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Adaptive Filter Implementation for Dstatcom

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ABSTRACT: Non sinusoidal current in a distribution system is mainly due to nonlinear characteristics of equipment such as adjustable speed drives, switch-mode power supplies, rectifiers, and others such type of loads. In most cases, nonlinear loads are represented either as a harmonic current source or a harmonic voltage source in practical applications and responsible for creating power-quality problems. Mitigation of power-quality problems can be achieved by using passive or active filters; however, due to certain advantages of active filter (AF) with digital control, it is used for improving power quality. An improved version of a shunt-connected AF used in the distribution system is known as a distribution static compensator (DSTATCOM). It is used for compensation of current-related power-quality problems such as reactive-power compensation, harmonics elimination, and load balancing in power factor correction (PFC) mode and zero voltage regulation (ZVR) mode. Improved responses and capacity for transient overload even at a reduced voltage level are the major advantages of DSTATCOM. Various international standards such as IEEE and IEC have reported the guidelines of harmonics limit at the point of common coupling (PCC).

Effective utilization of a converter used as a DSTATCOM depends upon the control algorithm used for extraction of reference currents and switching schemes. For extracting reference signals, many time-domain control algorithms are available, which are based on phase-dictated sinusoid-tracking parameter extraction of non-stationary sinusoidal, amplitude phase-locked loop (PLL), etc; unit template-based control algorithm without sensing load currents; one-cycle control, which has excellent harmonics suppression, simple circuitry, robust performance, and low cost linear feedback control and signal-processing algorithm for selective harmonic identification based on heterodyning, moving-average finite-impulse response filters, and PLL using feed forward based control. These algorithms are based on basic arithmetic operation of mathematical function, transform, tuning of internal constants, clock, an integrator, flip-flops, comparators and logic circuits, etc. The performance of these classical control algorithms depends upon selection and tuning of internal parameters, circuit components, and their formulations. An AF is implemented in three-phase distorted voltage ac mains for reactive-power compensation, harmonics elimination, and load balancing with a self-supporting dc link in PFC and ZVR modes of DSTATCOM. This proposed control algorithm is also modified for DSTATCOM operation in ZVR mode. The main features of this control approach are high convergence speed and robustness with respect to input frequency and internal parameter variations and less sensitivity to voltage pollutions when it is used as a reactive-power component of current extraction. Design of control algorithm only needs multiplications, integral, gain, and subtraction blocks. Thus, the structure of this control algorithm is based on basic arithmetic operation; hence, its implementation is simple, and it does not require any extra synchronization circuit. Selected values of integral constants are not affecting the performance of the filter within a certain range. The simulations were performed in the environment of MATLAB/SIMULINK.

I. INTRODUCTION

VSCs using PWM control are the mainstay of modern power electronics controllers, such as STATCOM, DVR and HVDC-VSC stations. One of the many advantages of VSCs using PWM control is that they can produce quasi-sinusoidal voltage waveforms, having almost any desired phase relationship with an existing AC system waveform, thus dictating the direction and magnitude of the active and reactive power exchanged with the AC system. In practice, the high harmonic frequencies generated by the VSC could be filtered out by high-frequency harmonic filter, but in practice the operation of such filters will not be perfect or they may not even be operating. Moreover, harmonic interactions between the VSC and the electric network will always take place. This interaction may produce harmonic resonances which can only be predicted with realistic models of the VSC and the electric network. Comprehensive models for power converters have been reported in the open literature. In power systems harmonic studies, switching functions have found widespread acceptance in the modelling of converters based on thyristor, where the commutation period of the thyristor has been included in the switching functions. As an extension, switching functions have also been used in the modelling of converters based on GTOs or IGBTs, showing even greater adequacy than in the former application. In this chapter, switching functions in the form of harmonic transfer matrices are used to model three-phase PWM VSCs for steady-state harmonic analysis. The models are given in the form of harmonic equivalent impedances. In these models, the capacitor and its effects on the AC and DC sides are taken explicitly into account. The model is

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derived with a view to be used as the main building block with which other power electronics controllers can be assembled, and consequently a modular approach is adopted in its development.

Voltage source converters (VSC's) provide constant/controllable dc bus voltage, nearly sinusoidal input current, controllable power factor (leading, lagging, or unity), and regenerating capability. Because of these features, they become attractive in industrial applications as part of high performance integrated drives or as stand-alone units with common dc bus and multiple drives. Although harmonic distortion of the input current is usually below 5%, the utility current contains high-frequency components caused by the pulse width modulation (PWM) switching (frequencies: 2–15 kHz). These high-frequency components can cause improper operation of other EMI sensitive loads/equipment on the grid.

One method to prevent pollution of the utility by high frequency current ripple is to use an RLC filter at the input of the VSC. The RC elements in the filter provide a low impedance path for the high-frequency components, preventing them from entering the utility. A resistor in series with a capacitor is used for damping the high-frequency resonance in the filter. Because of the power losses in the resistor, and its additional cost, it is advantageous to use only an LC input filter and make use of control algorithms to "actively" damp resonance. Two principally different approaches are used in to damp resonance in the output LC(R) filter of an inverter. The method in is based on an additional current feedback in the LC filter and introduces extra cost of the current sensor. In the voltage from the capacitor is used for active damping in the stationary and synchronous reference frames, respectively.

II. EXISTING SYSTEM

(CR) A simulation study of adaptive filter (AF) for synchronous-extraction-based control has been reported for a single-phase ac system in the literature for PFC. It is used for estimation of only harmonics from distorted signal. Moreover, the structure is simple and effective with less number of internal constants. A key factor for selection of this control is insensitive with the selection of an integral gain value up to a certain range. Generally, load currents are distorted or have a reactive-power component due to the nature of loads. This filter takes energy from input as the load current, and it is not in the same direction as the PCC voltage. This AF is able to handle variation in supply frequency because any variation in supply frequency equally affects in current and voltage signals.

III. PROPOSED SYSTEM

Figure1 shows a block diagram of the proposed AF based on the adaptive nature for synchronous extraction in the time domain for deriving reference supply currents. It is applied under distorted ac mains feeding to linear and nonlinear loads. The basic steps for estimation of different control variables of the control algorithm are given below. The block diagram of this algorithm is shown in Figure1 Error in the phase "a" voltage is the difference between v_{sa} and v_{so}, and it is denoted by Ve. A1, A2, and A3 are internal constants of the algorithm, which are positive-real values. The selection process of internal constants is described in [15]–[17], and these constants decide the behaviour of the algorithm in terms of convergence speed and accuracy. The values of these internal parameters A1, A2, and A3 are considered as 4, 2, and 1.5 for this implementation. The proposed algorithm is able to identify sinusoidal components of input that is close to fundamental frequency after assigning an initial condition in its integration block. It is observed that the variations in $\sin \theta_{va}$ and $\cos \theta_{va}$ components of the phase "a" PCC phase voltage are effectively tracked in less than a couple of cycles. The number of tracking cycles is reduced by increasing the value of internal constants up to a certain extent. The advantages of this algorithm are low computational time, robustness with respect to frequency variation, and high estimation accuracy, which are necessary in most practical applications. Similarly, $\sin \theta$ and $\cos \theta$ components ($\sin \theta_{vb}$, $\cos \theta_{vb}$ and $\sin \theta_{vc}$, $\cos \theta_{vc}$) of phase b and c are also estimated.

For extraction of the reactive-power component of load current, an error signal is multiplied with the quadrature component of PCC voltage (v_{qa}). After integration of this component again multiply with vqa term to extract the reactive-power component of phase "a" load current (i_{Lqa1}). After extraction of the reactive-power component of load current, its root-mean square value is estimated and converted to a peak value using gain (G). The amplitude of the reactive-power component of phase "a" load current is "i_{Lqa}." Similarly, the amplitude of the reactive-power component of phase "b" and phase "c" load currents iLqb and i_{Lqc} are estimated. The amplitudes of average fundamental active- and reactive-power components of load currents of three-phase loads are estimated using the amplitude sum of individual three-phase active- and reactive-power components of loads divided by 3.

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IV. ESTIMATION OF AMPLITUDE OF ACTIVE- AND REACTIVE-POWER COMPONENTS OF LOAD CURRENTS

Active-power, reactive-power, and harmonics components of load currents are the primary components in distorted and lagging power factor load currents. Active- and reactive-power components of phase "a" load current are subtracted from the original load current, and the generated error is multiplied with the in-phase component of PCC voltage (vpa). This signal is passed through an LPF before integration. After integration with a proper constant, this component is again multiplied with the in-phase component of PCC voltage ($_{vpa)}$ in a closed loop system. The active-power component of phase "a" load current (iLpa1) is extracted from the original load current using the previously described procedure in adaptive nature.

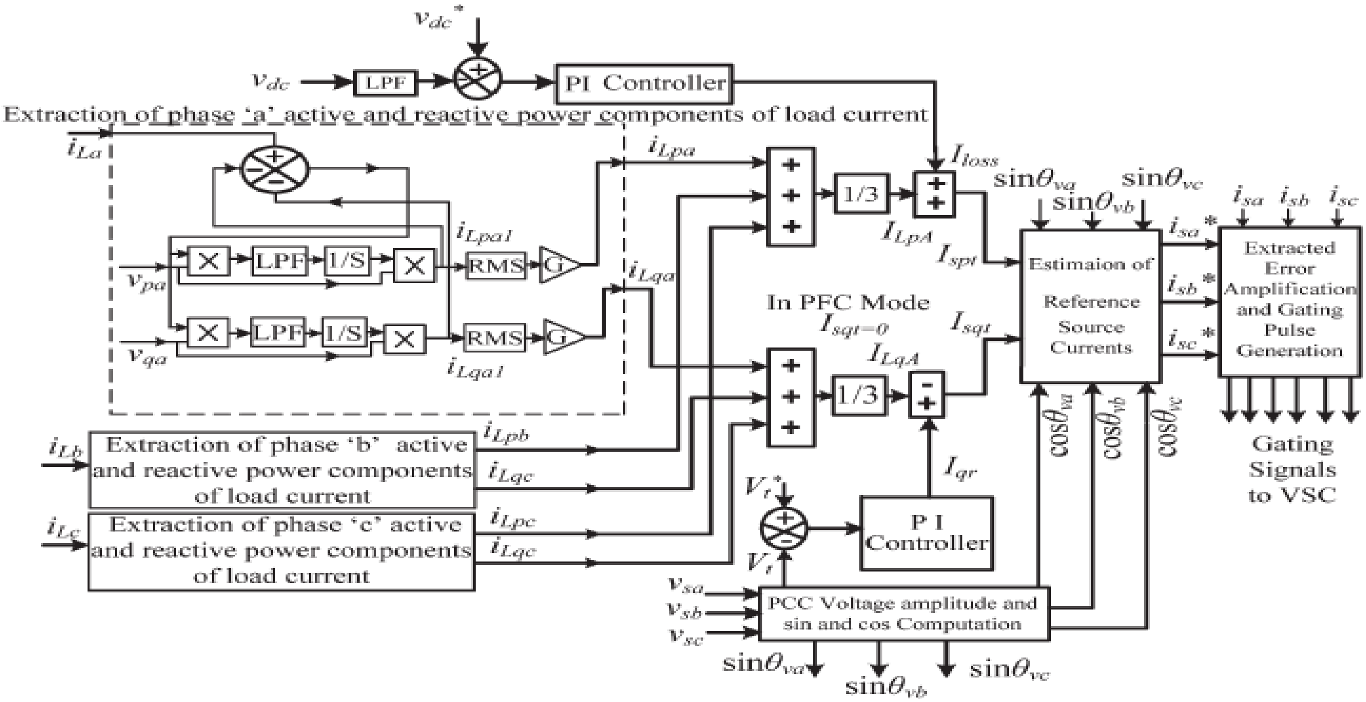

Figure 1: Generation of reference supply currents using Adaptive Filter.

After extraction of the active-power component of load current, its root-mean-square value is estimated and converted to a peak value using gain (G). The amplitude of the estimated active power component of phase "a" load current is i_{Lpa}. Similarly, the amplitude of the active component of phase "b" and phase "c" load currents iLpb and iLpc are estimated.

For extraction of the reactive-power component of load current, an error signal is multiplied with the quadrature component of PCC voltage (v_{qa}). After integration of this component again multiply with vqa term to extract the reactive-power component of phase "a" load current (iLqa1). After extraction of the reactive-power component of load current, its root-mean square value is estimated and converted to a peak value using gain (G). The amplitude of the reactive-power component of phase "a" load current is "i_{Lqa}." Similarly, the amplitude of the reactive-power component of phase "b" and phase "c" load currents i_{Lqb} and i_{Lqc} are estimated. The amplitudes of average fundamental active- and reactive-power components of load currents of three-phase loads are estimated using the amplitude sum of individual three-phase active- and reactive-power components of loads divided by 3.

V. SIMULATION RESULTS

Figure 2 shows a schematic of a DSTATCOM connected to three-phase ac mains feeding three-phase linear/nonlinear loads. Three-phase linear and nonlinear loads are connected through a three-pole single-throw switch (TPSTS) at the PCC, as shown in this figure. The TPSTS is used for disconnection of linear loads, and for single operation, another single-pole single-throw switch is used, which is not shown in the figure. A three-phase diode bridge rectifier with

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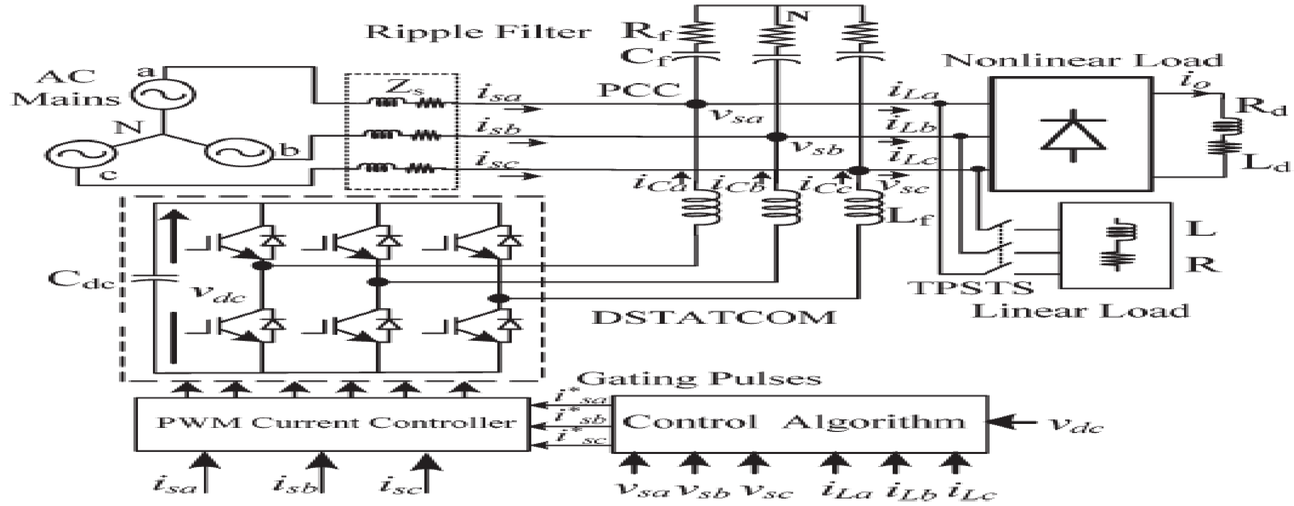
resistive load (Rd) and filter inductance (L_d) is modelled as a nonlinear load for testing purposes. This type of load has zero demand of reactive power in an ideal condition. A set of three-phase resistors (R) with inductors (L) is modelled as a linear load. L_s and R_s are considered as ac mains impedance parameters (Z_s). The normal available grid voltage with an extra supply inductance is considered as the distorted voltage of ac mains. For implementation of a control algorithm, sensed variables are PCC voltages (v_{sa}, v_{sb}, v_{sc}), supply currents (i_{sa}, i_{sb}, isc), load currents (iLa, iLb, iLc), and dc-link voltage (v_{dc}).



Interfacing inductors (L_f) are connected at the ac side of the voltage source converter (VSC) for reducing ripple in compensating currents. The series-connected capacitor (C_f) and resistor (R_f) form the passive ripple filter installed at PCC in parallel with the load, and it is used for filtering the high-frequency switching noise of PCC voltages.

VI. SIMULATION RESULT ANALYSIS

6.1 Performance of AF:

Figure 3 shows the various intermediate signals of the control algorithm, which include phase "a" distorted-voltage waveform (v_{sa}), filtered-voltage waveform (v_{sa1}), load current (i_{La}). The scale of phase "a" voltage "vsa" and vsa1 is 200 V/div, and other signals' scale is 20 A/div with time in the x-axis. Extraction of these control signals under load injection is shown in Figure 5.2 respectively, which demonstrates the variation and extraction speed of control signals using the proposed AF under time-varying non- linear load in ZVR mode of DSTATCOM.

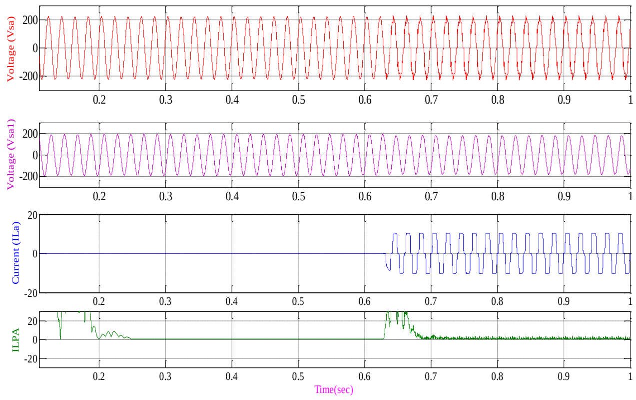


Figure 3: Various intermediate signals of the control algorithm at load injection.

6.2 Steady-State Performance of DSTATCOM at Linear and Nonlinear Loads in PFC Mode:

Three PCC voltages (vab, vbc, vca) and respective supply currents (i_{sa}, i_{sb}, i_{sc}) are shown in Figure 4 (a)–(c). It is observed that PCC voltage drops from rated value due to supply impedance and load demand.

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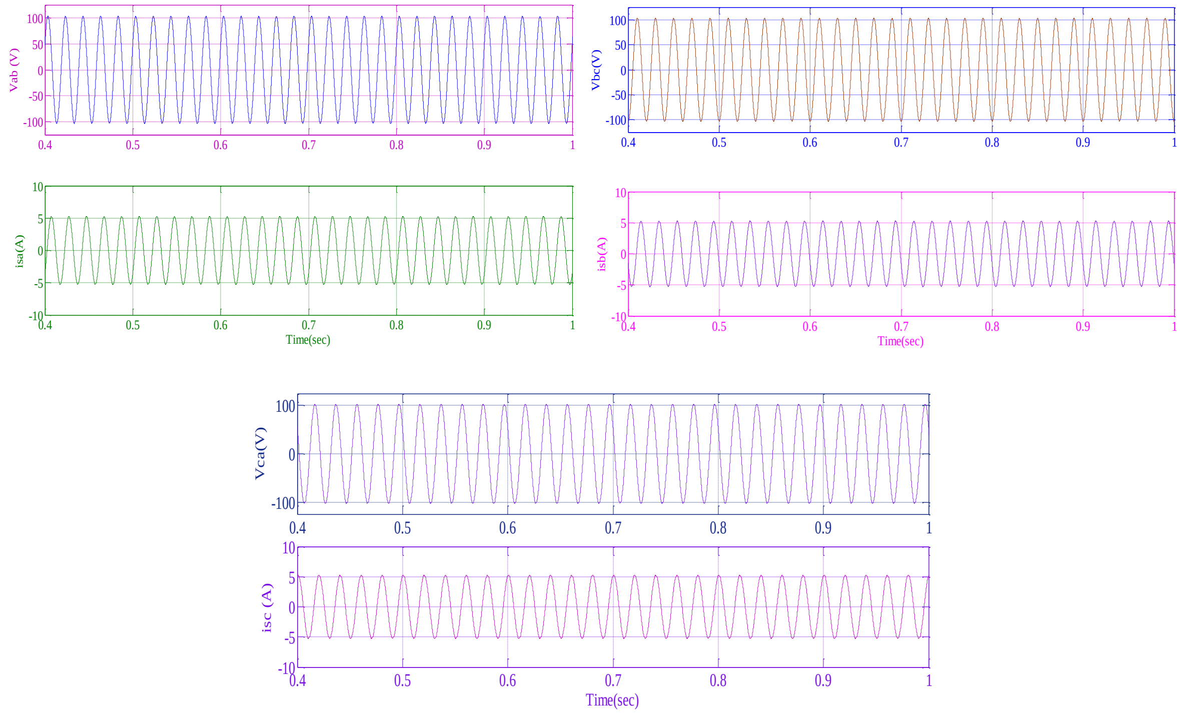

Figure 4: Steady-state performance of DSTATCOM at linear lagging PF load in PFC mode.

Figure 5 (a)–(f) shows the waveform of three-phase PCC voltages (v_{ab}, v_{bc}, v_{ca}) with respective phase supply currents (i_{sa}, i_{sb}, i_{sc}), harmonic spectrum of phase "a" supply current and distorted waveform of phase "a" load current (i_{La}) and its harmonic spectrum under three diode-based rectifier loads.

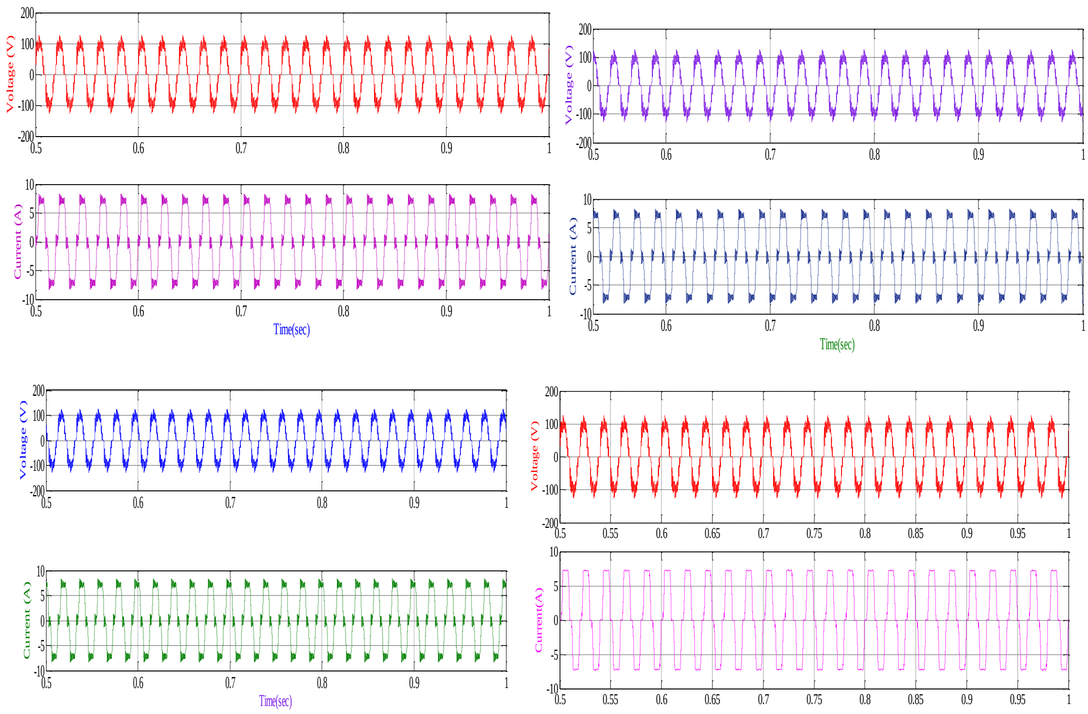

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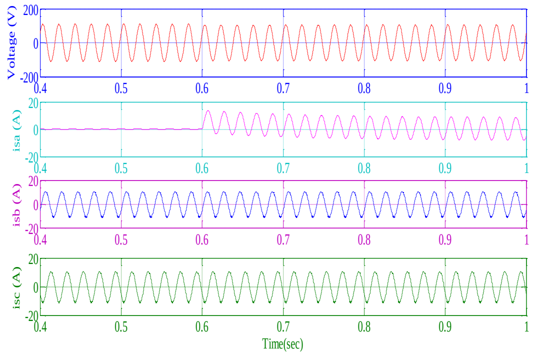
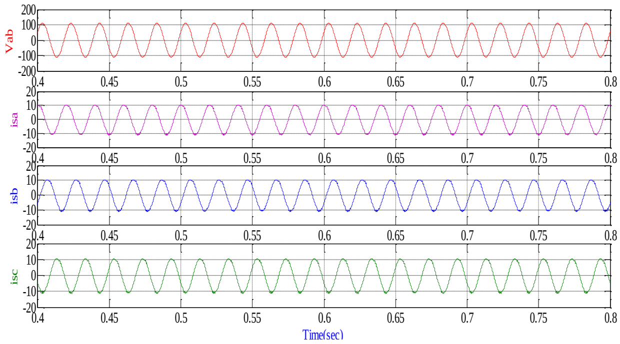
Figure 5: Steady-state performance of DSTATCOM at nonlinear loads in PFC mode.

6.3 Dynamic Performance of DSTATCOM in PFC Mode:

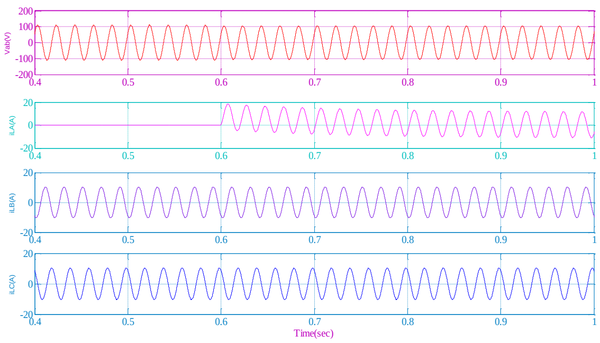
Figure 6 (a) and (b) shows the waveforms of supply currents (isa, isb, isc) and load currents (iLa, iLb, iLc) with distorted PCC line voltage (vab) under unbalanced linear loads. An unbalanced load condition is created by the removal of load in phase "a." The variation of supply current (isa), DSTATCOM current (iCa), and load current (iLa) are shown with dc-link voltage (vdc) in Figure 5.5(c). It is observed that during load unbalancing, dc-link voltage regulated at the reference level without any variation. It shows the function of DSTATCOM for load balancing and also observed the fast action of AF during sudden load injection. Load injection in phase "a" (iLa) and action of DSTATCOM current (iCa) is observed at the same time.



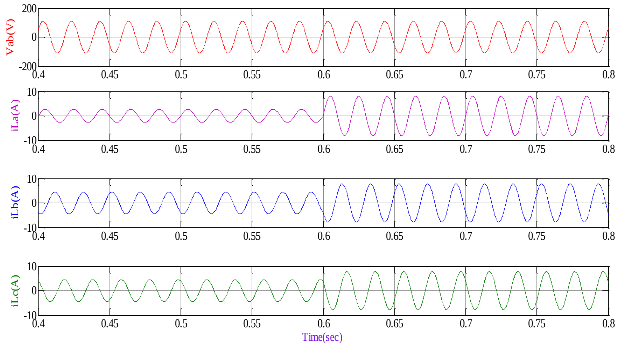
(a)



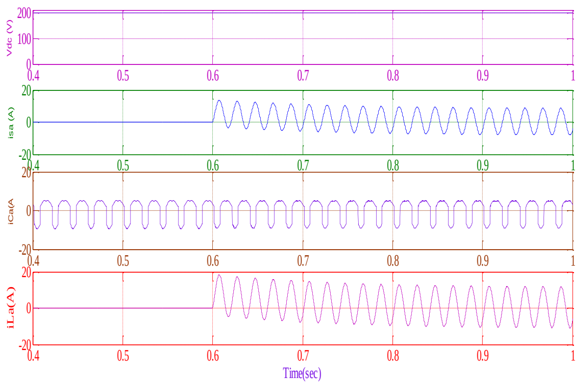
(a)



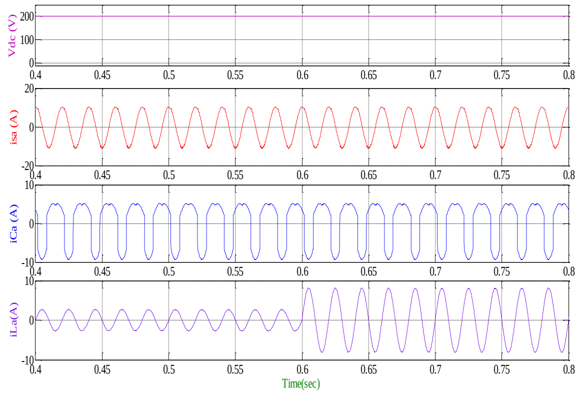
(b)



(b)



(c)



(c)

Figure 6: Dynamic performance of linear loads unbalanced nonlinear loads

Figure 6: Dynamic performance of DSTATCOM at DSTATCOM at unbalanced

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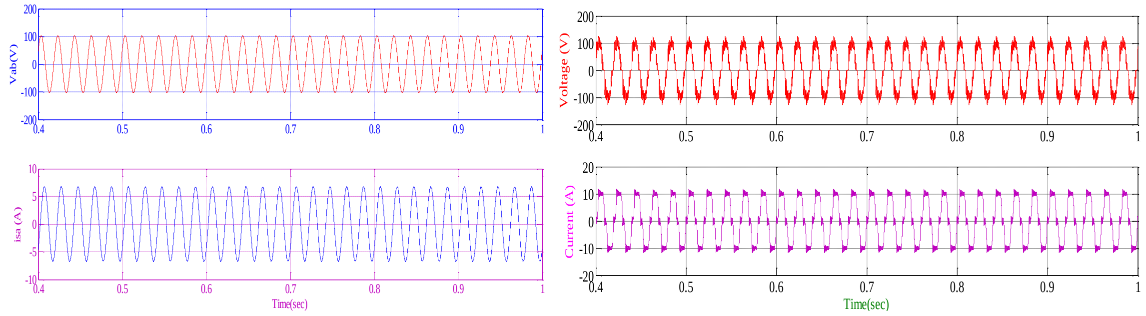
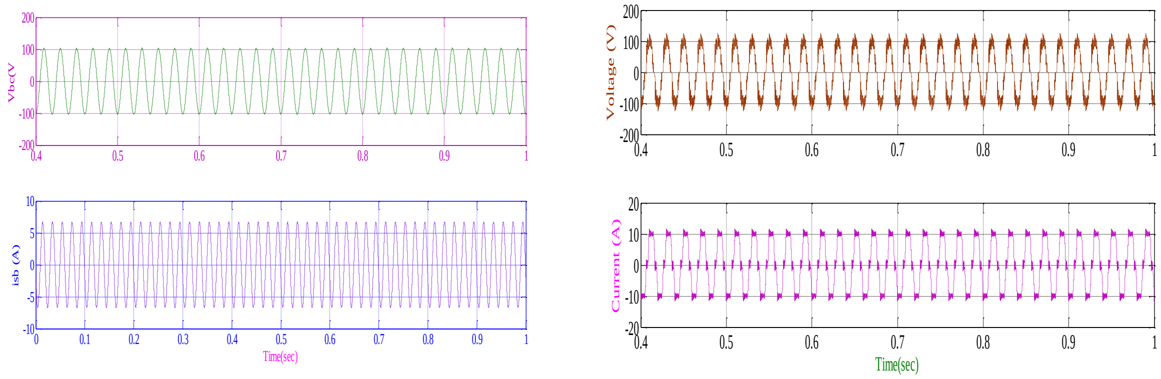
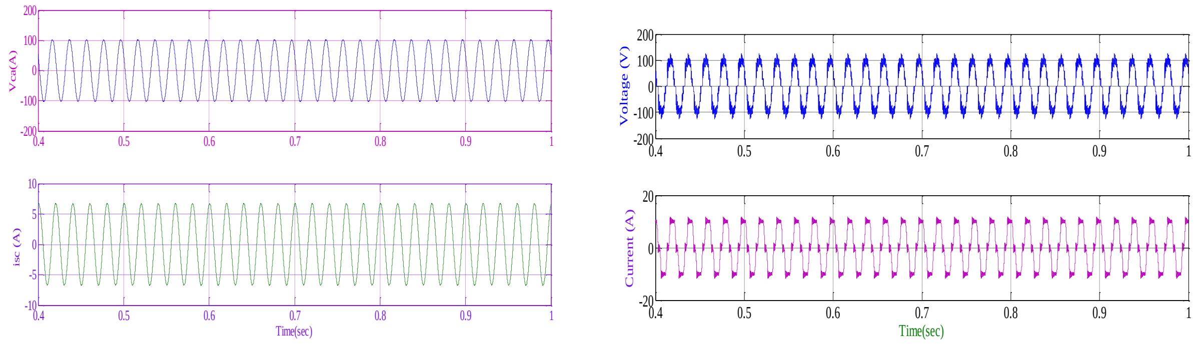
6.4 Steady-State Performance of DSTATCOM Under Linear and Nonlinear Loads in ZVR Mode



(a) (a)



(b) (b)



(c) (c)

Figure 7: Steady-state performance of DSTATCOM at linear lagging PF load in ZVR mode.

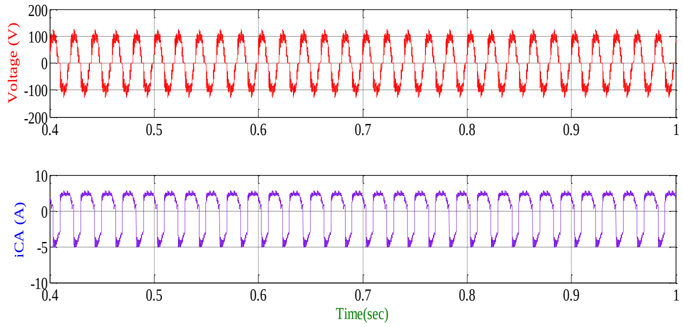


Figure 8: Steady-state performance of DSTATCOM at nonlinear load in ZVR mode.

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6.5 Dynamic Performance of DSTATCOM in ZVR Mode:

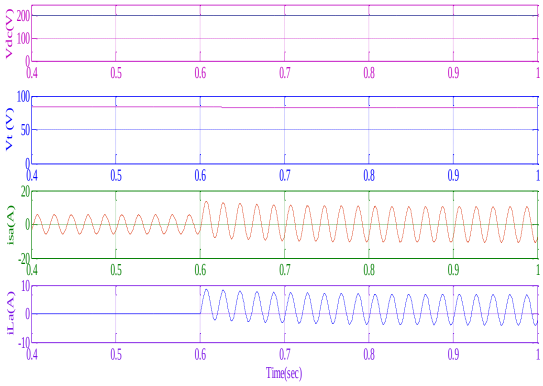
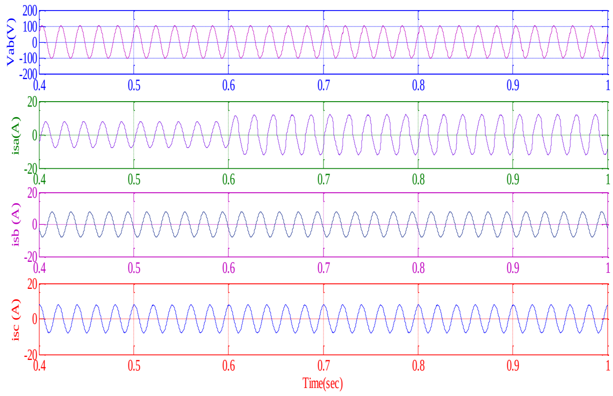
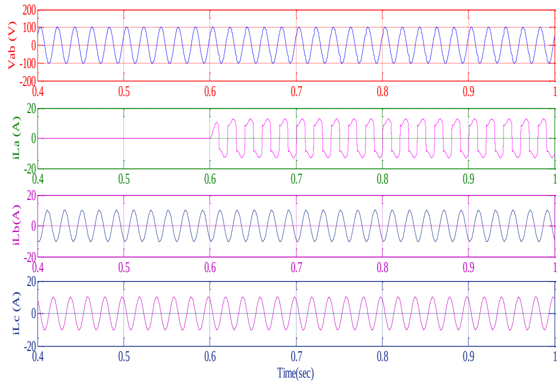


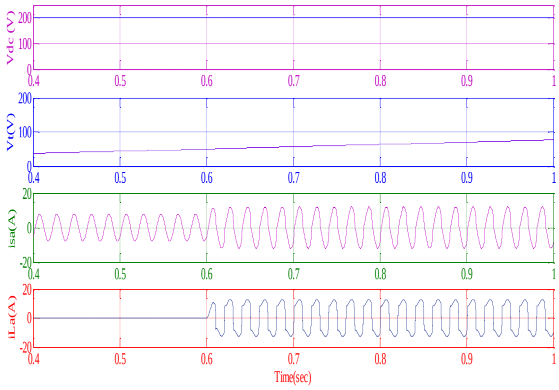
Figure 9: Variation of V_t, i_{sa}, and i_{La} with v_{dc} under unbalanced linear loads.



(a)



(b)



(c)

Figure 10: Steady-state performance of DSTATCOM at nonlinear load in ZVR mode.

CONCLUSION

A DSTATCOM has been implemented for a three-phase distribution system. An AF has been used for control of DSTATCOM. This AF has been found simple and easy to implement, and its performance has been observed satisfactory with non-sinusoidal and distorted voltages of ac mains under load variation. The performance of DSTATCOM with its AF has been demonstrated for harmonics elimination, reactive power compensation, and load

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balancing with self-supporting dc link in PFC and ZVR modes. The dc-link voltage of the DSTATCOM has been also regulated to a desired value under time-varying load conditions.

In future work, it will be report that the application of control algorithm for DSTATCOM in multilevel converters.

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