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Coordinated Real–Reactive Power Support in Distribution Grids Using a Composite-Filter-Linked DSTATCOM Framework

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Abstract
Owing to the fact that multi-resolution analysis is a suitable method to use when studying transient signals, the wavelet transform has been of much significance to the current studies in power systems. In order to enhance the quality of power in the point of interconnection (CPI), the research paper based on a Distribution Static Compensator (DSTATCOM) suggests a discrete wavelet transform (DWT) control technique to address the research objectives.The research objectives were power system protection, power quality disturbance, power system transient, load forecast, fault detection, and power system measurement. Within the framework of the proposed method, the misaligned load current of each of the phases is decomposed through the application of the DWT, a time-frequency analysis, to extract the fundamental frequency components within the harmonic content and approximate the active power components.The wavelet transform is a strong signal processing tool that concurrently analyses signals (time-domain) and time frequency representations (time-frequency analysis). It is widely used in electric power system analysis due to these abilities especially when used with the voltage source converter (VSC) of the DSTATCOM. The difference between the calculated reference active components and the measured load currents is used as reference currents to control the VSC of the DSTATCOM.The DSTATCOM is tested in MATLAB simulations under various linear and nonlinear load conditions. It is shown that when unity power factor operation is used, the total harmonic distortion (THD) of the source current is less than 5 percent over a broad range of loading conditions.

Keywords: ***Comb filter, D-STATCOM, proportional resonant (PR) controller, voltage source inverter (VSI.***

1.Introduction
Over the last few years, the quality of power supply has become of particular concern both to the consumers and to the electric utilities. Unstable power power quality may cause instability of the system, decrease in equipment life, failure of power service equipment and general deterioration of the system performance. Voltage flicker, voltage sag, voltage swell, and harmonic distortion are the significant groups of issues of power quality. The real causes of such disturbances are supposed to be identified correctly as a prerequisite to enhancing the quality of power supply (1).

Problems encountered in the quality of power in the distribution systems are mainly related to harmonic currents, lagging power factor, high reactive power demand, and system unbalances. The major reasons of these problems include the extensive application of nonlinear and unbalanced loads. Also, it can be added that the penetration of the power electronic equipment, including the rectifiers, leads to the voltage distortion and high neutral currents in the power supply network (2). Power quality is usually determined by inputting acceptable levels of disturbance that are agreed upon by the utilities and the consumers. The greater the disturbance the lower the power quality and the lesser the disturbances the higher the power quality is. International standards recommend the maximum disturbances in quality of power to ensure reliability of the system. When these limits are exceeded, it can lead to the improper functioning or the failure of electrical equipment in the long term.

To improve the quality of the power and to deliver dependable power at the interconnection point which is the common point of interconnection (CPI), custom power devices like the Distribution Static Compensator (DSTATCOM) is commonly used (3). The power monitoring on the CPI is essential in the determination of the performance of the supply and the identification of the disturbance of the balance of power quality. Traditional Fourier Transform (FT) and Short-Time Fourier Transform (STFT) methods are associated with constraints of fixed time frequency resolution. Wavelet analysis was created in order to overcome these limitations. The wavelet analysis has multi-resolution analysis unlike FT-based techniques as it analyzes signals at varying levels of time and frequency. This enables proper signal breaks like spikes, jumps and non smooth event to be detected (4).

Wavelets are mathematical functions that are characterized both in time and scale and thus they are very well suited to the analysis of non stationary and transient signals. Therefore, the application of wavelet-based methods is a common method of detecting and alleviating the disturbances of power quality. The wavelet transform has a theoretical basis of signal analysis based on multiple time-frequency resolutions and formalized in the 1980s. French geophysicist Jean Morlet presented the idea of wavelets, but with the input of Croatian theorist physicist Alex Grossmann. Morlet noted Fourier Transform did not perform well in analysing the seismic signals that exhibit high variation and thus a new transform that would accurately time localize high frequency seismic events was developed (2).

Faulted signals in electric power systems are normally non-periodic and transient oscillations at high frequency due to electromagnetic transients. These properties present a difficulty to classical Fourier analysis, as periodic and wide-band signals are also assumed and dense sampling and longer time windows are needed to obtain adequate resolution at lower frequencies (3). Wavelet Transform (WT) has however been found to be useful in examining such transient phenomena. WT has been used in the place of Fourier-based methods because it can obtain time- and frequency-domain information at once and is used in a wide variety of applications in power systems (4).

One of the most important conditions of implementing the Discrete Wavelet Transform (DWT) with the help of filter-bank structures is perfect signal reconstruction or flawless reconstruction. This condition puts certain restrictions on the analysis and synthesis filters that are based on the orthogonal or the bi-orthogonal wavelet bases. In order to alleviate the disturbances caused by current-related power quality, the present paper suggests a DSTATCOM control strategy on the basis of Discrete Wavelet Transformer (DWT). The control method proposed removes the basic element of the load current of the decomposed wavelet levels to determine the approximated active current component of the reference. Besides, the technique allows assessing total harmonic distortion (THD) and other power quality disturbances, including load unbalance, at the same time based on the load current decomposition levels (5).

2. Proposed System

In non-adaptive control systems resonant controllers that are selectively filtered to resonant frequencies of single harmonic frequencies are used in combination with proportional-resonant (PR) controllers to reject harmonic components. Nonetheless, payment of higher harmonic orders would involve several resonant controllers which complicate the computational processing and delay the response of the system. To mitigate this problem, a control strategy that offers simultaneous compensation of various harmonics with a comb filter together with a PR controller will be proposed in this paper (9).

Figure 1 shows the structure of the DSTATCOM that is coupled with the proposed control scheme. In this research, the compensating current needed is applied to a standard DSTATCOM to improve the performance of the grid. The DSTATCOM will work in parallel with a three phase grid system to provide the required reactive power and harmonic compensation. Reference current generation process aims at the proper reactive power supply and harmonic reduction within a three-phase ABC-coordinate system (10).

Figure 1 provides a schematic diagram of a three-phase DSTATCOM system. At the CPI, both linear and nonlinear loads are joined. The DSTATCOM comprises of voltage source converter (VSC), DC bus capacitor, interface inductance, and load connected to them. Depending on the control algorithm used, the three phase VSC is operated by gate signals produced by a hysteresis current controller. The VSC leg midpoints are connected to the main supply with interface inductors to shunt the high frequency switching elements in the compensating currents. A ripple filter between the CPI and a capacitor and resistor is also added to reduce high -frequency switching noise of the VSC.

At the DC end, a nonlinear RL load, and a 3-phase bridge rectifier are linked to this system to allow the reactive power and harmonic currents to be effectively compensated under a variety of operating conditions.

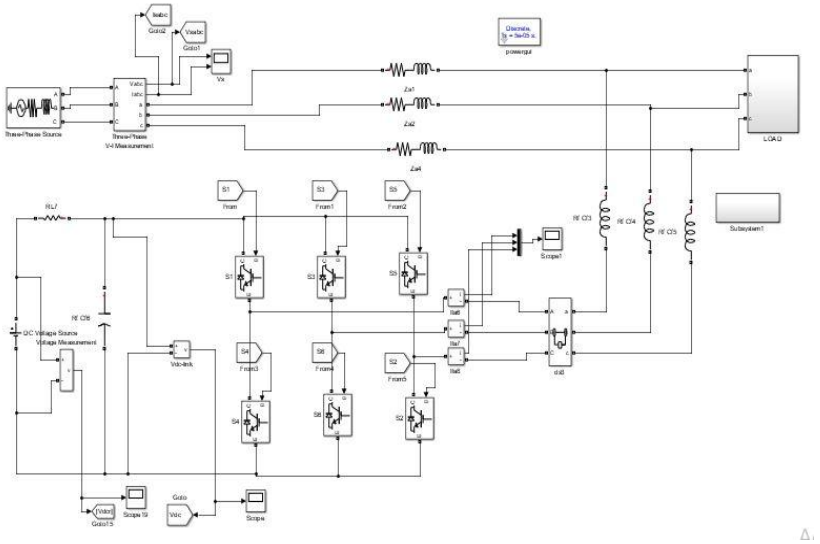


FIGURE 1 Simulation model of DSTATCOM

3. Simulation Results

In order to measure how well the suggested control strategy is working, the Simulink and Sim Power Systems toolboxes are applied to construct a MATLAB/Simulink model of a three-leg Voltage Source Converter (VSC)-based DSTATCOM. The simulations are carried out in three phases distribution system, both with linear and nonlinear load conditions, with balanced and unbalanced operating conditions. The results of the simulation done with various cases are discussed below in the subsections.

3.1 Performance Not with DSTATCOM.

A. System Performance at both Balanced Linear and Nonlinear Loads.

Figure 5.5 displays the voltages at interconnection point (CPI) when DSTATCOM is not connected to the system. Figure 2 shows the corresponding source currents that supply both linear and nonlinear loads that are not DSTATCOM compensated. The source currents have serious harmonic content since no compensating currents are injected at the CPI in the absence of the DSTATCOM. Accordingly, the sources under nonlinear load conditions are no longer sinusoidal.

Figure 3 shows the load currents attracted by nonlinear loads whereas Figure 4 depicts the load currents when the load is linear. Without DSTATCOM the harmonic distortion in the load currents is passed directly into the source currents, producing poor quality of power.

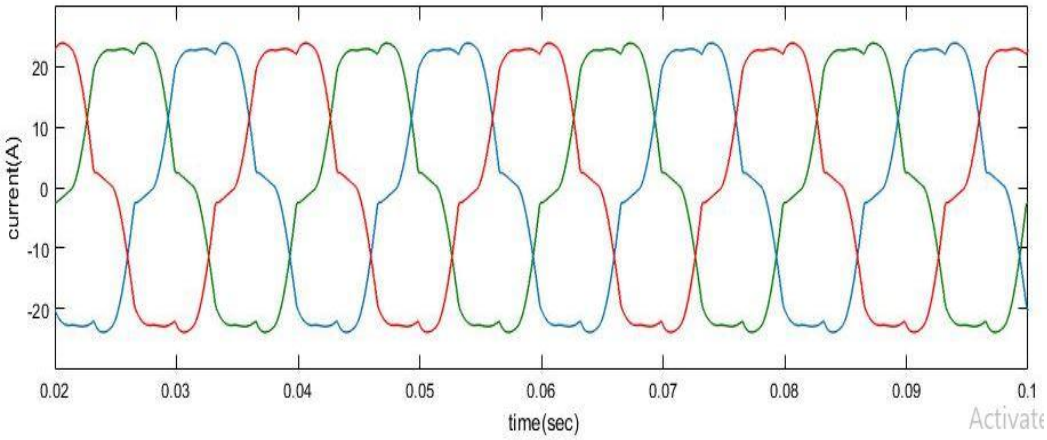


FIGURE 2 Source currents due to balanced load without DSTATCOM

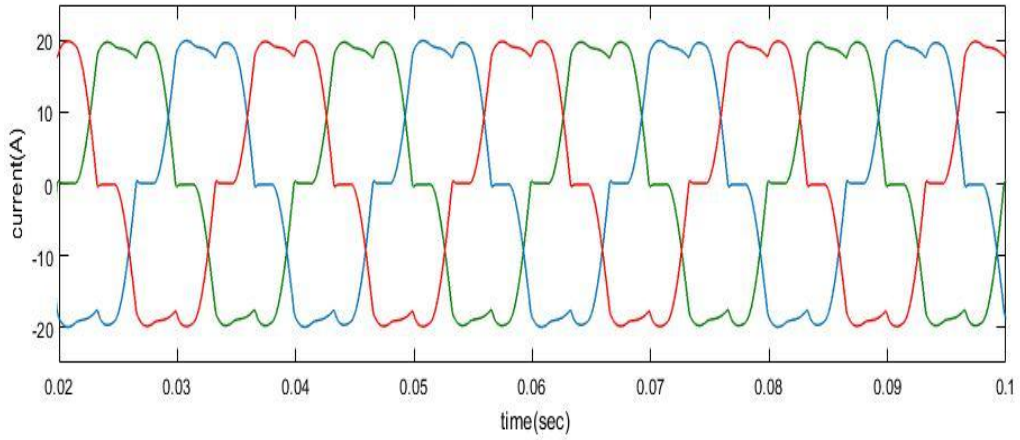


FIGURE 3 load currents due to balanced non-linear load without DSTATCOM

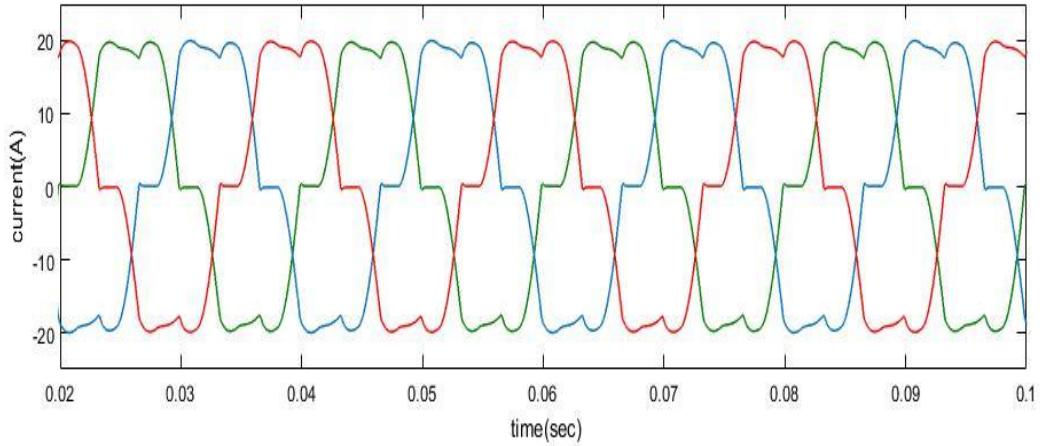


FIGURE 4 Source currents due to balanced linear loads without DSTATCOM

Figure 9 illustrates the harmonic spectra of phase R in the condition without-DSTATCOM with (a) source voltage, (b) source current and (c) load current. Figure 9 a-c clearly shows that there are higher-order harmonic content in the source and load current when there is no DSTATCOM compensation in the case of a linear and nonlinear load.

3.2. Performance With DSTATCOM

A. System Performance at both Balanced Linear and Nonlinear Loads.

Figure 5 represents the three-phase supply voltages in case the DSTATCOM is connected to the system. Figure 5 also demonstrates the corresponding source currents when the load is balanced. Figure 6 shows the load current that a nonlinear load will attract. With balanced nonlinear loading conditions, the dissimilarity between source and load currents is minor because of the presence of source impedance.

The DSTATCOM works to provide the required reactive power at the location to keep the unity power factor operating at the CPI and to considerably minimize grid-side current harmonics. Figure 7 shows the R-L load currents at the CPI and Figure 8 shows the compensating currents entering through the DSTATCOM. It is seen that the compensating currents mostly consist of the harmonic components that are required to cancel the harmonics in the load currents.

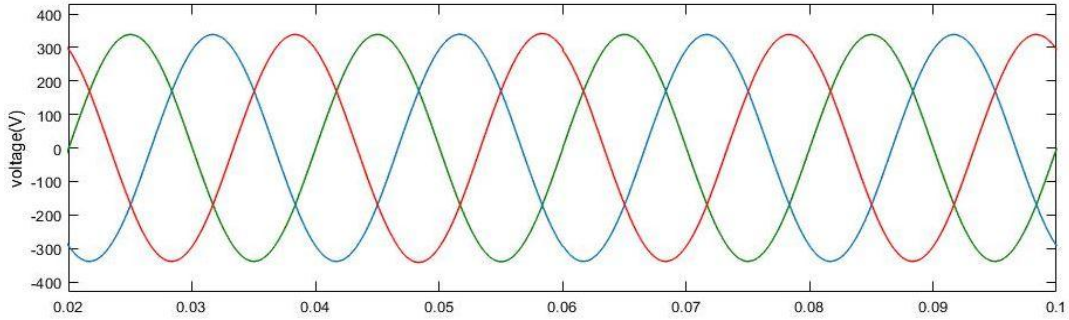


FIGURE 5 The CPI voltage with DSTATCOM

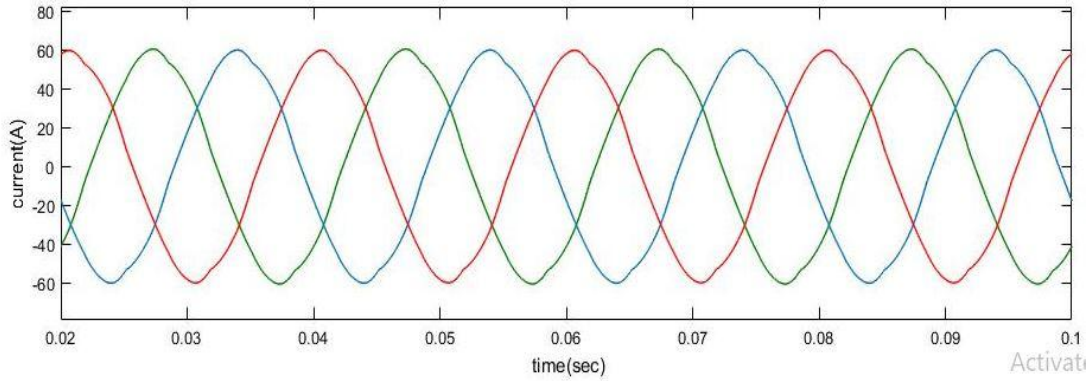


FIGURE 6 Source currents of non-linear load with DSTATCOM

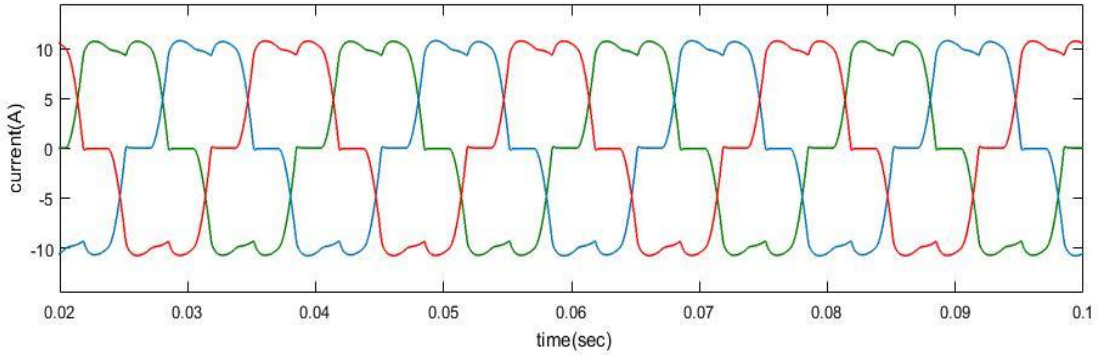


FIGURE 7 load currents due to non-linear load

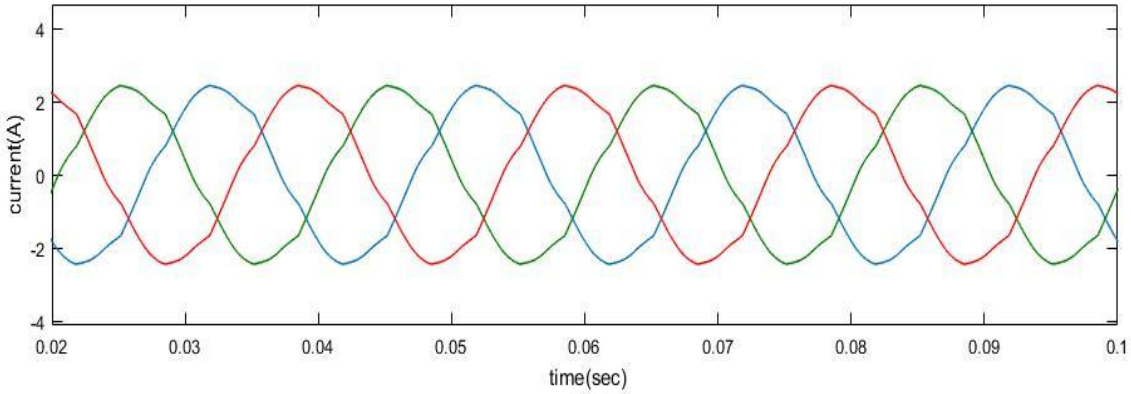


FIGURE 8 Load currents due to linear load with DSTATCOM

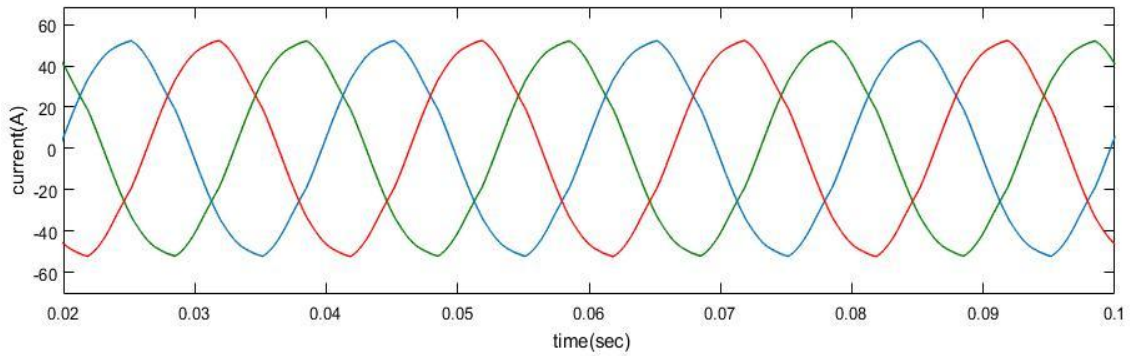


FIGURE 9 Compensating currents with DSTATCOM

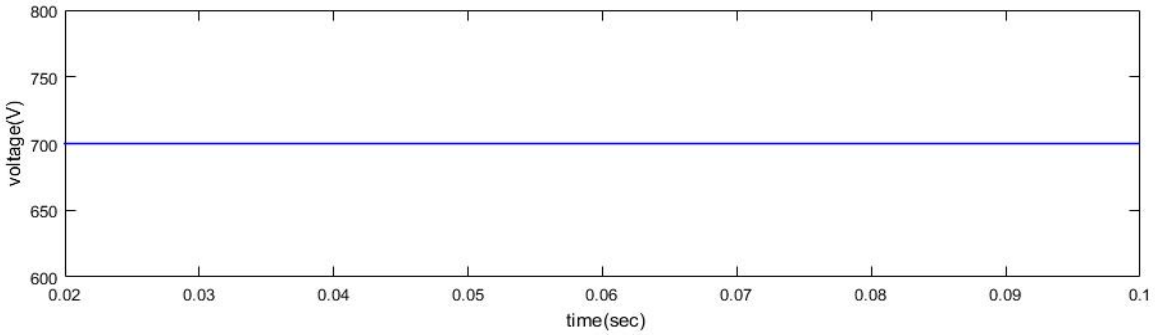
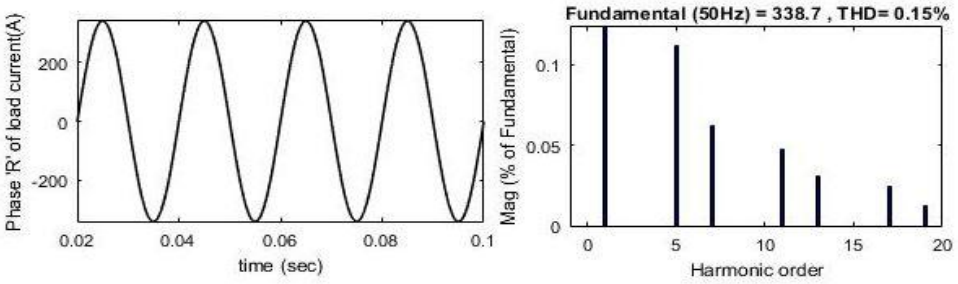


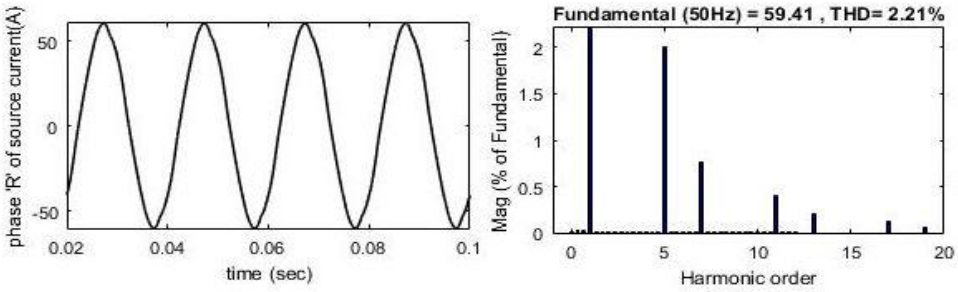
FIGURE 10 DC link voltage

Figure 9 indicates the DC-link voltage of the DSTATCOM to be held at a constant level when the conditions are balanced linear or nonlinear load, and indicates the stability of the proposed control strategy.

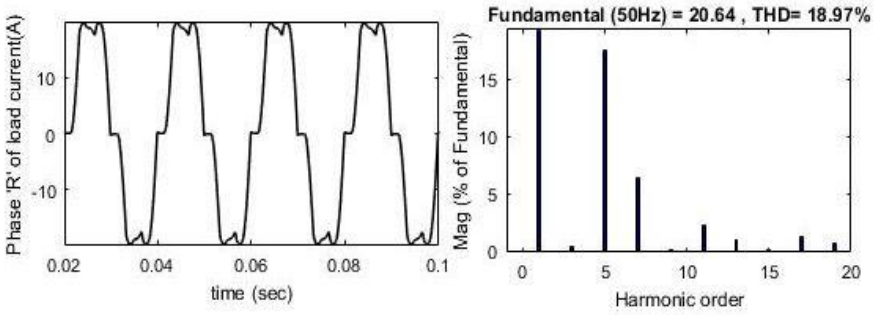
A comparative analysis of the percentage total harmonic distortion percent-THD of the source voltage and the source current with and without DSTATCOM of the load current is presented in the following table. The findings suggest that the level of THD of the source voltage and currents is much greater with no DSTATCOM present. The suggested DWT-based DSTATCOM control plan is successful in minimizing the distortion of source current, and, therefore, enhancing the overall performance of the system. Moreover, the DWT-based method offers more information, like the grouped harmonic estimates, which increases the monitoring and control of the DSTATCOM. Therefore, the control scheme of the DSTATCOM under the proposed control scheme is well within acceptable ranges.



11(a)



11(b)



11(c)

TABLE 1 Comparison of THD With and Without DSTATCOM

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%

B. System Performance when subjected to Unbalanced Linear and Nonlinear Loads.

In this section, simulation results are given of the operating state of the distribution system when subjected to unbalanced load which is aided by DSTATCOM compensation. Figure 17 depicts the CPI voltages in the case where the system is hooked to the DSTATCOM in unbalanced conditions. Figure 18 represents the corresponding source currents.

Representative waveforms of the load currents in nonlinear and linear load conditions under imbalanced load are shown in figure 19 and figure 20 respectively. The load and the source currents are balanced and sinusoidal up to time t = 0.04 s. At t = 0.04 s the load on phase “b” is cleared, and this creates an imbalance in the system.

To curb the unbalanced state, the VSC commences to inject suitable reactive compensating currents to make balanced and sinuoidal supply currents. The load imbalance is paid back by t = 0.06 s and the system is restored to the normal operating conditions. The nonlinear load is provided by a three phase diode bridge rectifier that is connected at the CPI.

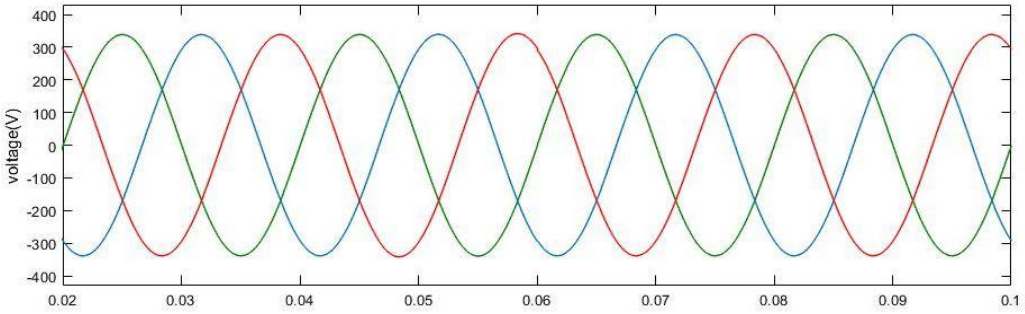


FIGURE 12 The CPI voltages with DSTATCOM

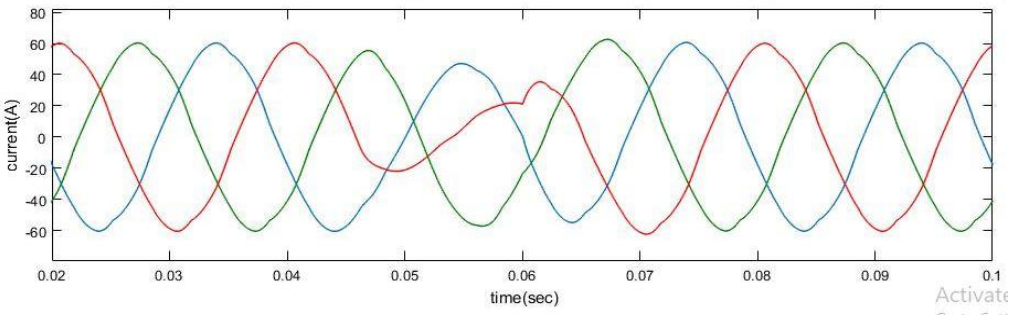


FIGURE 13 Source current t=0.04s to t=0.06s

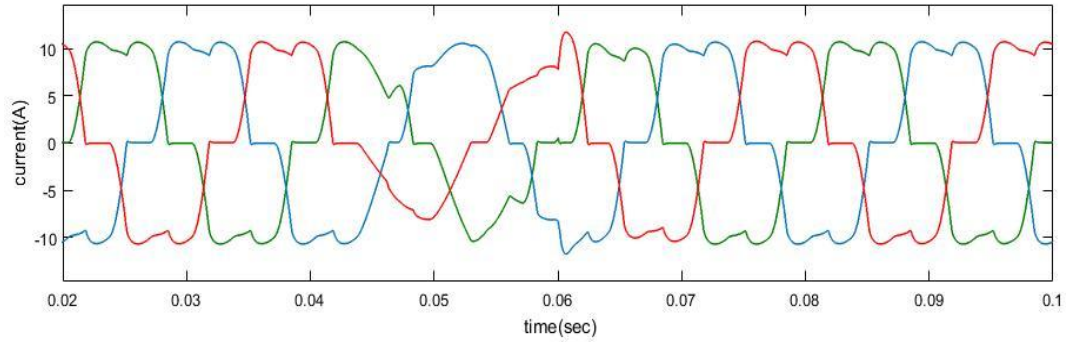


FIGURE 14 load currents due to nonlinear loads under unbalanced condition

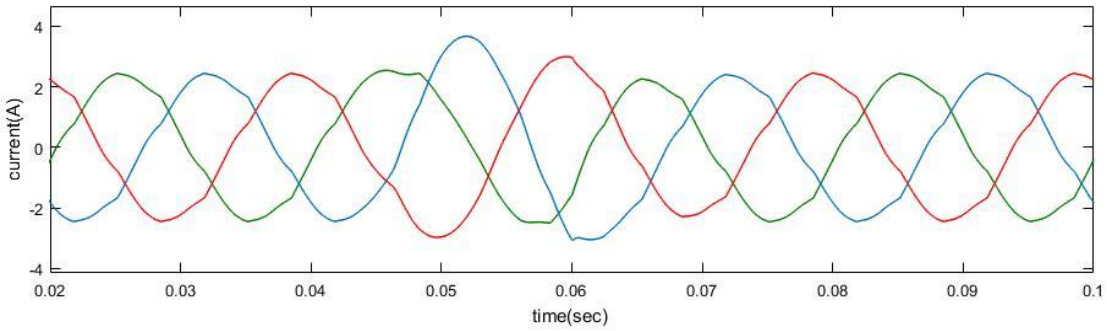


FIGURE 15 load current due to linear load under unbalanced condition

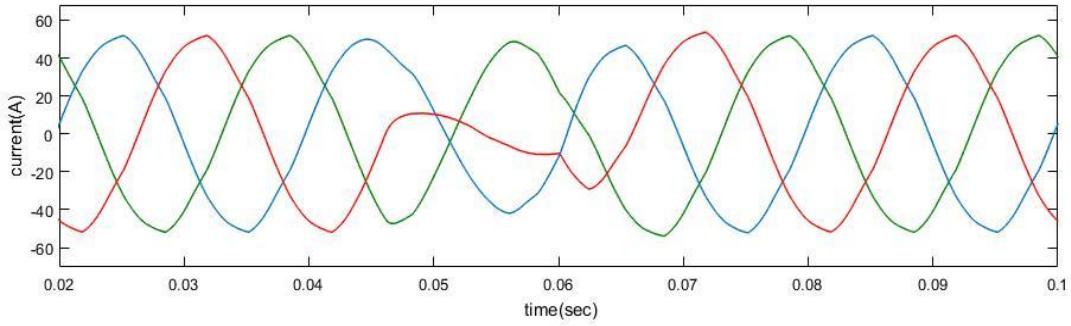


FIGURE 16 Compensating currents due to unbalanced loads

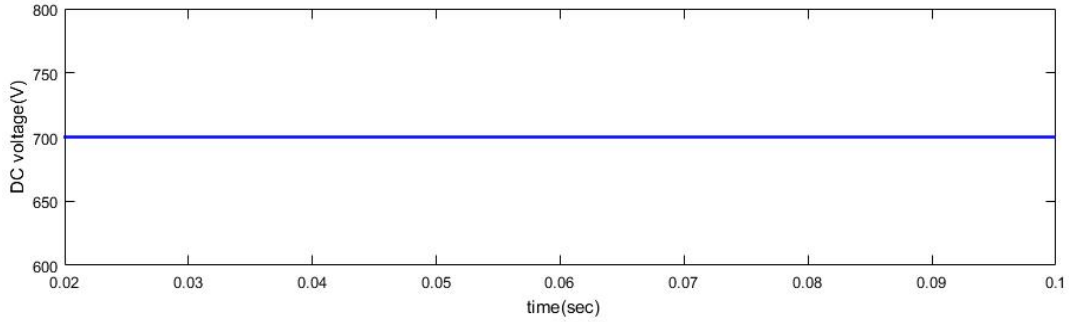


FIGURE 17 The DC link voltage

Figure 21 shows the compensating currents injected by the DSTATCOM in the case of unbalanced nonlinear load conditions. Combined with the harmonically distorted load currents these compensating currents lead to balanced and sinusoidal grid-side source currents. Figure 22 represents the DC-link voltage of the DSTATCOM at unbalanced linear and nonlinear loads. The DC-link voltage will also be stabilized during steady-state operation which will once again prove the strength of the proposed control strategy.

4. Conclusion

The proposed work is aimed at improving the power quality in the distribution system by suggesting a Discrete Wavelet Transform (DWT)-based control algorithm of a DSTATCOM in real-time. The suggested plan utilizes

multi-resolution analysis (MRA) including finite impulse response (FIR) filters and inverse DWT (IDWT) to deconstruct the basic element of the load current. With this obtained fundamental component, currents of balanced reference sources are produced.

The suggested control scheme is useful in compensating reactive power and balancing the R, Y and B phase currents and highly effectively in minimizing the overall harmonic distortion (THD) of the source currents and load currents. The simulation results indicate that the source current THD can be kept below 5% and meet the standard power quality requirements and proves the successful work of the DSTATCOM with the offered control strategy. As a result, the total performances and power quality of the distribution system is increased significantly.

Acknowledgement: Nil

Conflicts of interest

The authors have no conflicts of interest to declare

References

1. Bollen MHJ. Understanding power quality problems: Voltage sags and interruptions. IEEE Press. 2000;1(1):1–543.
2. Institute of Electrical and Electronics Engineers. IEEE Std 519-2014: Recommended practice and requirements for harmonic control in electric power systems. IEEE Power and Energy Society Standard. 2014;29(1):1–29.
3. Akagi H, Nabae A, Atoh S. Control strategy of active power filters using multiple voltage-source PWM converters. IEEE Transactions on Industry Applications. 1986;IA-22(3):460–465.
4. Blaabjerg F, Teodorescu R, Liserre M, Timbus AV. Overview of control and grid synchronization for distributed power generation systems. IEEE Transactions on Industrial Electronics. 2006;53(5):1398–1409.
5. Yang Y, Blaabjerg F, Zou Z. Benchmarking of grid fault modes in single-phase grid-connected photovoltaic systems. IEEE Transactions on Industry Applications. 2013;49(5):2167–2176.
6. Timbus A, Liserre M, Teodorescu R, Rodriguez P, Blaabjerg F. Evaluation of current controllers for distributed power generation systems. IEEE Transactions on Power Electronics. 2009;24(3):654–664.
7. Liserre M, Teodorescu R, Blaabjerg F. Multiple harmonics control for three-phase grid converter systems using PI–RES current controller in a rotating frame. IEEE Transactions on Power Electronics. 2006;21(3):836–841.
8. Teodorescu R, Blaabjerg F, Liserre M, Loh PC. Proportional resonant controllers and filters for grid-connected voltage-source converters. IEE Proceedings – Electric Power Applications. 2006;153(5):750–762.
9. Chmielewski T. Comb filters for harmonics control in grid-connected power electronic converter applications. Proceedings of the 19th European Conference on Power Electronics and Applications (EPE'17 ECCE Europe). 2017;1(1):P1–P6.
10. Srikanthan S, Mishra MK. DC capacitor voltage equalization in neutral clamped inverters for DSTATCOM application. IEEE Transactions on Industrial Electronics. 2009;57(8):2768–2775.