Dstatcom Based on the Non Linear Predictive Controller for Improved Compensation

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Abstract— **The demand for power quality improvement has been growing in recent years, mainly due to the increase of nonlinear loads connected to the electrical power system causing distortions in the utility voltages at point of common coupling. In order to mitigate the issues with the power quality in this project a fuzzy based a versatile unified power quality conditioner (UPQC), which can be connected in either three-phase three-wire or three-phase four-wire distribution system for performing the series-parallel power-line conditioning. Thus, even when only a three-phase three-wire power system is available at a plant site, the UPQC is able to carry out power-line compensation for installed loads that require a neutral conductor to operate. Different from the control strategies used in the most of UPQC applications in which the controlled quantities are non-sinusoidal. This UPQC employs dual compensation strategy, such that the controlled quantities are always sinusoidal. Thereby, series converter is controlled to act as a sinusoidal current source, whereas parallel converter operates as a sinusoidal voltage source. Thus, the controlled quantities are sinusoidal, it is possible to reduce the complexity of the algorithms used to calculate the compensation references. Static and dynamic performances, as well as effectiveness of the dual UPQC are evaluated by means of experimental results.**

Key words – Power quality, dual compensation, filters

I . INTRODUCTION

Now a day's power electronic based equipment is used in industrial and domestic purposes. These equipments have significant impact on the quality of supplied voltage and they increased the harmonic current pollution of the distribution system. They have many negative effects on power system equipment and customer, such as additional losses in overhead lines and underground cables, transformers and rotating electric machines, problem in the operation of the protection systems, over voltage and shunt capacitor, error of measuring instruments, and many function of low efficiency of customer sensitive loads. Passive filter have been used commonly for mitigating the distortion due to harmonic current in industrial power systems. But they have many drawbacks such as resonance problem, dependency of their performance on the system impedance, absorption of harmonic current of nonlinear load, which could lead to harmonic propagation through the power system.

To overcome of such drawbacks active power filters is introduced. A new combination of a shunt hybrid power filter (SHPF) and a TCR (SHPF-TCR compensator) is proposed to suppress current harmonics and compensate the reactive power generated from the load. The hybrid filter consists of a series connection of small-rated active filter and a fifth-tuned *LC* passive filter. In the proposed topology, major part of the compensation is supported by the passive filter and the TCR while the APF is meant to improve the filtering characteristics and damp the resonance, which can occur between the passive filter, the TCR, and the source impedance. The shunt APF when used alone suffers from the high kilovoltampere rating of the inverter, which requires a lot of energy stored at high dc-link voltage

II. SYSTEM CONFIGURATION

The DSTATCOM is designed using a three-phase VSC with a DC bus capacitor at DC side. Passive filters comprising series connected capacitive (Cf) and resistive (Rf) elements at the PCC, are used to suppress switching noise produced by IGBTs (Insulated Gate Bipolar Transistors). This noise contains high frequency components. A nonlinear load is represented in form of a three-phase diode bridge rectifier.

III.MATHEMATICAL FORMULATION OF ALGORITHM

A.*Dual compensation Principle*

Fig.1 shows In order to make the input currents sinusoidal, balanced and in phase with the utility voltages, in the dual compensating strategy, the series PWM converter is controlled to operate as a sinusoidal current source. In this case, its impedance must be high enough to isolate the harmonic currents generated by the non-linear loads. On the other hand, parallel PWM converter also makes the output voltages sinusoidal, balanced, regulated and in phase with the utility voltages. In other words, it is controlled to operate as sinusoidal voltage source, such that its impedance must be sufficiently low to absorb the load harmonic currents.

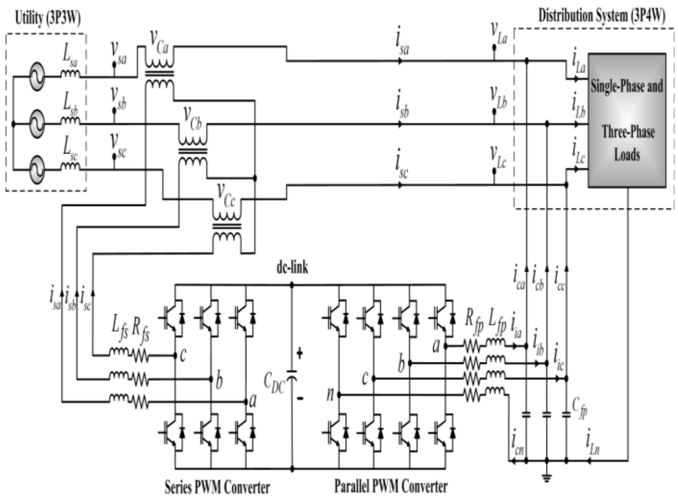


Fig1. 3P4W distribution system based on UPQC topology Connected to 3P3W power system.

B. Modeling of series and parallel converters

The modeling of the series and parallel PWM converters are presented in this section. In addition, the voltage and current controllers implemented in the Synchronous Reference Frame (dq0-axes) are discussed.

C. Series converter modeling

The state-space system and the transfer functions of the series converter in the dq-axes are obtained based on a mathematical model. The modeling is accomplished considering that all involved inductances and resistances are identical, asfollows: $L_{fsa}=L_{fsb}=L_{fsc}=L_{fs}$ and $R_{fsa}=R_{fsb}=R_{fsc}=R_{fs}$. By means of Fig. 3.1, the equations that represent the system are given by (1) and (2).

$u_{sab\_pwm}=V_{Lfsa}+V_{Rfsa}+V_{Ca}-V_{Rfsb}-V_{Lfsb}$--------------(1)

$u_{sbc\_pwm}=V_{Lfsb}+V_{Rfsb}+V_{Cbc}-V_{Rfsc}-V_{Lfsc}$--------------(2)

Where: u_{sab_pwm} and u_{sbc_pwm} are the respective PWM voltages at the 3-Leg series converter terminals.Considering the voltages of the PWM series converter in the *dq*-axes (u_{sd_pwm} and u_{sq_pwm}), the state-space equation is given by:

$$\dot{x}_{sdq}(t) = A_{sdq}.x_{sdq}(t) + B_{sdq}.u_{sdq}(t) + F_{sdq}.w_{sdq}(t) \quad (3)$$

Where

$$\dot{x}_{sdq}(t) = \begin{bmatrix} \frac{di_{sd}}{dt} \\ \frac{di_{sq}}{dt} \end{bmatrix};\ x_{sdq}(t)=\begin{bmatrix} i_{sd} \\ i_{sq} \end{bmatrix};\ u_{sdq}=\begin{bmatrix} u_{sd\_pwm} \\ u_{sq\_pwm} \end{bmatrix};$$

$$w_{sdq}(t)=\begin{bmatrix} v_{Cd} \\ v_{Cq} \end{bmatrix};\ A_{sdq} = \begin{bmatrix} -\frac{R_{fs}}{L_{fs}} & \omega \\ -\omega & -\frac{R_{fs}}{L_{fs}} \end{bmatrix};\ B_{sdq} = \frac{1}{3L_{fs}}\begin{bmatrix} 1 & 0 \\ 0 & 1 \end{bmatrix};$$

$$F_{sdq} = \frac{1}{3L_{fs}}\begin{bmatrix} -1 & 0 \\ 0 & -1 \end{bmatrix}.$$

Thereby, based on (3), the series converter model represented as a signal flow graph is shown in the dotted area of Fig. 2(a). In addition, the current controller into the *dq*-axes is also shown, where $(PI)d$ and $Gs(PI)q$ represent the transfer functions of the PI current controllers; D_{sd} and D_{sq} are the duty cycles; V_{DC} is the DC-bus voltage; K_{PWM} is the gain of the PWM modulator given by $K_{PWM} = 1/P_{PWM}$ [31], where P_{PWM} is the peak value of the PWM triangular carrier implemented in the digital signal processor (DSP). The current coupling between the *dq*-axes, shown in the average model of Fig.2(a), is eliminated by using the scheme presented in Fig.2(b), where the dotted blocks represent the decoupling effects implemented in the block diagram shown in Fig. 2(a). Thus, based on Fig.2(a), the transfer functions of the closed loop system can be represented by (4), where $K_{(d,q)}$ and $Ki_{s(d,q)}$ are the proportional and integral controller gains, and $i_{s(d,q)}{}^*(s)$ represents the continuous current references in the dq coordinates.

$$\frac{i_{s(d,q)}(s)}{i^*_{s(d,q)}(s)} = \frac{X_1(Kp_{s(d,q)}s + Ki_{s(d,q)})}{L_{fs}s^2 + (R_{fs} + X_1Kp_{s(d,q)})s + X_1Ki_{s(d,q)}} \quad (4)$$

Where: $X_1 = K_{PWM} V_{DC}$

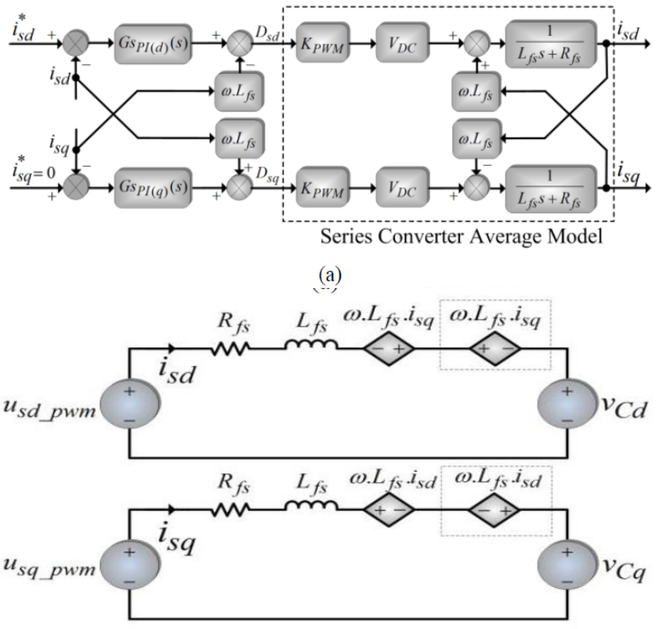


Fig. 2. Series converter: (a) Signal flow graph of the current controllers and average model; (b) Model of the uncoupled system in SRF dq-axes.

D.Parallel Converter Modeling

The state-space system and the transfer functions of the parallel converter in the *dq0*-axes are obtained based on a mathematical model. The modeling is accomplished considering that all involved inductances, resistances and capacitances are identical, as follows: $L_{fpa} = L_{fpb} = L_{fpc} = L_{fpn} = L_{fP}$; $R_{fpa}=R_{fpb}=R_{fpc}=R_{fpn}=R_{fp}$, and $C_{fpa}=C_{fpb}=C_{fpc}=C_{fp}$.

By means of Fig.1the equations represent the system are given by (5) ,(6) and (7), as follows :

$$u_{pan\_pwm} = R_{fpa}.i_{ia} + L_{fpa}\frac{di_{ia}}{dt} + v_{La} + L_{fpn}\frac{di_{cn}}{dt} + R_{fpn}.i_{cn} \quad (5)$$

$$u_{pbn\_pwm} = R_{fpb}.i_{ib} + L_{fpb}\frac{di_{ib}}{dt} + v_{Lb} + L_{fpn}\frac{di_{Cn}}{dt} + R_{fpn}.i_{cn} \quad (6)$$

$$u_{pcn\_pwm} = R_{fpc}.i_{ic} + L_{fcc}\frac{di_{ic}}{dt} + v_{Lc} + L_{fpn}\frac{di_{Cn}}{dt} + R_{fpn}.i_{cn} \quad (7)$$

Where : u_{pan_pwm} , u_{pbn_pwm} , and u_{pcn_pwm} are the respective PWM voltages at the terminals *a*, *b* and *c* of the 4-L parallel converter.

The capacitor currents of the output filters (i_{Cfpa}, i_{Cfpb}, and i_{Cf}) are given by:

$$i_{Cfpa} = C_{fpa}\frac{dv_{La}}{dt} = i_{ia} - i_{ca} \quad (8)$$

$$i_{Cfpb} = C_{fpb}\frac{dv_{Lb}}{dt} = i_{ib} - i_{cb} \quad (9)$$

$$i_{Cfpc} = C_{fpc}\frac{dv_{Lc}}{dt} = i_{ic} - i_{cc} \quad (10)$$

Where i_{ia} , i_{ib} and i_{ic} are the currents of inductors , and i_{ca} , i_{cb} and i_{cc} are the output currents of the parallel converter.

Considering the PWM converter voltages of the parallel synchronous rotating frame (u_{pd_pwm}, u_{pq_pwm}, and u_{p0_pwm}), the state-space equation is found as:

$$\dot{x}_{pdq0}(t) = A_{pdq0}.x_{pdq0}(t) + B_{pdq0}.u_{pdq0}(t) + F_{pdq0}.w_{pdq0}(t) \quad (11)$$

where :

$$\dot{x}_{pdq0}(t) = \left[\frac{di_{id}}{dt} \quad \frac{di_{iq}}{dt} \quad \frac{di_{i0}}{dt} \quad \frac{dv_{Ld}}{dt} \quad \frac{dv_{Lq}}{dt} \quad \frac{dv_{L0}}{dt}\right]^T$$

$$x_{pdq0}(t) = [i_{id} \quad i_{iq} \quad i_{i0} \quad v_{Ld} \quad v_{Lq} \quad v_{L0}]^T;$$

$$A_{pdq0} = \begin{bmatrix} -\frac{R_{fp}}{L_{fp}} & \omega & 0 & -\frac{1}{L_{fp}} & 0 & 0 \\ -\omega & -\frac{R_{fp}}{L_{fp}} & 0 & 0 & -\frac{1}{L_{fp}} & 0 \\ 0 & 0 & -\frac{R_{fp}}{L_{fp}} & 0 & 0 & -\frac{1}{4L_{fp}} \\ \frac{1}{C_{fp}} & 0 & 0 & 0 & \omega & 0 \\ 0 & \frac{1}{C_{fp}} & 0 & -\omega & 0 & 0 \\ 0 & 0 & \frac{1}{C_{fp}} & 0 & 0 & 0 \end{bmatrix};$$

E. Control reference of the series and parallel converters

The strategies used to generate the sinusoidal reference quantities to control the series and the parallel converters are presented. As aforementioned, the current and voltage control references are controlled to be in phase with the utility voltages. Since the controlled voltages and currents are sinusoidal quantities, a significant advantage is attained when the dual compensating strategy is compared with the conventional strategy, whose controlled quantities are always non-sinusoidal. This advantage is highlighted mainly because the control references into the SRF-based controllers are continuous, leading to reduced errors in the steady-state of the PI controllers.

IV.SIMULATION RESULTS

In order to validate the performance of the DSTATCOM, the model is designed with the source modeling in MATLAB/Simulink and the experimental waveforms are obtained. The performance of the STATCOM is studied under steady state condition. The performances of the existing and proposed methods are validated with the models to their efficiency conditions

Due to use of non linear load the sinusoidal becomes a non sine with a rich of harmonics Which affects the source grid too.

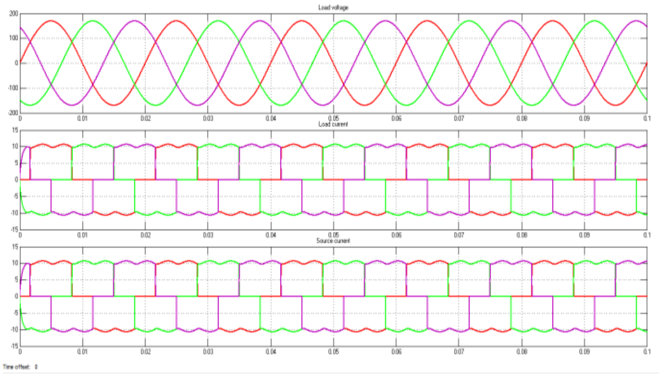


Figure 3: Impact of non-linear filter.

Due to the inclusion of the non-linear load in the transmission line the source /grid current has been turned out to be non-sinusoidal .This non sinusoidal will have a larger harmonic content which destabilizes the grid.

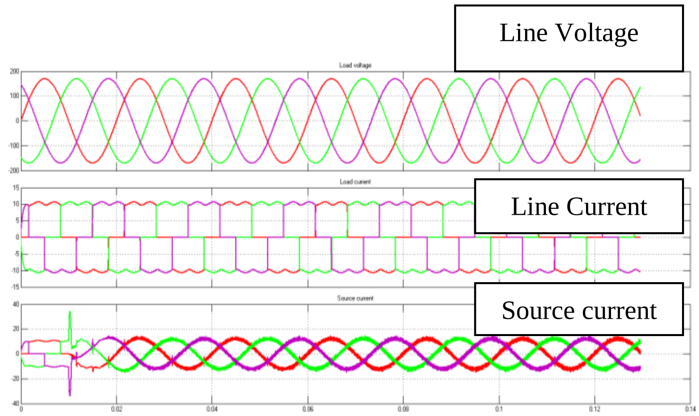


Figure 4: Non-linear load compensation

It has been a difficult to estimate the required current to compensate under non linear conditions . Hence a compensator with a additional filter is added to estimate clear compensation current Based on filtering the compensation sequence is estimated.

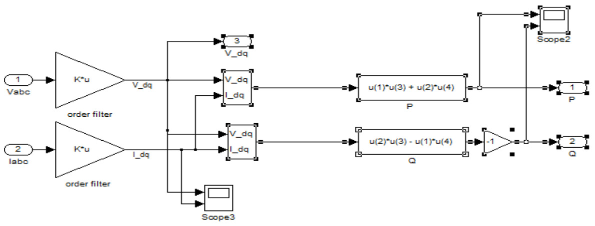


Figure 5: Volteraa filter

Inclusion of the filter under the current estimation is introduced.

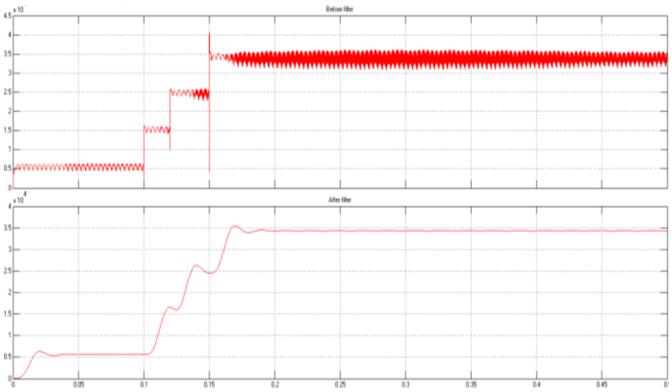


Figure 6: Estimation of current difference

The undesired oscillation over the current estimation is eliminated, Which makes the inverter control reference to regulate much simpler

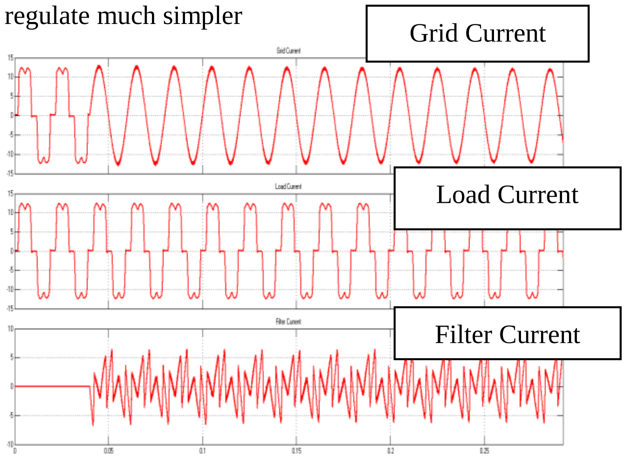
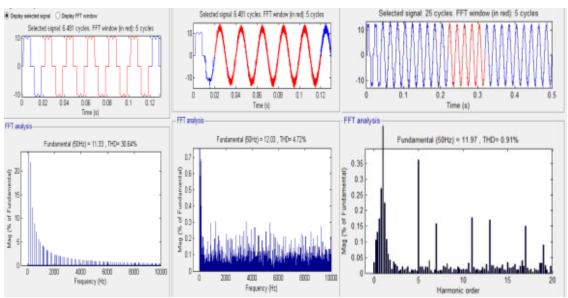


Figure 7: compensation in the volterra filter

The inclusion of the volterra filter has made a larger reduction of damping to effect as a sine patterns.



Non-compensated Non-filtered Filtered with Volterra Filter

Figure 8: Comparison of filter performance

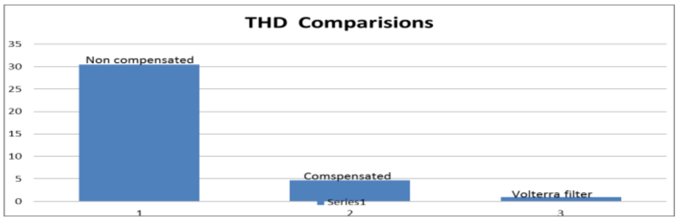


Figure.9: THD comparison Proposed system

A UPQC is proposed by implementing two 5-levels Cascaded Asymmetric Multilevel Converters (CAMC). The CAMC has the properties of the hybrid multilevel converter and in addition it can be used in back-to-back connection.

This converter, which is built as the cascade of two different topologies together with a hybrid modulation strategy, allows to obtain five voltage levels with a reduce number of components and reduce control complexity. A three phase four leg inverter is been proposed for the reactive compensation

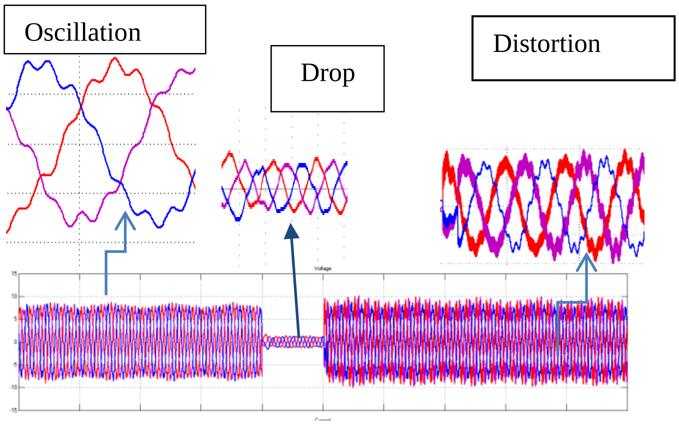


Figure10: Problems in transmission line due to load unbalance

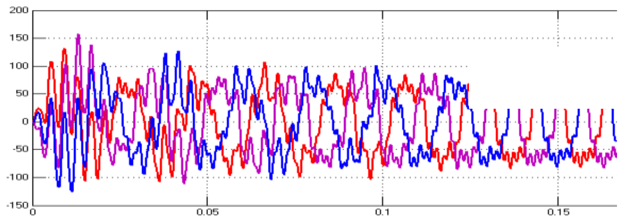
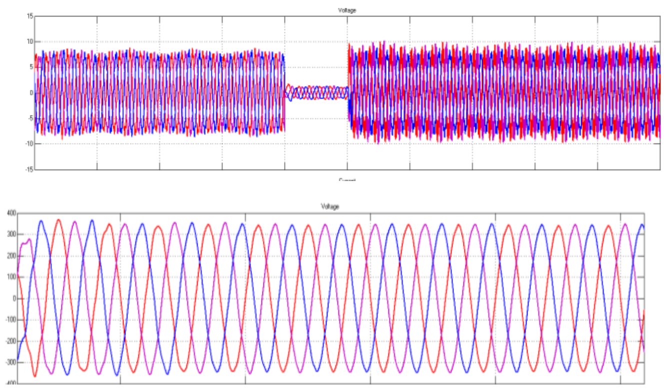


Figure 11: current imbalance

The figure 11 shows the unbalance in the load current due to the unbalanced and non-linear loads.



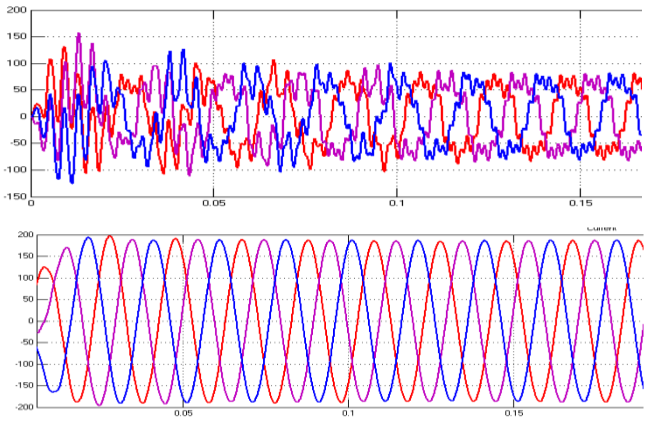


Figure 12: Compensated current

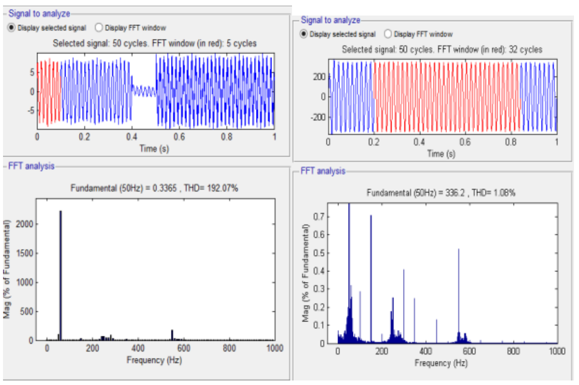


Figure 13: Voltage Harmonics before and after filtering

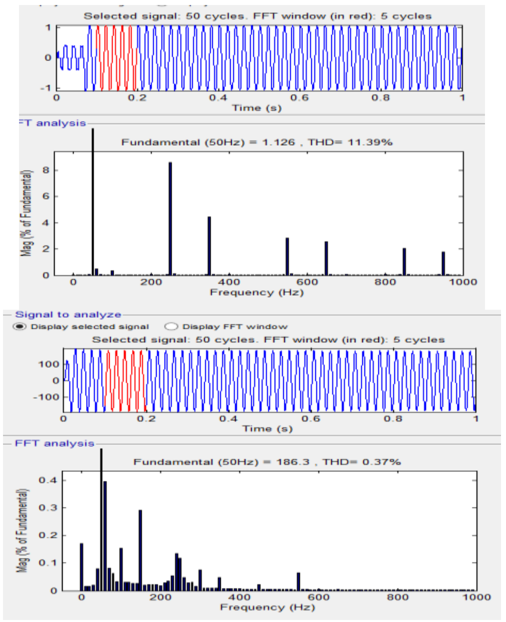


Figure 14: Current harmonics before and After filtering

ADVANTAGES OF THE PROPOSED SYSTEM:

- Simpler to calculate
- Off line and Online schemes
- No need of look up table s
- Reduced math computation can be easily implemented in the hardware's.
- Complete band elimination

V CONCLUSION

This work presents the DSTATCOM-based control scheme for power quality improvement in grid connected PVsystem with non linear loads. DSTATCOM injects current to the grid and it cancel out the reactive and harmonic parts of the induction generator current and load current . The THD analysis revealed that the Shunt and series controller proved to be the best against only shunt controller along with volterra filter. This shunt and series compensator is simpler and has faster response.

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