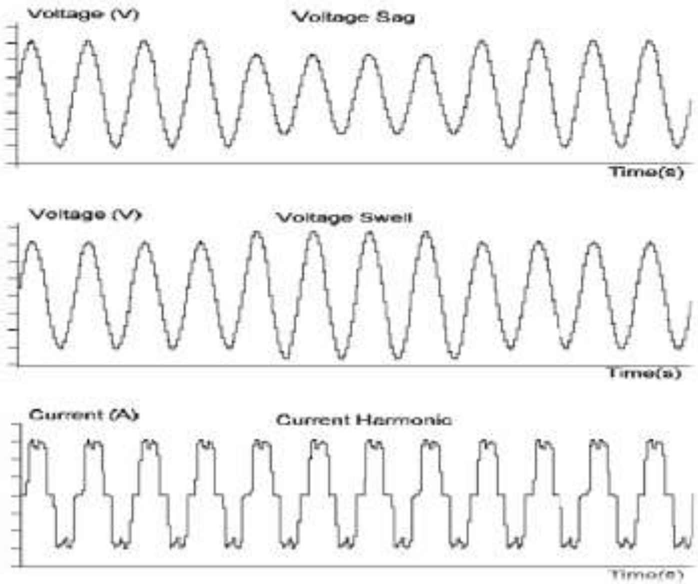

Figure-2.1 Most Common Types of Power Quality Problems

2.2. Voltage Swells

A voltage swell is defined as an enhance in rms voltage or current between 1.1 and 1.8 pu at the power frequency for the durations from 0.5 cycle to 1 min. Voltage swells are generally connected with system error conditions, however they do not occur as frequent as voltage sags. The voltage swell can be caused by energizing a large capacitor bank, sudden load reduction, switching off a large load, open neutral connection and insulation breakdown. Voltage swells show negative effect on the performance of sensitive electronic equipment causing data errors, equipment shutdowns, and equipment damage and may lessen equipment life. It causes annoyance tripping and deprivation of electrical contacts.

2.3. Current Harmonic Distortion

The harmonic voltage distortion and harmonic current distortion are robustly linked with each other since harmonic voltage distortion is mostly due to non-sinusoidal load currents whereas current harmonic distortion needs over-rating of series components such as transformers and cables. Distorted current causes more losses compared to a sinusoidal current with the same rms value because of the increase in the series resistance with frequency. The equipment that causes current harmonics is switched mode power supplies, single-phase loads, small Uninterruptible Power Supply (UPS) units, electronic fluorescent lighting ballasts and variable speed drives. The following are the problems caused by current harmonics such as overloading of neutrals, circuit breakers nuisance tripping, overheating of transformers, over-stressing of capacitors used for power factor correction and skin effect. The calculation of total harmonic distortion (THD) describes the harmonic distortion levels that measure the complete harmonic spectrum of every individual harmonic component with magnitudes and phase angles. THD is described as the square-root of sum of squares of each individual harmonic. The following is the Voltage THD

$$V_{THD} = \frac{\sqrt{\sum_{n=2}^{\infty} V_n^2}}{V1}$$

where $V1$ represents the rms magnitude of the fundamental component and V_n is the rms magnitude of component n, where n = 2,3,.....,∞

2.4. Voltage Fluctuations / Flickers

Voltage fluctuations/flickers are relatively small (less than 5 percent) changes in the rms line voltage. The main contributors of these changes/variations are arc furnaces, cyclo converters and other systems. They draw current with no synchronization with the line frequency.

The voltage flicker results in an unnecessary pulsating torque because of the fluctuation in the speed of electric drives.

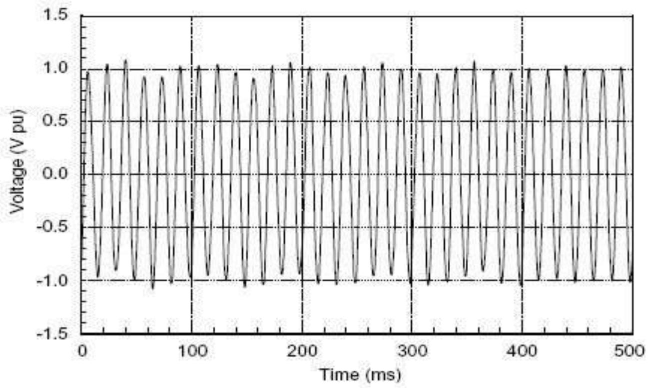

Figure-2.2.: Voltage Fluctuations or Flicker

III. CUSTOM POWER DEVICES

N.G.Hingorani [6] introduced the custom power concept that means the usage of power electronics controllers in distribution systems. The quality and also the reliability of the power delivered to the customers are increased by the custom power. There are two categories of custom power devices, network configuring type and compensating type.

The former type is used for current transferring, current limiting and current breaking. The later type is used for load balancing, active filtering, voltage regulation and power factor correction. The family of compensating devices includes DSTATCOM (Distribution Static compensator), DVR (Dynamic voltage restorer) and Unified power quality conditioner (UPQC).

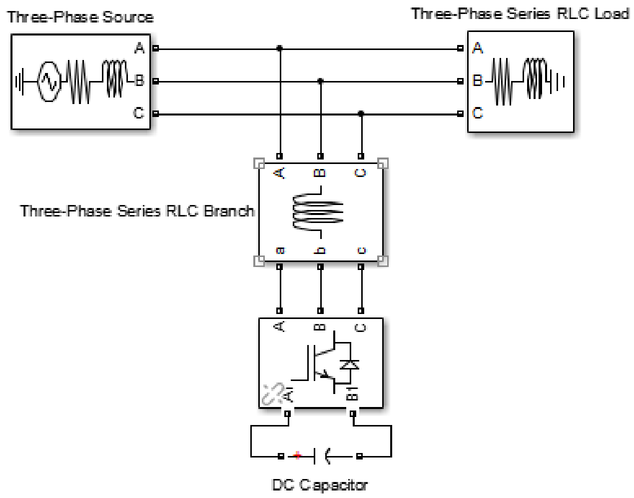

Figure-3.1: DSTATCOM

3.1. Distribution Statcom (DSTATCOM)

Fig. 2(3.1) shows the key components of a DSTATCOM. It comprises a dc capacitor, an ac filter, one or more inverter modules, a transformer that matches the output of the inverter to the line voltage and finally a PWM control strategy. The purpose of the DSTATCOM is to terminate load harmonics provided to the supply. DSTATCOM work as current sources and connected to the nonlinear load in parallel. It generates the harmonic currents required by the load and balances them besides providing the reactive power [6]. The current is injected by the DSTATCOM into the point of common coupling, to compensate unwanted components of the load current. The power factor and also unbalanced loads can be corrected through an appropriated control strategy. Shunt Active Power Filter in current control mode is also called as DSTATCOM.

3.2. Dynamic Voltage Restorer (DVR)

In order to compensate the voltage sags/swells at the load side, a voltage component is injected by DVR in series with the supply voltage which is shown in figure-3.2. The capability of active power transfer via dc link is implied by injecting voltage in arbitrary phase with regard to the load current. The sources for the supply of active power can be a diode bridge linked to the ac network, a shunt connected PWM converter and an energy storage device. DVR works as a harmonic isolator that prevents the harmonics in the source voltage additionally balancing and regulating the voltages.

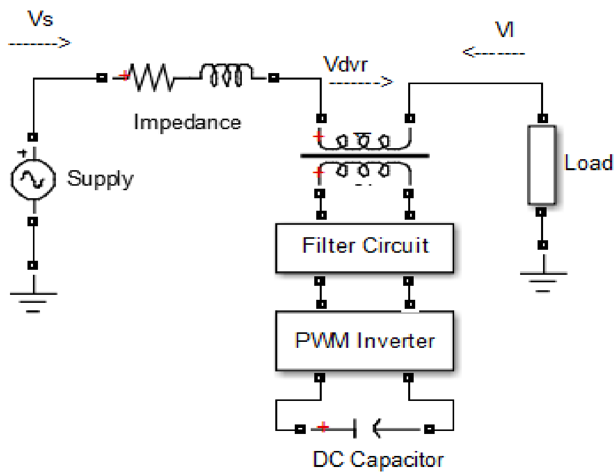

Figure-3.2: Dynamic Voltage Restorer

3.3 SVC Light

SVC Light is a flicker mitigating device that attacks the root of the problem, ie the erratic flow of reactive power through the supply grid to the furnace. It does this by measuring the reactive power consumption and generating a corresponding amount for injection into the system, thereby reducing the net reactive power

flow to an absolute minimum. As an immediate consequence, voltage flicker is also minimized. Important added benefits are a high and constant power factor, regardless of the load fluctuations over furnace cycles, as well as a high and stable bus rms voltage. These benefits translate into improved furnace productivity as well as lower operating costs due to lower specific electrode and energy consumption and reduced refractory wear.
To balance the rapidly fluctuating consumption of reactive power, an equally rapid compensating device is required.

3.4 Unified Power Quality Controller (UPQC)

Unified power quality conditioner (UPQC) is in shunt series connection and research efforts have been ended towards utilizing UPQC in solving nearly all power quality problems such as voltage sag, voltage outage, voltage swell, over correction of power factor and unacceptable levels of harmonics in the voltage and current. Figure-3.3 illustrates the configuration of UPQC. The main principle of UPQC is to compensate for supply voltage flicker/imbalance, reactive power, negative-sequence current, and harmonics . That is, the UPQC is capable of improving power quality at the installation point on power distribution systems or industrial power systems. Thus the UPQC, considered as one of the most powerful solutions for large capacity sensitive loads to voltage flicker/imbalance.

The UPQC comprises two three phase inverters which are connected in cascade that is inverter I is connected with the supply voltage in series via a transformer and inverter II is connected in parallel with the load. The shunt compensator mainly compensates for the reactive power that is demanded by the load, eliminates the harmonics and regulates the common dc link voltage. The operation of the series compensator is in PWM voltage controlled mode. The voltage is injected by it in quadrature advance to the supply voltage (current) in a way that the voltage at load end is maintained at the desired value at all times. The two inverters function in a coordinated manner.

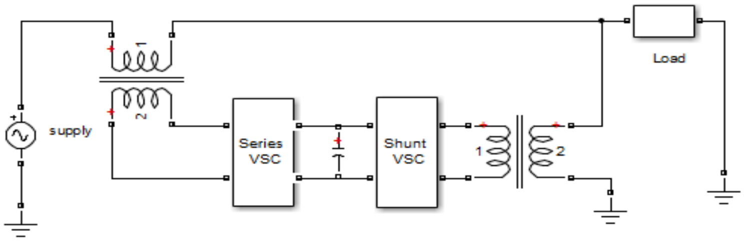

Figure-3.3: Unified Power Quality Controller

3.5. Superiority of UPQC over Other Devices

The custom power devices have their own benefits and limitations. Among various devices, UPQC is considered as one of the most powerful solutions to loads of large capacity which are sensitive to supply voltage and load current disturbances. It is more flexible than any single inverter based device. UPQC can correct the unbalance and distortion at the same time in both the source voltage and load current while all other devices either correct current or voltage distortion. Thus the function of two devices is served by UPQC alone.

IV. SIMULATION RESULTS

The simulations of the D-STATCOM, DVR ,Open UPQC and SVC Light for current harmonics, voltage harmonics and both current and voltage harmonics respectively are done in this work using Matlab.

i) DSTATCOM

DSTATCOM is used for the reduction of harmonics in source current.

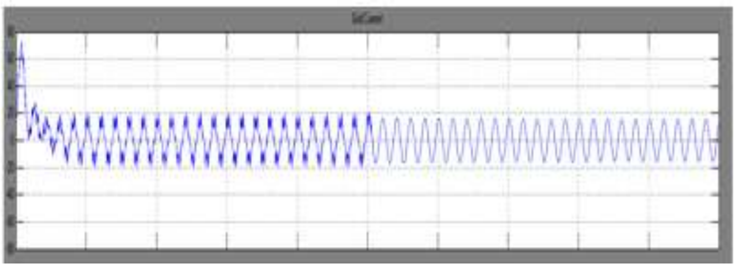

Fig 4.1 source current without and with compensation

Output waveform of the source current without compensation and with compensation is shown in Fig 4.1. In the figure the source without DSTATCOM is from 0 to 0.5 sec and after 0.5 sec the waveform with DSTATCOM is shown in which current harmonics is reduced.

Fig 4.2 shows the THD analysis of the current at the source side without compensation.

The THD analysis of the current at the source side after compensation is shown in fig 4.3. In this the THD is reduced from 28.31% to 0.49% as shown indicating the reduction in the current harmonics.

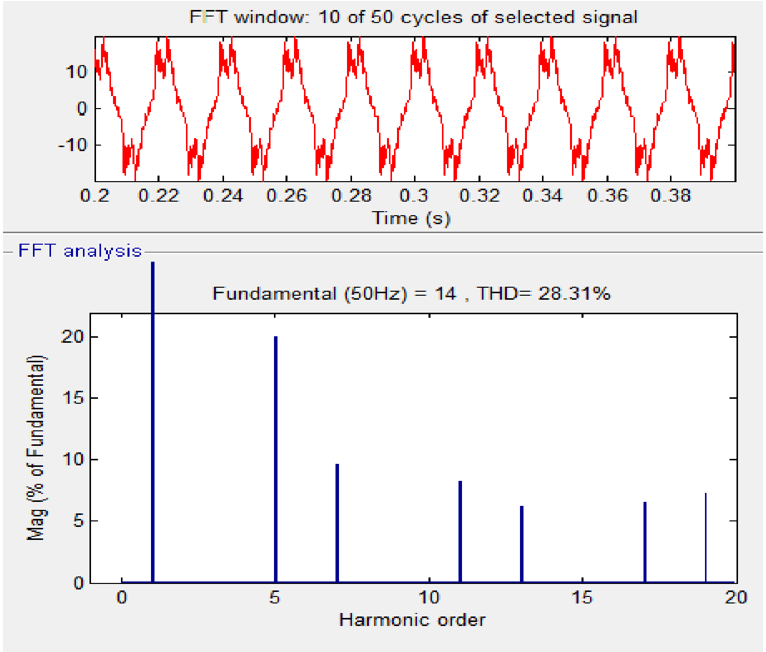

Fig 4.2 without compensation FFT analysis of source current

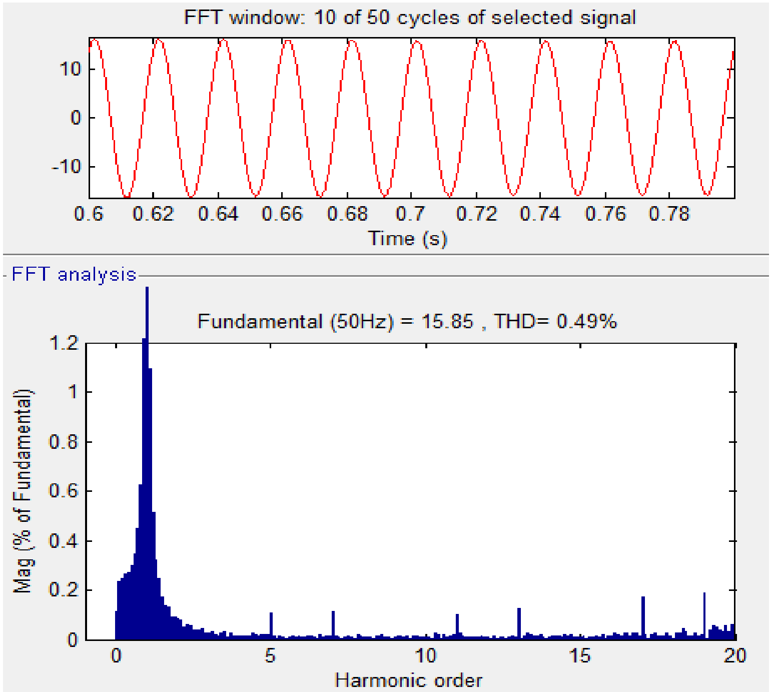

Fig 4.3 without compensation FFT analysis of source current

ii) DVR

The load voltage harmonics are reduced by using DVR.

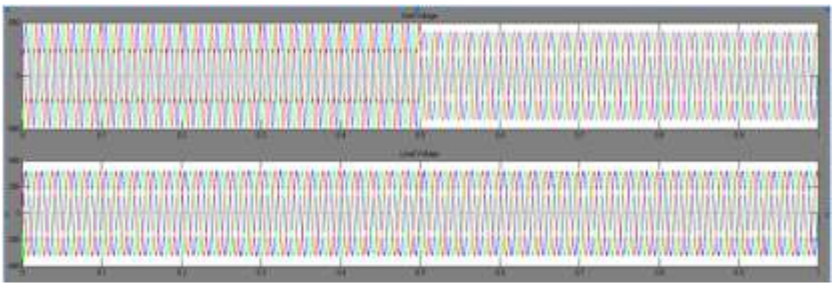

Fig 4.4 load voltage without and with compensation

In fig 4.4 the output waveform of the voltage at load side without and with compensation is shown. The figure shows the reduction in the voltage harmonics after 0.5 sec which is done by using DVR.

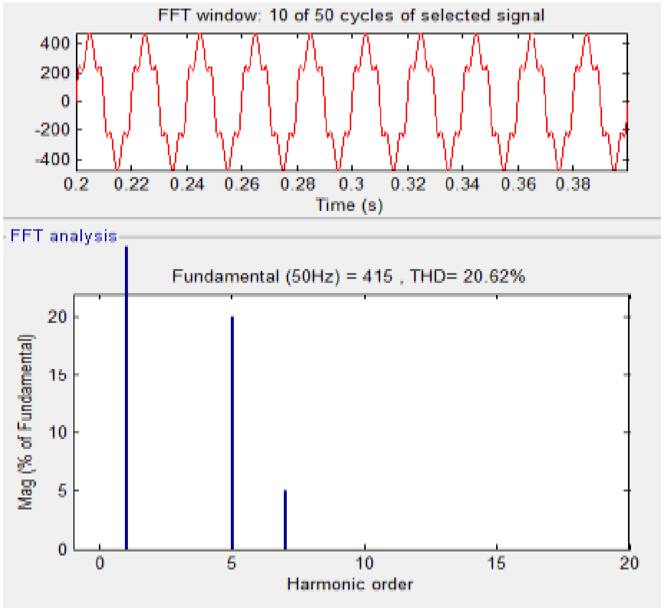

Fig 4.5 without compensation FFT analysis load voltage

Figures 4.5 and 4.6 shows the THD analysis of load voltage in which voltage harmonics are reduced from 20.62% (as in fig 4.5) to 1.99%.(as in fig 4.6)

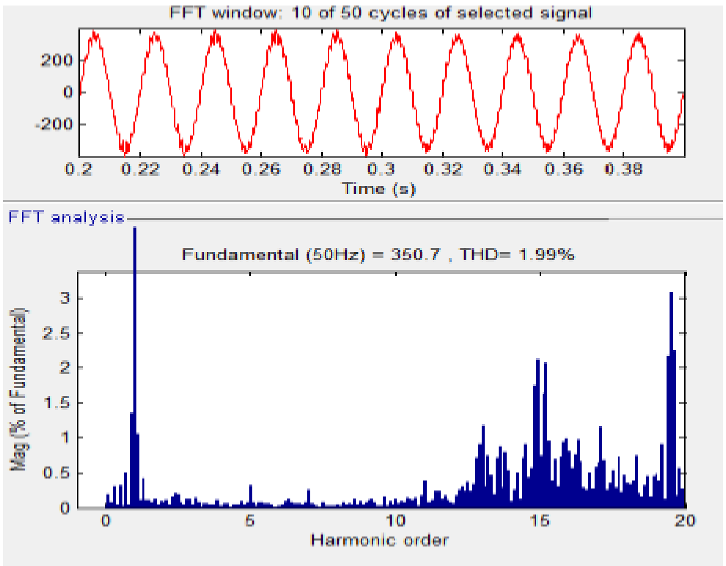

Fig 4.6 with compensation FFT analysis load voltage

iii) OPEN UPQC

Using OPEN UPQC both the current harmonics and voltage harmonics are reduced thus it is more preferable device compared to DVR and DSTATCOM.

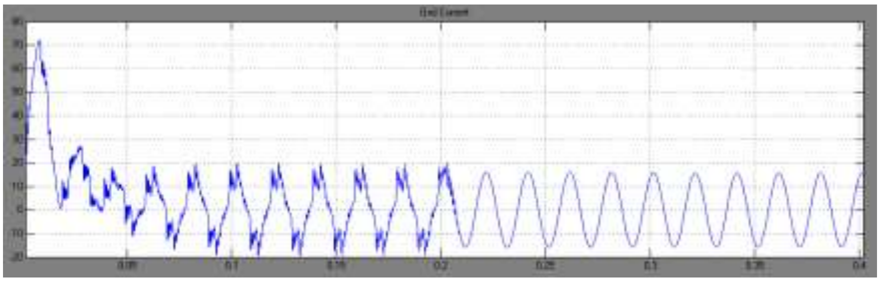

Fig 4.7 Source current without and with compensation

Fig 4.7 shows the waveform in which the current harmonics at source side without and with compensation is shown.

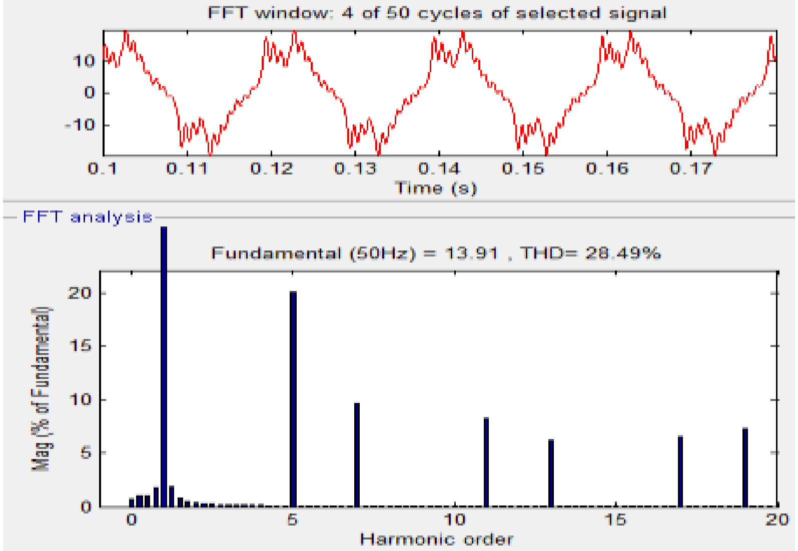

Fig 4.8 without compensation FFT analysis of source current

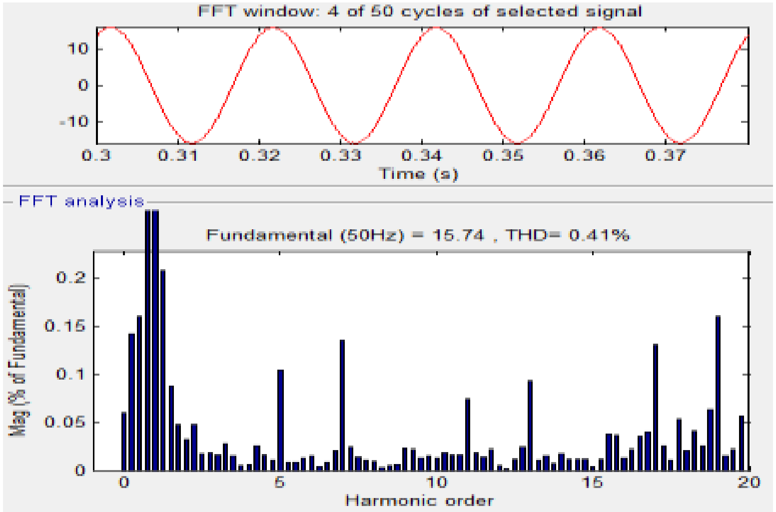

Fig 4.9 with compensation FFT analysis of source current

FIG 4.8 and FIG 4.9 shows the THD analysis in which the current harmonics is mitigated from 28.49% to 0.41%.

iv) SVC Light

The SVC light is similar to DSTATCOM which reduces the harmonics in source current.

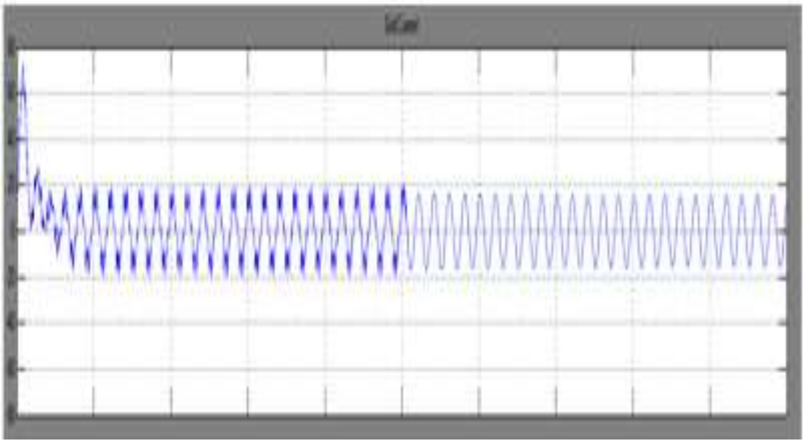

Fig 4.10 source current without and with compensation

The output waveform form fig 4.10 shows the source current without and with compensation.

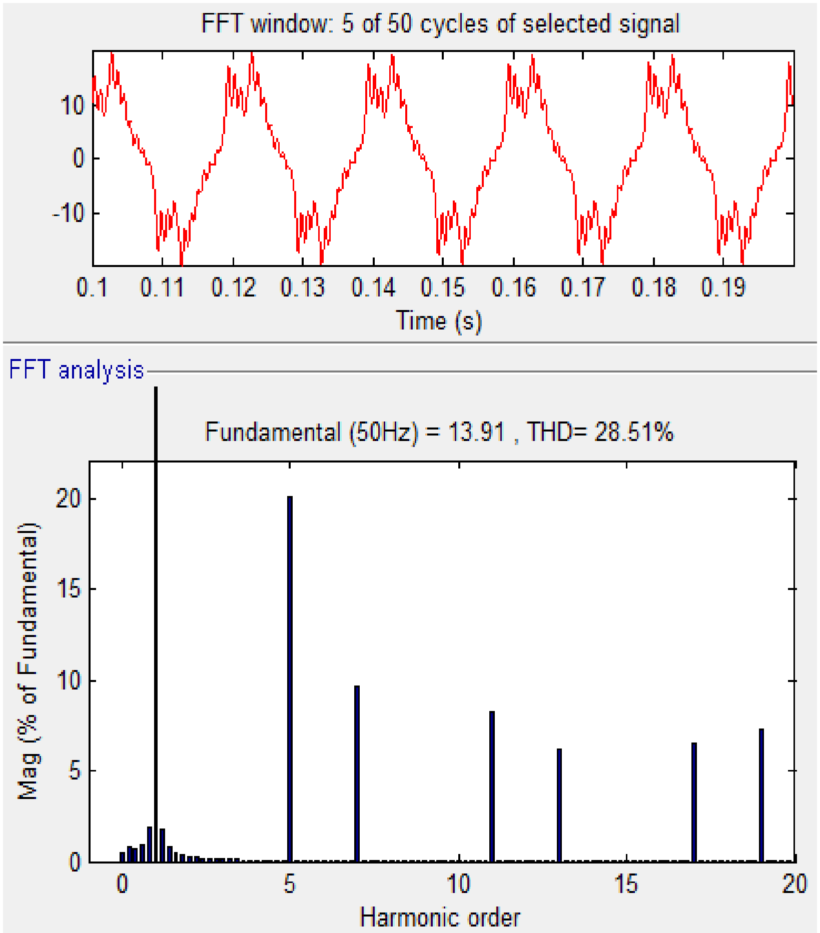

Fig 4.11 without compensation FFT analysis of source current

From Fig 4.11 and Fig 4.12 respectively it is clear that the total harmonic distortion without compensation is 28.51%, which is reduced to 0.53% where SVC light is connected.

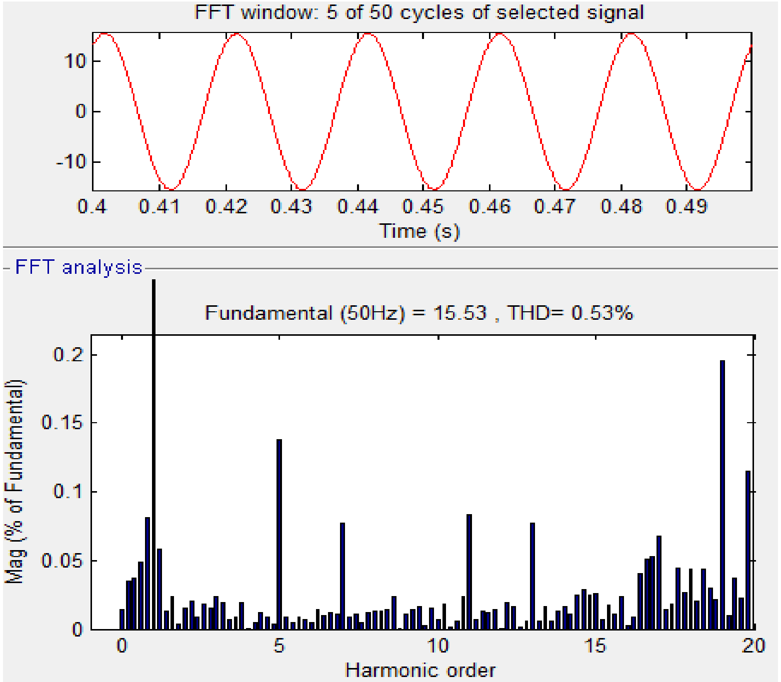

Fig 4.12 with compensation FFT analysis of source current

V. CONCLUSION

In this paper, work has been done to compare DSTATCOM, DVR, SVC LIGHT AND OPEN UPQC. Performance analysis has been done by comparing the power quality of each compensator in Matlab Simulink . DSTATCOM is proved to compensate current levels under faulty conditions. Current harmonics has been reduced considerably. Harmonics generated at source side has THD of 28.31% which has been compensated to 0.49% at PCC. DVR is proved to compensate voltage harmonics which has been reduced considerably. Harmonics generated at load side has THD of 20.62% which has been compensated to 0.92% at load end. Even the voltage sag during fault duration has also been compensated to a desired level. SVC LIGHT is proved to compensate current harmonics at source side. Current harmonics generated at source side has THD of 28.51% which has been compensated to 0.53% at PCC. OPEN UPQC is proved to compensate current and voltage harmonics which has been reduced considerably. Current harmonics generated at source side has THD of 28.49% which has been compensated to 0.41% at PCC. Voltage Harmonics generated at load side has THD of 26.8% which has been compensated to 0.50% at load end.

Comparison Of Thd's

Parameter	DSTATCOM		DVR		OPEN UPQC		SVC LIGHT	
	without	with	without	with	without	with	without	with
Source voltage V_S	-	-	20.62	20.62	26.80	26.80	-	-
Source current I_S	28.31	0.66	-	-	28.49	0.41	28.51	0.53
Load voltage V_L	-	-	20.62	0.92	26.80	0.50	-	-
Load current I_L	28.31	28.31	-	-	28.49	28.49	26.23	26.23

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