POWER QUALITY IMPROVEMENT BY USING DISCRETE WAVELET TRANSFORM BASED DSTATCOM USING COMBINED PR AND COMB FILTER CONTROLLER

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Abstract— The wavelet transform has received great importance in the last years on the power system analysis because the multi-resolution analysis presents proprieties good for the transient signal analysis. This thesis presents a review on main application of wavelet transform in electric power systems. The study areas have been classified as power system protection, power quality disturbances, power system transient, load forecasting, faults detection, and power system measurement. The discrete wavelet transform-based control technique for the distribution static compensator (DSTATCOM) is utilized in this paper to improve power quality at common points of interconnection (CPI). The discrete wavelet transform, the time frequency analysis technique, is used here to split distorted load current of each phase in order to recover the line frequency of harmonic components for estimating the respective active power components. Wavelet transform is a powerful signal processing tool that transforms a time-domain waveform into time-frequency domain and estimates the signal in the time and frequency domains simultaneously. So, it is mostly used in electric power systems analysis with the D-STATCOM's Voltage Source Converter (VSC).The difference between the estimated reference active component and the detected load currents is utilized to create reference currents for DSTATCOM's voltage source converter (VSC) management. The performance of DSTATCOM is presented using MATLAB software under varied linear and non-linear load circumstances. Under various load situations, total harmonic distortion (THD) of the source current is less than 5% with a power factor of unity.

Keywords— wavelet transform, power system protection, power quality disturbances, power system transient, load forecasting, faults detection, common points of interconnection (CPI), D-STATCOM.

1. INTRODUCTION

In the present days, power quality of supply has become the major concern for electrical customers and utilities. Low power quality causes instabilities, shortens life of equipment, and causes power service equipment to malfunction, among other things. Voltage sag, harmonic distortion, voltage swell, and flicker are the four types of power supply problems. To improve the quality of power supply by properly detecting source of disruptions [1]. Power quality issues in distribution systems include harmonics in currents, lag power factor, excessive reactive power, and so on. These issues are produced by the use of non-linear and unbalanced loads in the distribution system. Using power electronic equipment such as rectifiers in the distribution system may cause voltage distortion and increase neutral currents in the power supply [2]. A low level of power quality indicates high level of disturbances, while a low level of disturbances indicates high level of power quality, with consumers and providers agreeing solely on the acceptable degree of disturbances. The power quality restrictions are maintained in accordance with international standards. If these restrictions are exceeded, the device will not operate for an extended period of time or will malfunction. Installing custom power devices (DSTATCOM) at the CPI to improve power quality and provide consumers with a stable power supply [3].

Power monitoring is essential to record performance of power supply and identifies power quality issues at CPI. Wavelet analysis was created to address the shortcomings of Fourier analysis and brief time Fourier analysis. Time constraint Fourier analysis offers uniform time and the frequency resolution over whole time frequency domain. The wavelets, which are functions of the time and the scale, aid in looking at the signal at several scales, also known as multi-scale analysis. Wavelets are often employed to detect signal discontinuities such as spikes, jumps, and non-smooth characteristics [4]. Wavelet, which is widely used for recognizing various power quality disturbances, was used to create the control algorithm for these devices in order to mitigate the current-related power quality disturbances.

The wavelet transform theory is based on analysis of signal using varying scales in the time domain and frequency. Formalization was carried out in the 1980s, based on the generalization of familiar concepts. The wavelet term was introduced by French geophysicist Jean Morlet. The seismic data analyzed by Morlet exhibit frequency component that changed rapidly over time, for which the Fourier Transform (FT) is not appropriate as an analysis tool. Thus, with the help of theoretical physicist Croatian Alex Grossmann, Morlet introduced a new transform which allows the location of high-frequency events with a better temporal resolution [2]. Faulted EPS signals are associated with fast electromagnetic transients and are typically nonperiodic and with high-frequency oscillations. This characteristic presents a problem for traditional Fourier analysis because it assumes a periodic signal and a wide-band signal that require denser sampling and longer time periods to maintain good resolution in the low frequencies [3]. The WT is a powerful tool in the analysis of transient phenomena in power system. It has the ability to extract information from the transient signals simultaneously in both time and frequency domains and has replaced the Fourier analysis in many applications [4]. The most important criterion with filter-bank implementation (subband decomposition) of DWT is the proper retrieval of signal, which is commonly termed as perfect reconstruction in literature. The perfect reconstruction imposes certain constraints on analysis and synthesis filters. The nature of constraints relates these filters to either the orthogonal wavelet bases or to the biorthogonal wavelet basis as discussed.

This study proposes a control technique for DSTATCOM based on Discrete Wavelet Transform (DWT) to mitigate power quality disruptions. Here, fundamental component of the load current is derived from deconstructed level and employed in the control method to determine the reference active current component. It also aids in simultaneous assessment of the PQ disturbances such as unbalancing and the THD based on load current decomposition levels [5].

2. PROPOSED CONCEPT

SYSTEM CONFIGURATION

Figure 1 depicts a schematic diagram of the three phases of DSTATCOM. CPI connects the nonlinear and linear loads. The interface inductor, voltage source converter, DC bus capacitor, and loads are all part of the DSTATCOM. The gate signals control the three-phase VSC. The gating signals are created by the hysteresis current controller in accordance with the control algorithm.

To cancel the compensating currents of the high frequency switching component, interface inductors are inserted between the midpoints of each leg of VSC and the main supply. The placement of VSC generates high frequency switching noise, which is minimized by putting a ripple filter comprising capacitor and resistor at CPI. The three phase bridge rectifier and non-linear R-L load are connected to the system's DC side.

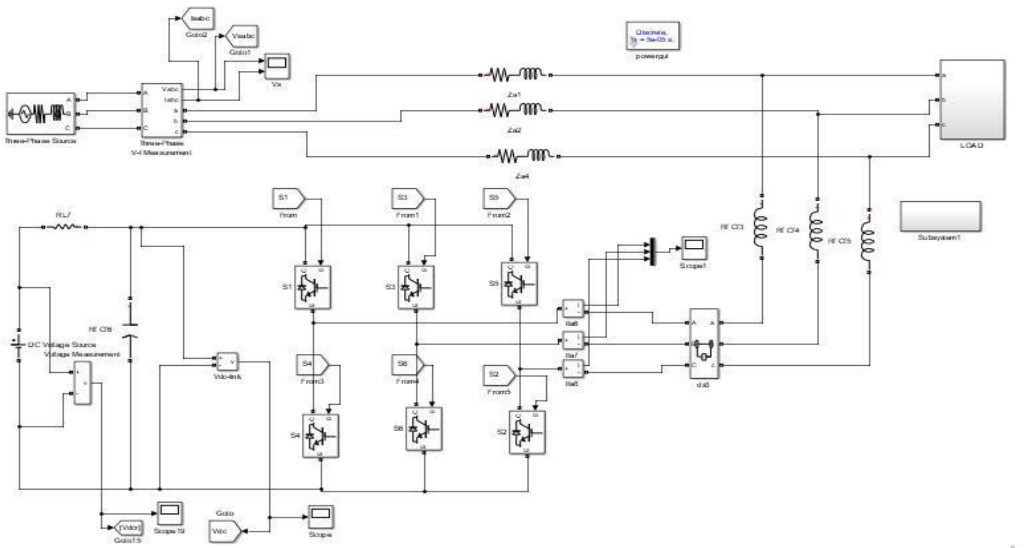


Fig1. Simulation model of DSTATCOM

3. Control Strategy

In this strategy, the estimated and sensed phase voltages of CPI are (V_{SR} , V_{SY} and V_{SB}), supply currents (I_{SR} , I_{SY} ,and I_{SB}), currents of load (I_{LR}, I_{LY} , and I_{LB}), and the DC bus voltage of VSC (V_{DC}) are the control algorithm's feedback signals, these detected waves are processed in following order to the generate VSC gate pulses, are exposed in fig.2

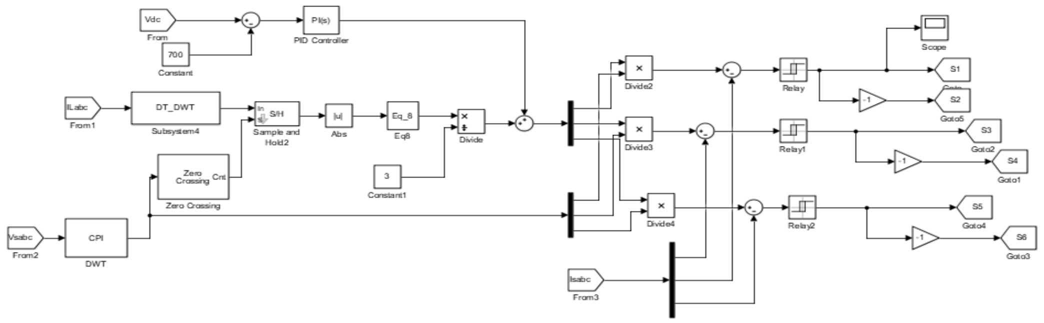


Figure.2. DSTATCOM Simulation diagram of DWT based control algorithm.

Here, peak magnitude of the voltages of CPI is determined as.

$$V_{PR} = \sqrt{2(V_{SR}^2+V_{SY}^2+V_{SB}^2)/3}$$

(1)

CPI voltage of the unit templates are intended as,

$u_{SRP}= V_{SR}/V_{PR}$;$u_{SYP}=V_{SY}/V_{PR}$;

(2)

$u_{SBP}=V_{SB}/V_{PR}$;

A. Mathematical calculation of the Average Active Power of the Load Currents (I_{RP})

Measured Load currents (I_{LR} ,I_{LY} and I_{LB}) are feedback signals of the control algorithm these detected signals are processed inorder shown in fig.2 to generate VSC gating pulses. Input signal sample down into 5 levels to get required band of frequencies by MRA. After sample down the input signal co-efficients are used for reconstruction by passing through low pass filters.

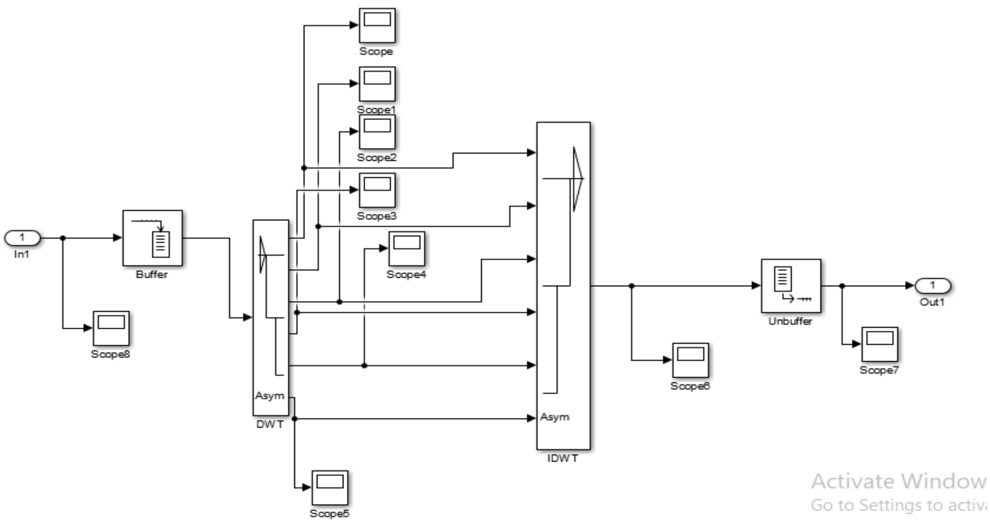


Figure.3. Extracting the Fundamental component of current using DWT bi-orthogonal5/5.

The fundamental load current retrieved with the co-efficients of each phase is in the quadrature to detect the load current of that phase with no delay. As a result, components (I_{QFLR}, I_{QFLY} and I_{QFLB}) of the predicted quadrature fundamental load currents are utilized to calculate the corresponding active power components (I_{RFLR}, I_{RFLY} and I_{RFLB}) respectively. The absolute (abs) magnitude of corresponding estimated quadrature components at each zero crossing of the related to each phase templates is used to extract these active power components. This extraction process's mathematical formulation for phase 'b' load current is as follows:

Therefore the phase 'b' voltage and the current be as follows:

$$V_{SC} = V_{PR} \sin(\omega t)$$
(3)

$$I_{LB} = I_{NC} \sin(\omega t - \emptyset) + \sum I_{HC}$$
(4)

Where $I_{NB} \sin(\omega t - \emptyset)$the fundamental is load current and I_{HB} is the harmonics of the phase 'b' load current. The DWT algorithm extracts the phase 'b' fundamental load current of the quadrature (I_{QFLB}).

$$I_{QFLB} = I_{NB} \sin(\omega t - \emptyset - \pi/2) = -I_{NB} \cos(\omega t - \emptyset)$$
(5)

$$I_{QFLC} = -I_{NB} \sin \omega t \sin \emptyset - I_{NC} \cos \omega t \cos \emptyset$$
(6)

$$I_{AFLB} = \text{abs}\,(-I_{NB} \sin \omega t \sin \emptyset - I_{NC} \cos \omega t \cos \emptyset)_{\sin \omega t = 0}$$
(7)

$$I_{AFLB} = I_{NB} \cos \emptyset$$
(8)

Where I_{AFLB} is active power component of fundamental load current of the 'b' phase. Similarly active power components for all the three load phases are (I_{AFLR}, I_{AFLY} and I_{AFLB}) estimated. Load balancing is accomplished by distributing active power equally throughout the three phases of the supply.

The average of the active power equation of load currents is as follows:

$$I_{APLG} = \frac{I_{AFLR} + I_{AFLY} + I_{AFLB}}{3}$$
(9)

B. Mathematical calculation of the Active Power Component of the DC-link Voltage Control (I_{PDC})

For managing the DC bus voltage of VSC utilized as the DSTATCOM, the controller based on proportional integral (PI) method is recommended. The PI controller's control equation in discrete domain is as follows:

$$I_{PDC} = I_{PDC}(N-1) + K_P\{V_{DCE}(N) - V_{DCE}(N-1)\} + K_I V_{DCE}(N)$$
(10)

Whereas I_{PDC} is PI controller output K_P is proportional gain, K_I is integral gain respectively and the V_{DCE} is an error input forwarded to PI controller. This controller regulates the DC link voltage to 700V. The controller parameters have been defined in Appendix.

Approximate of the Active Power Component (I_{NAPL}) is calculated as, by adding active power component of average load current and DC link voltage.

$$I_{NAPL} = I_{APLG} + I_{PDC} \quad (11)$$

C. Mathematical calculation of Reference Currents

This active source current is utilized to calculate reference balanced source currents by multiplying them by CPI unit voltage templates, as shown below,

$$I_{RRF} = I_{NAPL} U_{SRP}$$
$$I_{YRF} = I_{NAPL} U_{SYP} \quad (12)$$
$$I_{BRF} = I_{NAPL} U_{SBP}$$

Where I_{RRF} ,I_{YRF} and I_{BRF} are reference balanced supply currents for 'R' , 'Y' , 'B' phases respectively.

D. Generation of Switching Pulses of VSC (S_1 to S_6)

Measured source currents (I_{SR} , I_{SY} and I_{SB}) are calculate the inaccuracies, subtract the reference supply currents from the currents. These mistakes are fed into hysteresis current controller, which generates switching pulses for the DSTATCOM's VSC. By compensating currents, the generated VSC are added to source side in order to improve the THD and power factor correction across all load circumstances.

4. WAVELET TRANSFORMATION

The employment of a completely scaled modulated window in wavelet analysis eliminates the problem of signal clipping. It generates wavelets from a single basic wavelet with customizable resolution, translation, and scaling. This single basic wavelet is referred to as the mother wavelet. We acquire information and approximations via wavelet analysis. The details are the signal's low-scale, high-frequency components, whereas the approximations are the signal's high-scale, low-frequency components. The wavelet analysis's strength is its ability to represent signals in compact form and at multiple levels of resolution. Wavelet transforms are classified into two categories. They are discrete wavelets transform (DWT) and continuous wavelet transforms (CWT) [6]. MRA can be done by construction and dilation in case of CWT whereas DWT; the MRA is performed in time-frequency plane by using filter banks.

The filter banks are used to analysis the signal by decomposing the original signal into different bands of frequency with equal width. The figure.4 shows a filter bank with two channels X (k) is the discrete time signal which is analysed by low pass L (z) and high pass H (z) with the help of filter banks. The filter bank output consists of equal number of samples similar to the input signal with half frequency content. By adding two outputs the output frequency and input frequency will be same but amount of data will be doubled. Hence down sampling is applied to output signal by a factor of '2'.

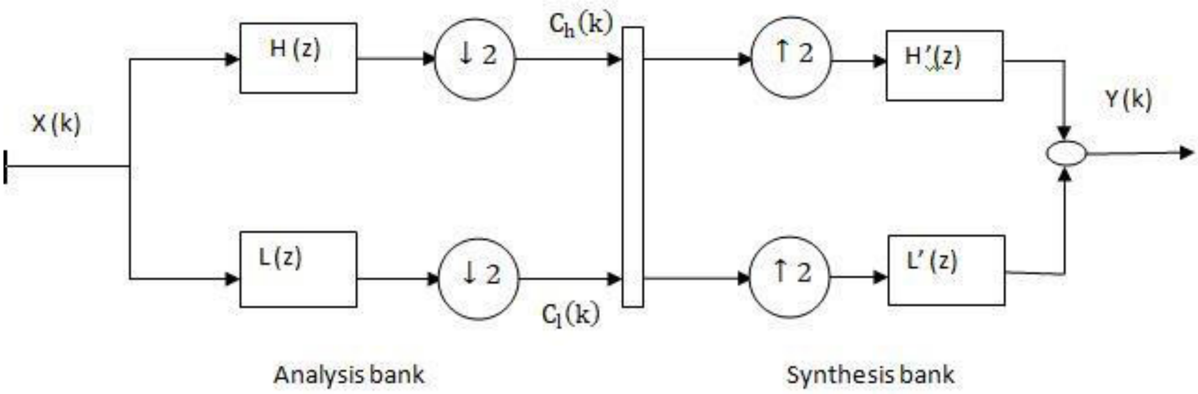


Figure.4. Estimation of fundamental by using decomposition and reconstruction.

An equally efficient approach exists to implement the Inverse Discrete Wavelet Transforms (IDWT) through Synthesis filter bank is helpful to get the reconstructed signal. The signal will up be sampled by a factor of '2' in synthesis filters bank and is given to low pass and the high pass filters. Here, output signal of two filters is added to get the reconstructed signal [7].

5. SIMULATION AND RESULTS

A MATLAB model based on this control algorithm is developed using Simulink and Sim Power toolboxes in a three-phase configuration for the control of a three leg VSC based DSTATCOM. Simulated results are presented for both balanced and unbalanced conditions under linear and nonlinear load respectively.

WITHOUT DSTATCOM CASE:

The System Performance under Balanced Linear and Nonlinear Loads without dstatcom

The CPI voltages of a system are shown in Figure.5. Figure.6. shows the source current due to linear and nonlinear loads when the system is not connected to DSTATCOM. The compensating currents are not present in the system because of DSTATCOM is not connected at CPI; due to this the harmonics are present in the load and source currents. The source currents are not sinusoidal in this non-linear load condition. Figure.7 represents load currents due to non-linear load. Figure.8 represents load currents due to linear load condition.

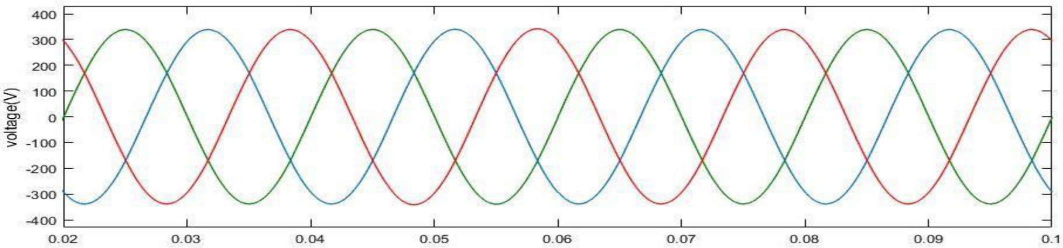


Figure.5. The CPI voltage without DSTATCOM

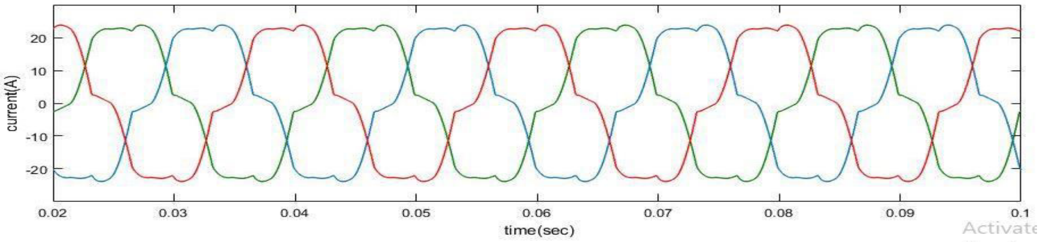


Figure.6. Source currents due to balanced load without DSTATCOM

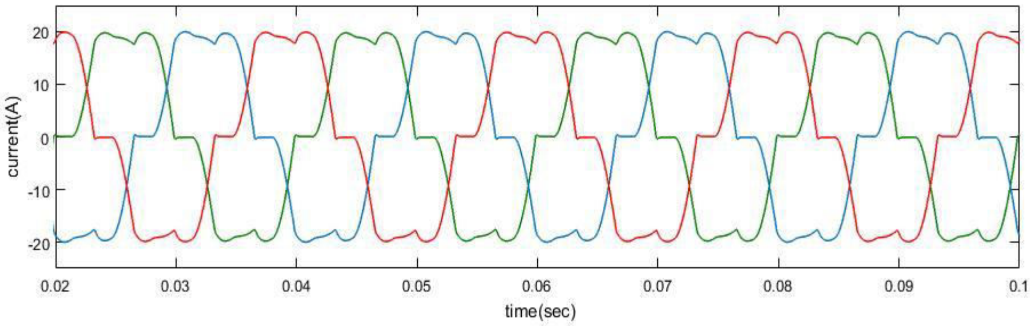


Figure.7.load currents due to balanced non-linear load without DSTATCOM

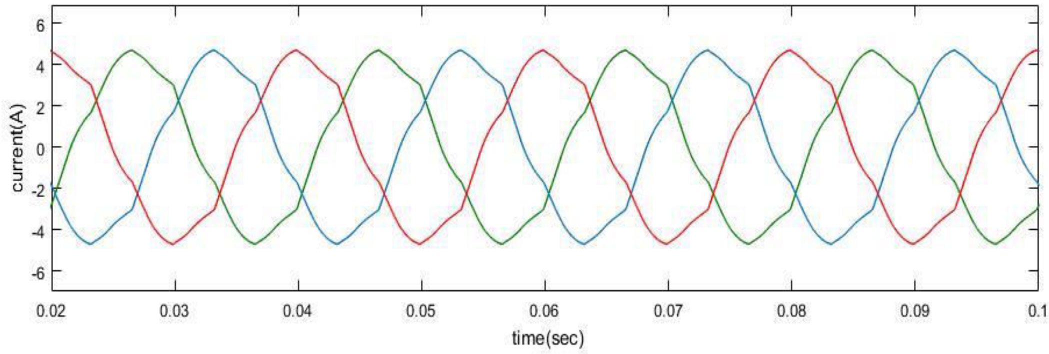
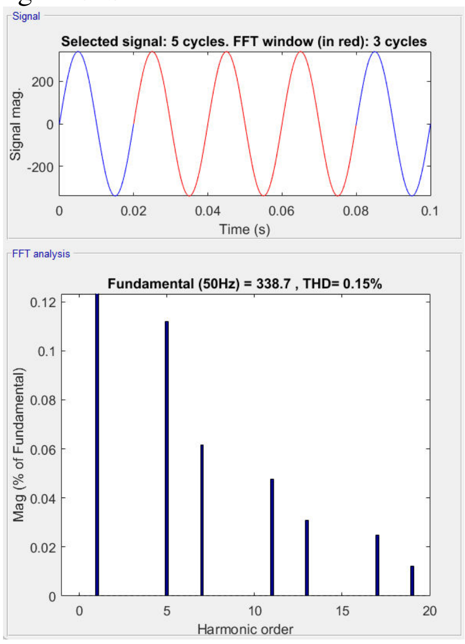
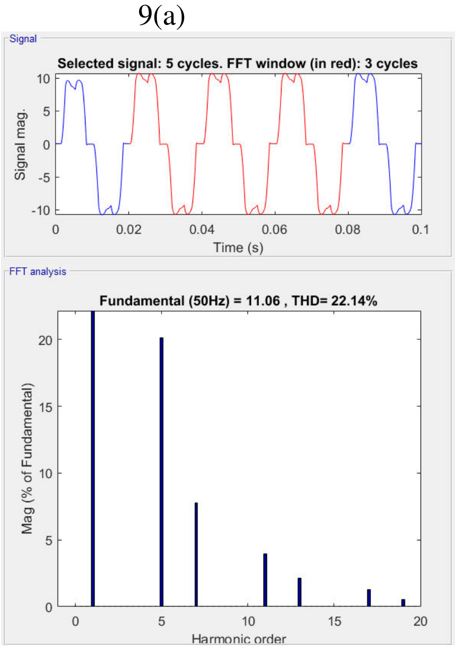


Figure.8. Source currents due to balance linear loads without DSTATCOM



9(a)



9(b)

Figure.9. Harmonic spectra of phase 'R' without DSTATCOM condition (a) Source voltage (b) Source current (c) Load current

Figure 9(a)-(c) shows the harmonic spectra of phase 'R' source voltage, source current and load current due to linear and non-linear load under without DSTATCOM condition.

The THD of supply voltage of phase 'R' is 0.15% and source current is 4.09% because it having more harmonics , while it is 22.14% for load current of non-linear load of same phase.

WITH DSTATCOM CASE:

A. **The System Performance for Balanced Linear and Non-linear Loads**

The supply voltages of the system are shown in Figure.10. Figure.11. represents the three phase source currents under balanced load condition. Figure.12. shows the load current as a result of non-linear load. Small magnitude is difference between source and load currents of balanced non-linear load situation because of source impedance. The supply's unity power factor controls the reactive power under balanced non-linear load while also efficiently reducing current harmonics on grid side. Figure.13. represents the R-L load currents are connected across the CPI. To maintain the unity power factor operation with respect to the CPI, VSC feeds the reactive power to distribution system locally. DSTATCOM's compensating currents are depicted in Figure.14. The compensatory current is primarily generating the harmonics to load current. Figure.15. Shows the DC voltage, it is maintained constant under balanced linear and non-linear load condition.

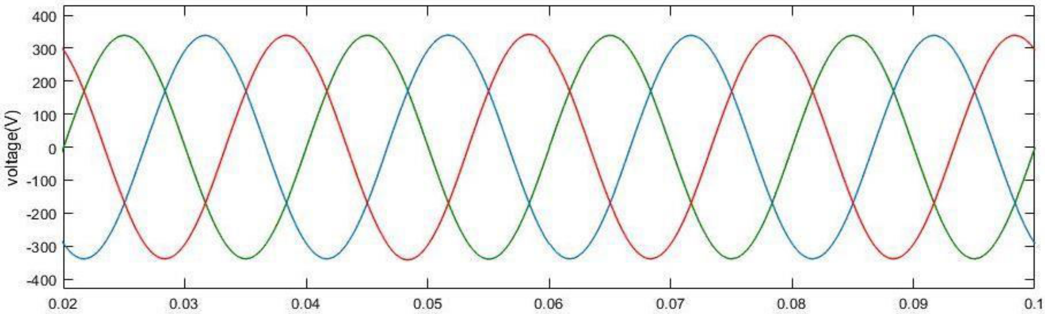


Figure.10. The CPI voltage with DSTATCOM

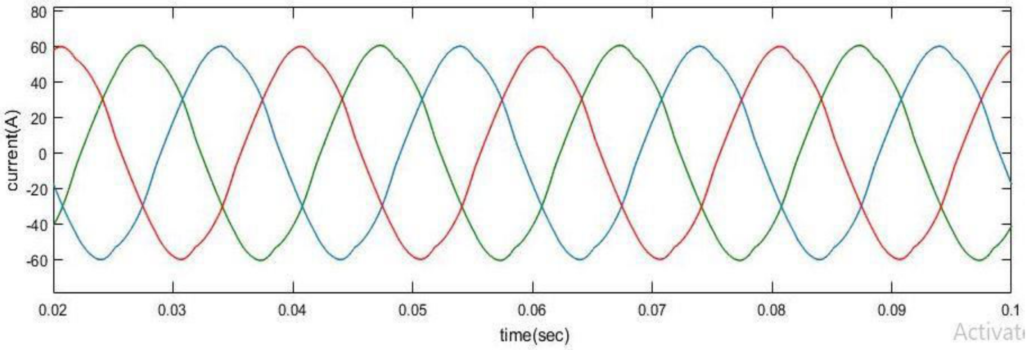


Figure.11. Source currents of non-linear load with DSTATCOM

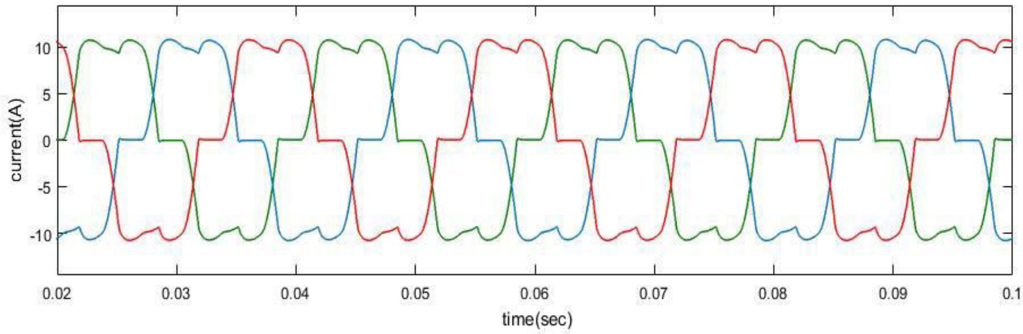


Figure.12. load currents due to non-linear load.

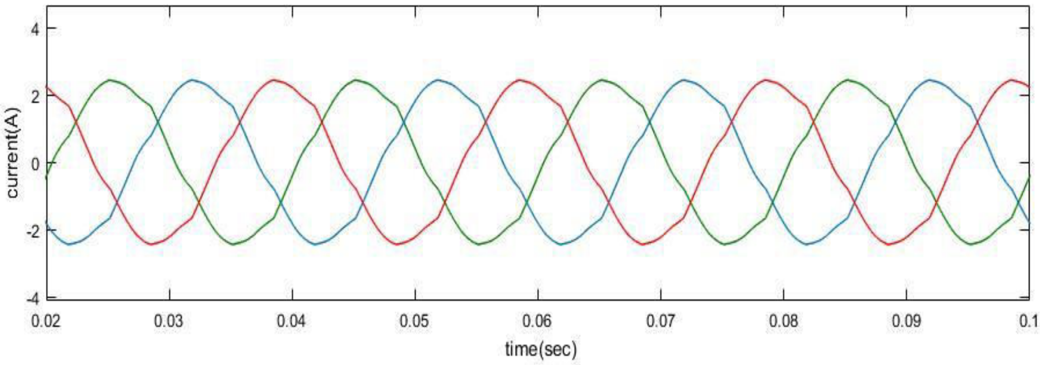


Figure.13. Load currents due to linear load with DSTATCOM.

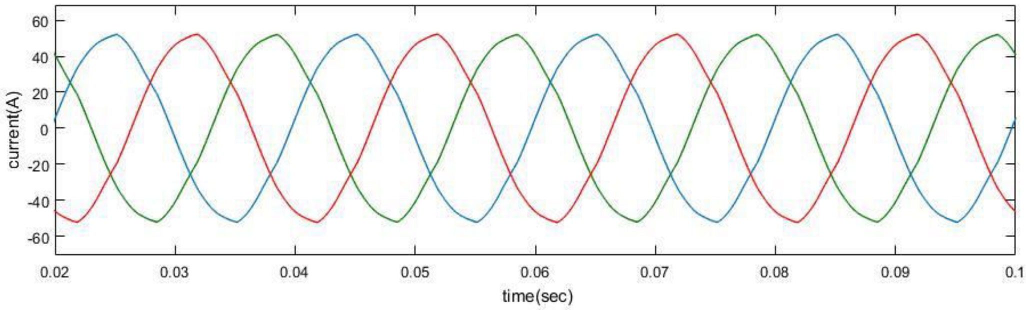


Figure..14. Compensating currents with DSTATCOM

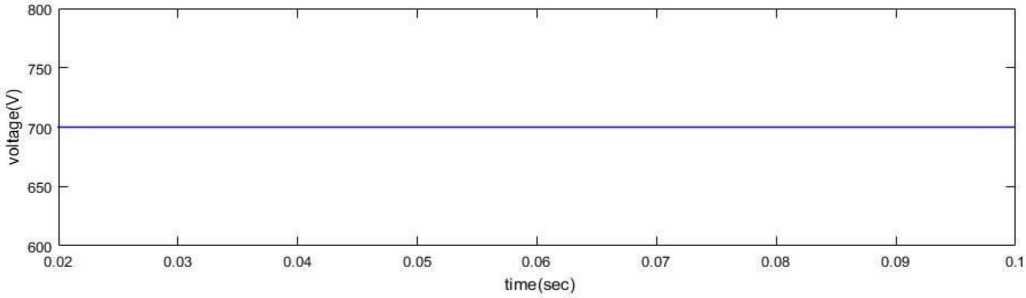
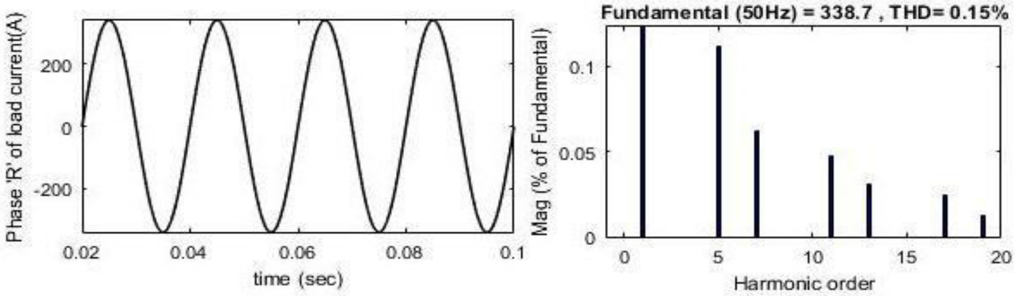
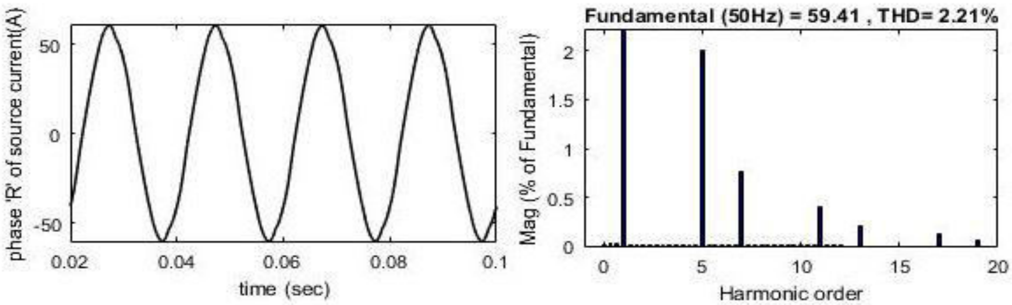


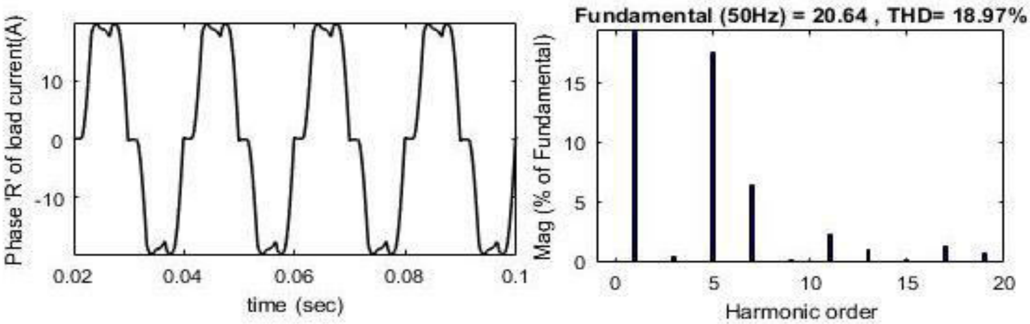
Figure.15. DC link voltage



16(a)



16(b)



16(c)

Figure.16. Harmonic spectra of phase ‘R’ with DSTATCOM (a) Source voltage (b) Source current and (c) Load currentFigure.

16(a)-(c) shows the Harmonic spectra of phase ’R’ source voltage , source current and load current with DSTATCOM condition . The THD of supply voltage is 0.15%. The mains currents are fairly sinusoidal. The THDs for supply currents are 2.21%, 2.24% and 2.22% for all the three phases respectively.The THDs for load currents due to non-linear and linear loads are 18.97%, 19.02% and 18.96% for phases of “R,Y and B” respectively. The supply currents THDs are below 5% even under non-linear load currents with 22.14% THD.

TABLE I

A COMPARISON OF THD WITHOUT AND WITH DSTATCOM CONDITION

Parameters	%THD for Without DSTATCOM	%THD for With DSTATCOM
Distortion of the source voltage	0.39%	0.15%
Distortion of the source current	14.57%	2.21%
Distortion of the load current	22.14%	18.97%

The TABLE show the performance comparison for %THD of a source voltage,source current and load current due to in the without and with DSTATCOM condition respectively. The without DSTATCOM condition THDs of source voltage and currens of source and loads are more. The performance of the proposed control system with DSTATCOM is better as the distortion on the source current is less with this technique. DWT based DSTATCOM is also having the additional ability to provide the additional information like harmonic estimation in group. So, the operation of DSTATCOM with this control system is within acceptable limits.

B. System Performance under Unbalanced Linear and Non-linear loads with dstatcom

The performance of the distribution system with the DSTATCOM is examined; the output results are shown in this below. Figure.17. depicts the CPI voltages when the system is linked to the DSTATCOM under unbalanced condition. Figure.18. shows the source current under unbalanced with DSTATCOM condition. Figure.19. and figure.20 are examples of formal represents the load currents due to non-linear and linear load balanced condition. The source currents and load currents are sinusoidal in the system up to t = 0.04s. Follows, an unbalance is introduced into the system by removing load of ‘b’ phase at t = 0.04s.

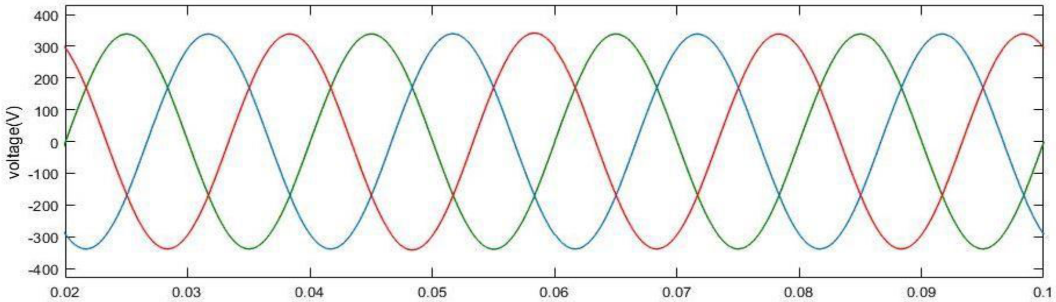


Figure .17. The CPI voltages with DSTATCOM

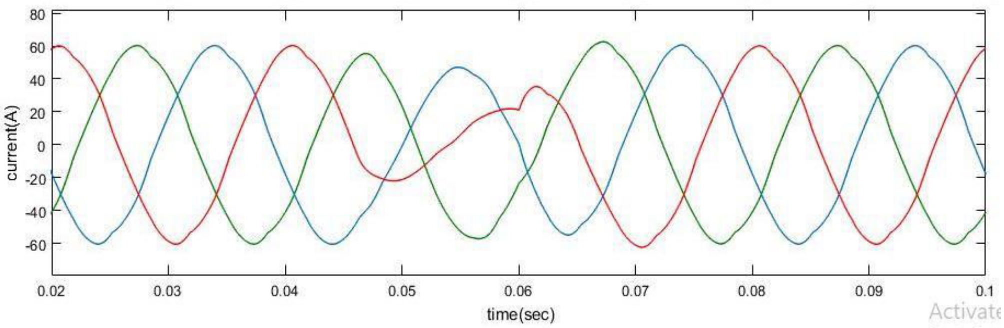


Figure.18. Source current due to non-linear loads under unbalanced at t=0.04s to t=0.06s

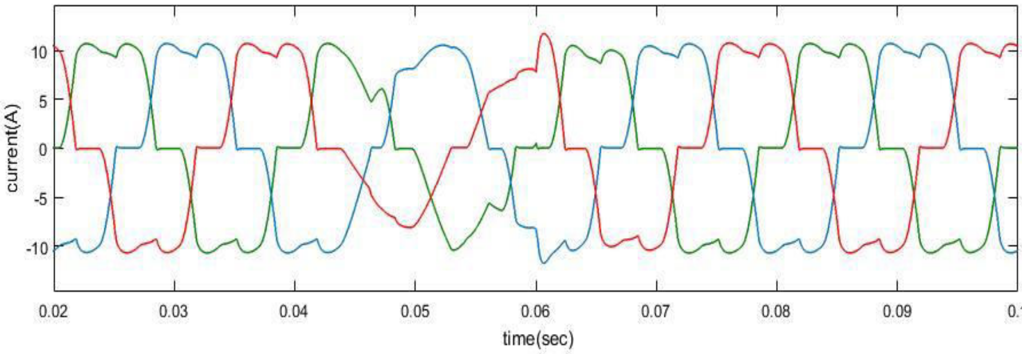


Figure.19. load currents due to nonlinear loads under unbalanced condition

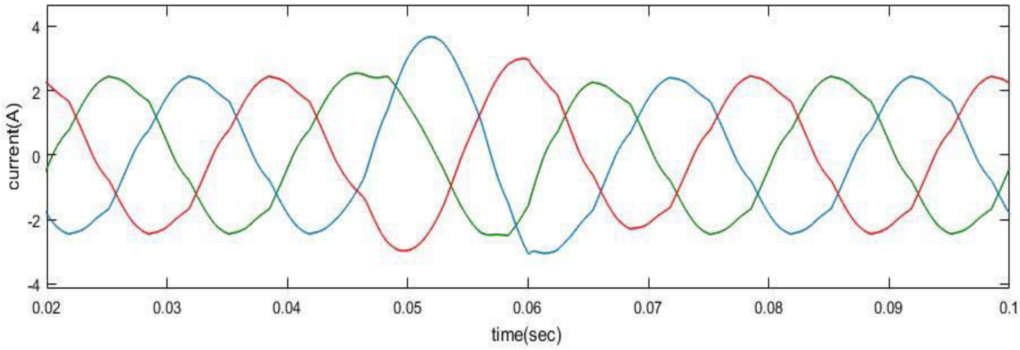


Figure.20. load current due to linear load under unbalanced condition

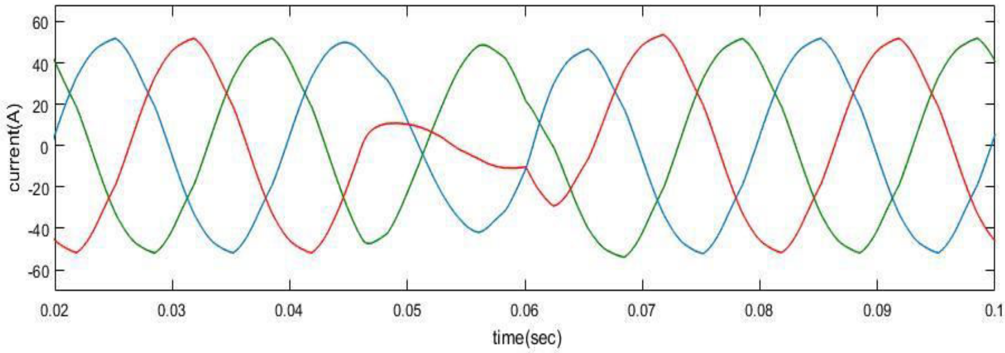


Figure.21. Compensating currents due to unbalanced loads

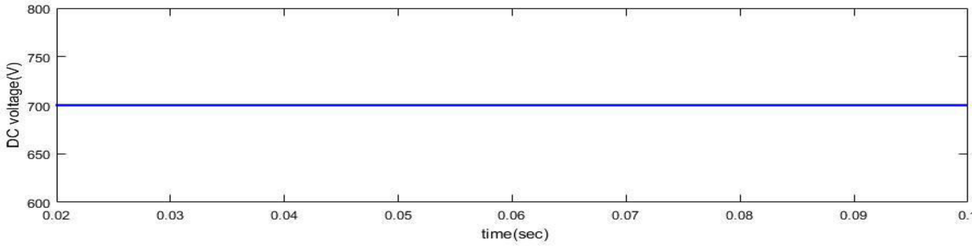


Figure.22. The DC link voltage with DSTATCOM non-linear load

DSTATCOM non-linear load

The VSC has begun to generate reactive compensating currents in order to balance and sinusoidalize the supply currents uniformly under the unbalanced load conditions. The unbalance in load is controlled at t = 0.06s, system resumes its previous performance. The three phase diode bridge rectifier is linked across CPI to provide the nonlinear load. Figure.21. Represents the compensating currents with unbalanced nonlinear load, the compensating currents generated by VSC are adding with harmonics polluted load currents to make supply currents balanced on grid side. Figure.22. shows the DC link voltage of system with DSTATCOM under unbalanced linear and nonlinear load conditions. It is maintained throughout the constant voltage.

SYSTEM PARAMETERS

Line impedance: R_s=3Ω , L_s=6mH

1) Linear RL load : R=50omh and L=80mH
2) Three-phase diode rectifier RL load
3) K_P =0.4 , K_I=0.1

Ripple filter:R_f=5Ω ,C_f=5μF

Interfacing inductor L=8mH

Capacitance of DC bus: 2250μF

Voltage of DC bus: 700V

Voltage of AC line: 415V, 50Hz

CONCLUSION

This paper proposed the DWT-based control algorithm was applied in real-time for DSTATCOM to improve the power quality in the distribution system. This DWT control approach uses the MRA method, which includes FIR filters and IDWT to extract basic component of the load current. Extracted the basic load component is then utilized to estimate the reference balanced source currents. in this paper, the proposed algorithm controls the THD of the source and load currents, unbalancing to balance conditions of the 'R', 'Y' and 'B' phase currents and the reactive power compensation in distribution system. According to specifications, THD of the supply current is less than 5%, indicating that the DSTATCOM with suggested control system is performing satisfactorily. The distribution system's power quality and performance have been upgraded.

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