Performance evaluation of different configurations of system with DSTATCOM using proposed Icos ϕ technique

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ABSTRACT

The proposed Icos ϕ control technique has been applied for power quality improvement using different configurations of system with distribution static compensator (DSTATCOM). Modeling, design and control of DSTATCOM are analyzed in detail. Three phase reference current are extracted with this technique. The proposed technique has been used for power factor enhancement, voltage regulation, harmonic suppression and load balancing under dynamic condition with non-linear load. The proposed control is very effective for three different configurations of system with DSTATCOM for power quality improvement. Results for each configuration of system with DSTATCOM are simulated using MATLAB/Simulink sim power tool box. For teaching the power quality course, these can also be helpful.

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1. INTRODUCTION

At the present the poor power quality is the major problems at load end in distribution system [1]-[4]. Most of linear loads are lagging power factor and non-linear loads which creates power quality problems, for example converter based on power electronics used in uninterruptible power supply (UPS), variable speed alternating current (AC) and direct current (DC) drives, television (TV), domestic load, battery charger. Reactive power is drawn by this type of load and generates harmonic problems in distribution system, which creates distortion in source and reduces load side voltage. For enhancement of these kinds of problems distribution static compensator (DSTATCOM) can be used at point of common coupling (PCC). Various configuration of DSTATCOM for enhancement of power quality are presented in literature for example, 3-legs voltage source converter (VSC) [1], three legs VSC with spilt capacitor [3], four legs based VSC [4], and H-bridge using star/delta transformer [5], and three legs VSC using zig-zag transformer [6]-[10].

Various control methods are presented literature for control of DSTATCOM and computation of supply reference current such as proportional integral (PI) controller based instantaneous reactive power theory (IRPT), instantaneous-symmetrical component (ISC), neural network controller and synchronous reference frame theory (SRFT) [1]-[4]. Mechanism based on Icos ϕ control technique has been described power factor improvement using DSTATCOM in [11]-[13]. The 3-phases 4-wires distribution system with zig-zag transformer and DSTATCOM are presented in [14] using MATLAB. DSTATCOM with 3-different system topologies have been implemented using synchronous reference frame theory (SRFT) technique [15]. Self tuned filter based IRPT technique for enhancement of power quality has been reported in [16]. Different topologies with DSTATCOM for mitigation of power quality issues in distribution system have been developed and implemented [17]. LMS based control technique is developed for reference current extraction and these currents are subtracted from real supply current for estimation of firing pulses for DSTATCOM [18]. Neural network based on back propagation in Icosϕ technique is presented for 3-phases 4-wires DSTATCOM for reduction of power quality related problems and active/reactive components of weight are estimated smoothly for reference current generation with this technique [19]. The comparison of star/delta and zig/zag transformer based DSTATCOM with unit templates based control technique has been presented in [20]. Fuel cell integration in distribution system through DSTATCOM for power quality improvement using Icosϕ technique for reference current extraction has been described [21]. The photovoltaic supported DSTATCOM in distribution system has been implemented with Icosϕ control technique for power quality improvement [22]. Comparisons of phase locked loop (PLL) based control mechanism with DSTATCOM have been implemented for mitigation of load created power quality problems [23]. The quasi newton least mean fourth based control mechanism has been described with DSTATCOM and used mitigation of power quality problems in PSMG which is used as wind generation unit [24]. The optimal step least mean square (LMS) based control technique with DSTATCOM in three phase distribution system has been presented for harmonic suppression and reactive power compensation [25]. Least mean square-least mean forth (LMS-LMF) based control technique for DSTATCOM in power factor correction (PFC) and zero voltage regulation (ZVR) mode operation has been presented for mitigation of power quality problems [26]. Adaptive volterra second-order filter (AVSF) based control algorithm with DSTATCOM has been presented for harmonic suppression and compensation of reactive power in distribution system [27].

The technique based on hopfield neural network (HNN) for DSTATCOM has been developed for improvement of power quality in terms of power factor improvement, source side harmonic suppression and load balancing in a distribution system [28]. The SRFT technique using advance phase-locked loop (PLL) for H bridge multilevel inverter based DSTATCOM has been presented for mitigation of power qualities issues [29]. The adaptive control using Kernel based training in Icosϕ technique used for retained the direct and quadrature component of load currents, has been proposed for fuel cell based DSTATCOM for power qualities problems improvement [30]. Different configurations of systems with DSTATCOM are described using proposed Icosϕ technique in MATLAB. DSTATCOM performances are studied in terms of supply current harmonics elimination, load balancing and reactive power compensation under non-linear varying load.

2. THREE DIFFERENT CONFIGURATIONS OF SYSTEM WITH DSTATCOM

Many configurations of system are exists with DSTATCOM. Out of many configurations of system three are selected and these are;

- Configuration1 of system with DSTATCOM using source side rectifier is presented in Figure 1 and implemented for power quality improvement with proposed Icosϕ technique for PFC mode of DSTATCOM operation for harmonic suppression, load balancing, reactive power compensation and voltage regulation.

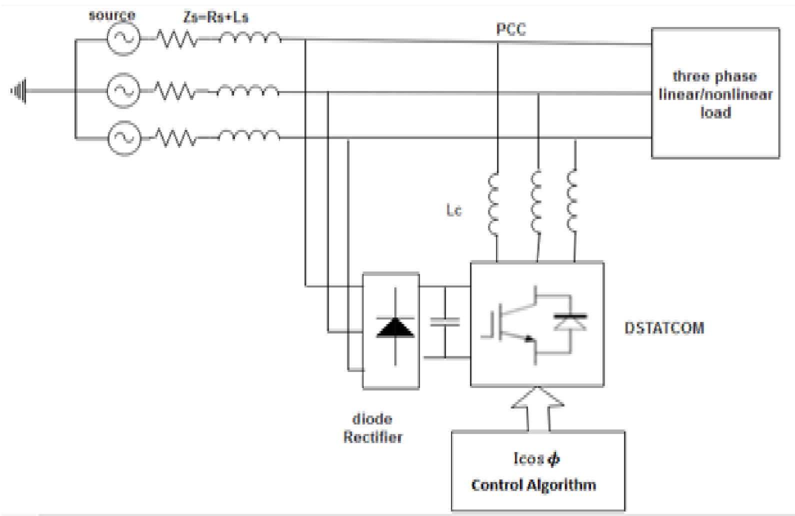


Figure 1. DSTATCOM with configuration1

- Configuration2 of system with DSTATCOM using rectifier on load side is presented in Figure 2 and implemented for power quality improvement with proposed Icos ϕ technique for PFC mode of DSTATCOM operation for harmonic suppression, compensation of reactive power, load balancing and voltage regulation.
- Configuration3 of system with DSTATCOM using DC voltage source is presented in Figure 3 and implemented for power quality improvement with proposed Icos ϕ technique for PFC mode of DSTATCOM operation for harmonic suppression, reactive power compensation, load balancing and voltage regulation.

Non-linear load with has been selected for all above system configurations under dynamic condition.

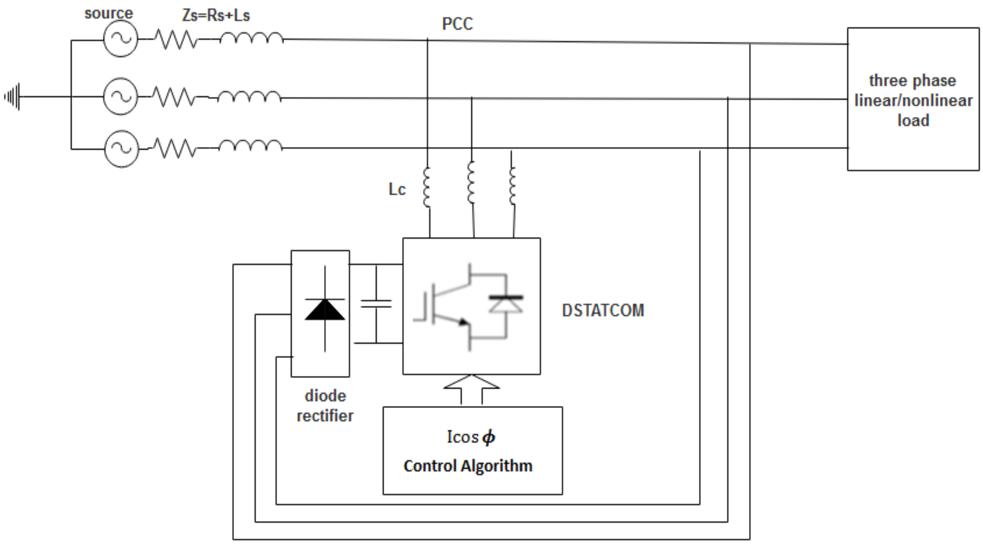


Figure 2. DSTATCOM with configuration2

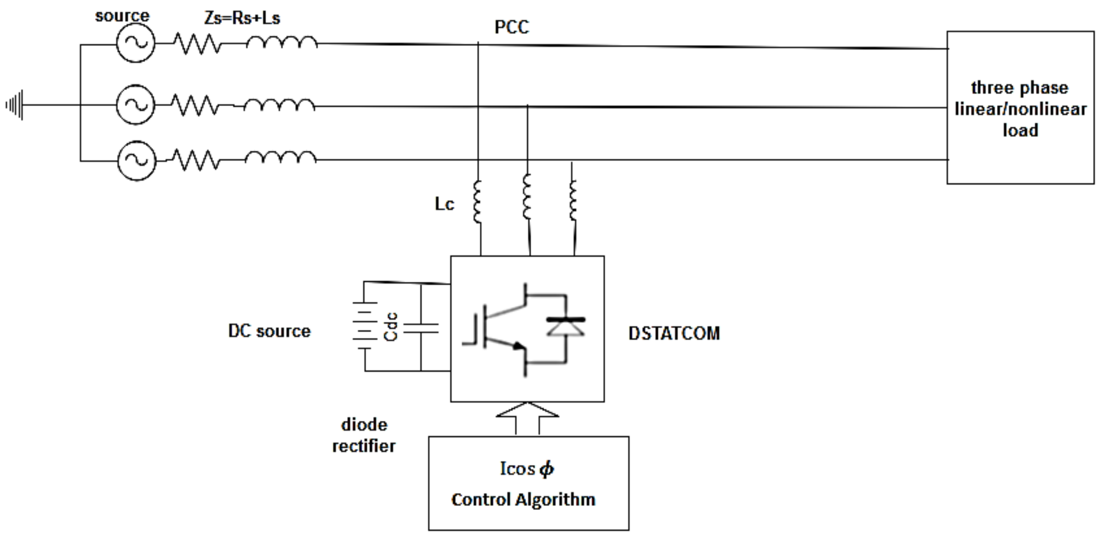


Figure 3. DSTATCOM with configuration3

3. PROPOSED CONTROL METHOD

The proposed Icos ϕ is shown in Figure 4. The coupling point voltages (V_{sa}, V_{sb},V_{sc}), source currents (i_{sa}, i_{sb},i_{sc}), load current (i_{La}, i_{Lb},i_{Lc}), and V_{dc}DC output voltage of DSTATCOM are used as feedback signal for controller design. Supply reference currents are extracted with the help of these signals.

Here it is assumed that using Icos ϕ technique only active power components of load current are supplied by source. Where I and ϕ represents the ampilude of essential load current and displacement angle w.r.t. PCC voltage. For estimation of supply reference current, Icos ϕ and Isin ϕ component of load currents are multiplied unit templates of coupling point voltage. The instantaneous value load currents are given by,

$$i_{La} = \sum_{n=1}^{\infty} I_{Lan} \sin(n\omega t - \phi_{an}) \quad (1)$$

$$i_{Lb} = \sum_{n=1}^{\infty} I_{Lbn} \sin(n\omega t - \phi_{bn} - 120^{\circ}) \quad (2)$$

$$i_{Lc} = \sum_{n=1}^{\infty} I_{Lcn} \sin(n\omega t - \phi_{cn} - 240^{\circ}) \quad (3)$$

where
ϕ_a , ϕ_b *and* ϕ_c are phase's angle for a, b and c phase respectively of essential component of load currents.
ϕ_{an} , ϕ_{bn} , ϕ_{cn} are the phase angle for a, b , c phase respectively of nth harmonic current.
i_{La}, i_{Lb} , $i_{Lc}$are the amplitude for a, b, c phase respectively of load current fundamental component.
I_{Lan} , I_{Lbn} and I_{Lcn} are the amplitude for a, b and c phase respectivelyof load current nth harmonic current component.

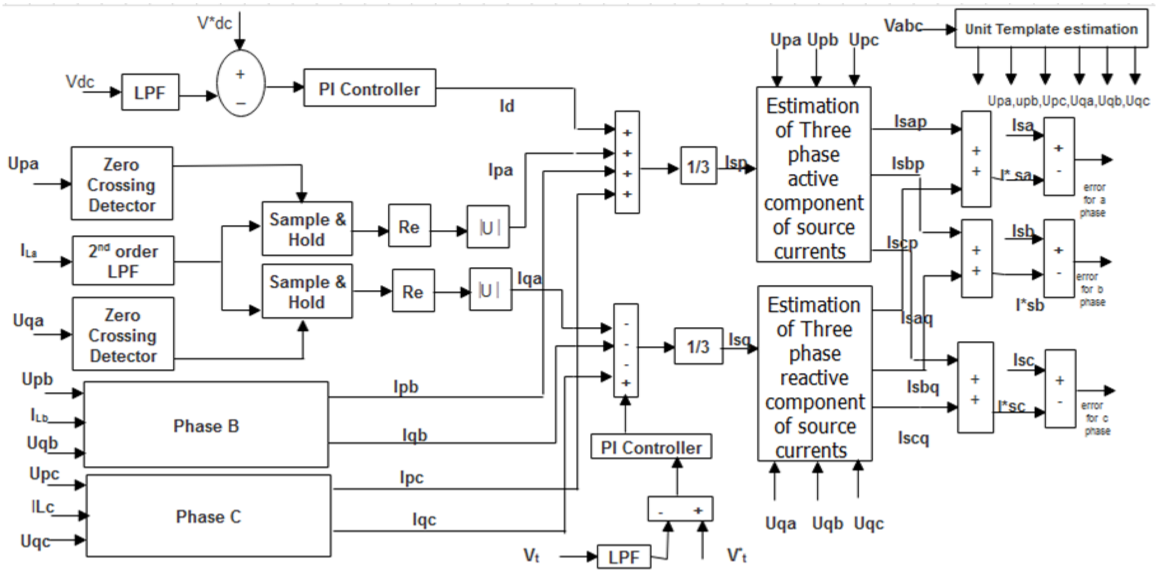


Figure 4. Proposed Icos $\boldsymbol{\phi}$ method

Amplitude of essential active load current components is recognized as (4).

$$|ReI_{La1}| = |I_{La}| \cos\phi_a \ , |ReI_{Lb1}| = |I_{Lb}| \cos\phi_b \ , |ReI_{Lc1}| = |I_{Lc}| \cos\phi_c \quad (4)$$

The magnitude Icos ϕ of essential active component of load current is computed at zero crossing of in-phase templates of coupling point voltage by shifting the load current via 90° from load current, through low power filter sets. Filters having cut of frequency 50 Hz are used to abstract essential load current. Zero crossing detector (ZCD) and a sample and hold circuit (SHC) are used for extraction of Icos ϕ. Reference source current active component average value magnitude is given by (5),

$$I_{sp} = \frac{(|I_{La}| \cos\phi_a + |I_{Lb}| \cos\phi_b + |I_{Lc}| \cos\phi_c + Id)}{3} \quad (5)$$

where $|I_{La}| \cos\phi_a$, $|I_{Lb}| \cos\phi_b$ *and* $|I_{Lc}| \cos\phi_c$ are the amplitude of active component fora, b and c phase respectively. I_d. Output current of DC PI controller of DSTATCOM and written as (6),

$$I_d = K_{pdc} V_{dce} + K_{Idc} \int V_{dc} \, dt \quad (6)$$

where $V_{dce} = V_{dc}^{*} - V_{dc}$ =error signal, $V_{dc=}$ output of DSTATCOM, V_{dc}^{*}=Reference DC voltage. K_{pdc} *and* K_{Idc} are gains for DC PI controller.

In same way the amplitude $I\sin\phi$ of essential load current reactive component is computed at zero crossing of quadrature template of coupling point voltage, from filtered essential load current. Avearage value of reference source current reactive component is given by (7),

$$I_{sd} = \frac{(-(|I_{La}|\sin\phi_a + |I_{Lb}|\sin\phi_b + |I_{Lc}|\sin\phi_c) + I_a)}{3} \quad (7)$$

where $|I_{La}|\sin\phi_a$, $|I_{Lb}|\sin\phi_b$ and $|I_{Lc}|\sin\phi_c$ are amplitude of reactive component a, b and c phase respectively. Output current of AC PI controller I_a is expressed as (8),

$$I_a = K_{pac}V_{dac} + K_{Iac}\int V_{dac}\, dt \quad (8)$$

where $V_{dac} = V_{ac}^* - V_{ac}$ = coupling point voltage error signal, V_{ac}^* = coupling point voltage reference value, V_{ac} = coupling point actual voltage. K_{pac} and K_{Iac}, are gains for AC-PI controller.

Source current active component for each phase can be achieved using in phase templates and given by (9).

$$I_{sap} = I_{sp}U_{pa}\,, I_{sbp} = I_{sp}U_{pb}\,, I_{scp} = I_{sp}U_{pc} \quad (9)$$

Source current reactive component for each phase can be achieved using quadrature templates and given by (10).

$$I_{saq} = I_{sd}U_{qa}\,, I_{sbq} = I_{sd}U_{qb}\,, I_{scq} = I_{sd}U_{qc} \quad (10)$$

Reference total source currents (I_{sa}^*,I_{sb}^* and I_{sc}^*) are calculated with addition ofrespective active and reactive phase component.

$$I_{sa}^* = I_{sap} + I_{saq}, I_{sb}^* = I_{sbp} + I_{sbq}\,, I_{sc}^* = I_{scp} + I_{scq} \quad (11)$$

By subtracting of these currents (I_{sa}^*,I_{sb}^* and I_{sc}^*) from source currents (i_{sa} , i_{sb} andi_{sc}) and an error signal for each leg of VSC are extracted. Error signal are supplied to hysteresis current controller (HCC). HCC produces the pulses with the help of theses error signals for insulated gate bipolar transistor (IGBT) based DSTATCOM.

4. RESULTS AND DISCUSSION

Three different system configurations are implemented with DSTATCOM in MATLAB/Simulink. Then proposed Icos ϕ method is used for control of DSTATCOM for enhancement of power quality, under dynamic condition, with non-linear load in distribution system. The performance of DSTATCOM with proposed controller is analyzed in time domain in three different system configuration.

4.1. DSTATCOM performance in PFC mode

Three system configurations performance with DSTATCOM is simulated in time domain analysis for 1.0 s. Following analysis is prepared based on simulation results. Figure 5 shows the DSTATCOM performance for configuration 1of system in PFC mode for nonlinear load with varying load of phase 'a' for time 0.6-0.7s and expressed in terms of coupling point voltage (V_{sabc}), supply current (I_{sabc}) load current (i_{Labc}) and inverter current (i_{cabc}) respectively. Source current is balanced and sinusoidal, load and inverter currents are unbalanced and non-sinusoidal. Figure 6 shows the V_{dc}dc link voltage of DSTATCOM is continuously increased before DSTATCOM is switched on and attain a value of 600V and after the switch on of DSTATCOM it increased to 825 V and finally it becomes constant 700V at t= 0.3 second. Figure 7 shows the DSTATCOM performance for configuration2 of system in PFC mode for nonlinear load with varying load of phase a for time 0.6-0.7s and expressed in terms of coupling point voltage (V_{sabc}), supply current (I_{sabc}) load current (i_{Labc}) and inverter current (i_{cabc}) respectively. Source current is balanced and sinusoidal, load and inverter currents are unbalanced and non-sinusoidal. Figure 8 shows the V_{dc}dc link voltage of DSTATCOM is continuously increased before DSTATCOM is switched on and attain a value of 600V and after the switch on of DSTATCOM it increased to 810V and finally it becomes constant 700V at t= 0.27 second. Figure 9 shows the DSTATCOM performance for configuration3 of system in PFC mode for nonlinear load with varying load of phase a for time 0.6-0.7s and expressed in terms of coupling point voltage (V_{sabc}), supply current (I_{sabc}) load current (i_{Labc}) and inverter current (i_{cabc}) respectively. Source current is balanced and sinusoidal, load and inverter currents are unbalanced and non-sinusoidal. Figure 10 shows V_{dc}DC link voltage of DSTATCOM 700V constant.

Figures 11(a)-(c) (see Appendix) shows the configuration1 harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current for phase ‘a’ are 3.13%, 3.78%, 27.31% respectively. Figures 11(d)-(f) (see Appendix) shows the configuration2 harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current of phase ‘a’ are 3.07%, 3.22%, 27.10% respectively. Figures 11(g)-(i) (see Appendix) shows the configuration3 harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current for phase ‘a’ are 0.53%, 2.02%, 27.74% respectively. Comparison of THD spectrum of modified Icos ϕ technique with existing Icos ϕ for different system configuration of the system is shown in Table 1.THD % for three different configuration are graphically presented in Figures 11(a)-(i) (see Appendix). The Table 1 shows the modified Icos ϕ technique is better than existing Icos ϕ technique.

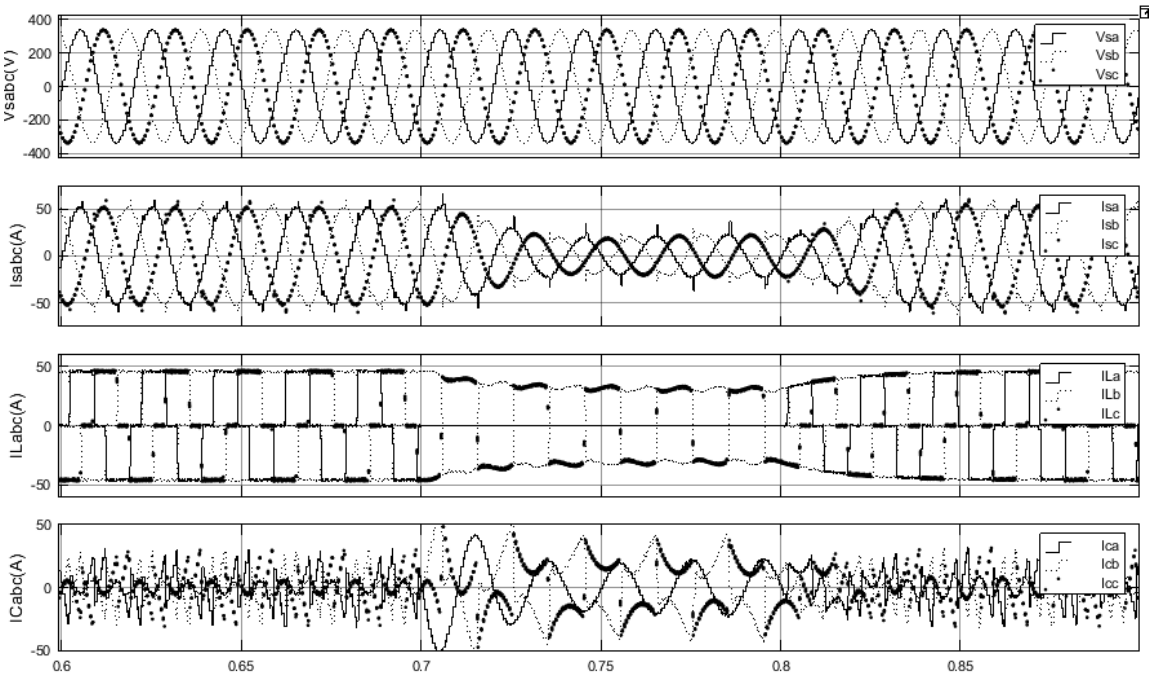


Figure 5. DSTATCOM performance for system configuration1

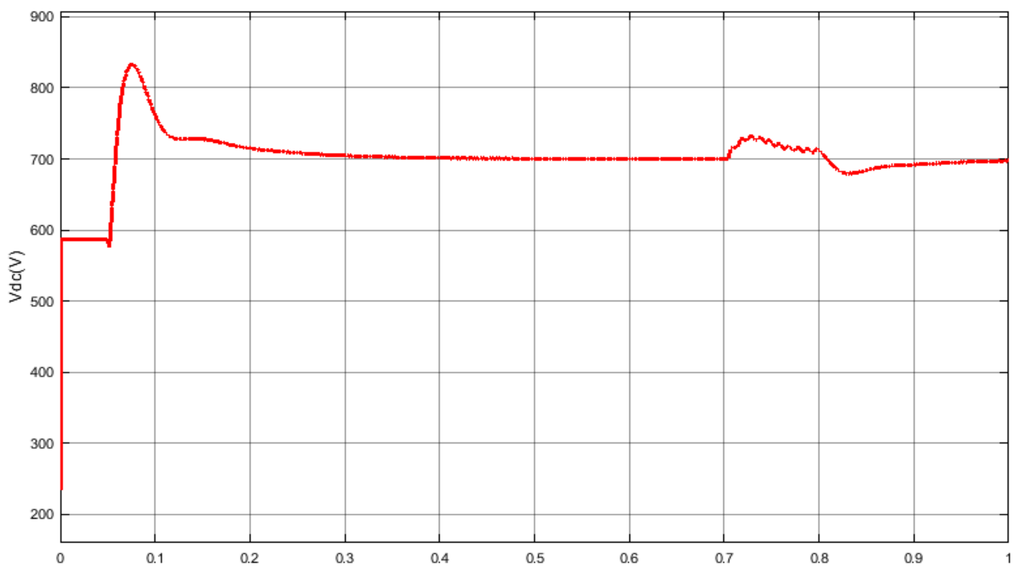


Figure 6. DC link voltage in PFC mode under variable nonlinear load for system configuration1

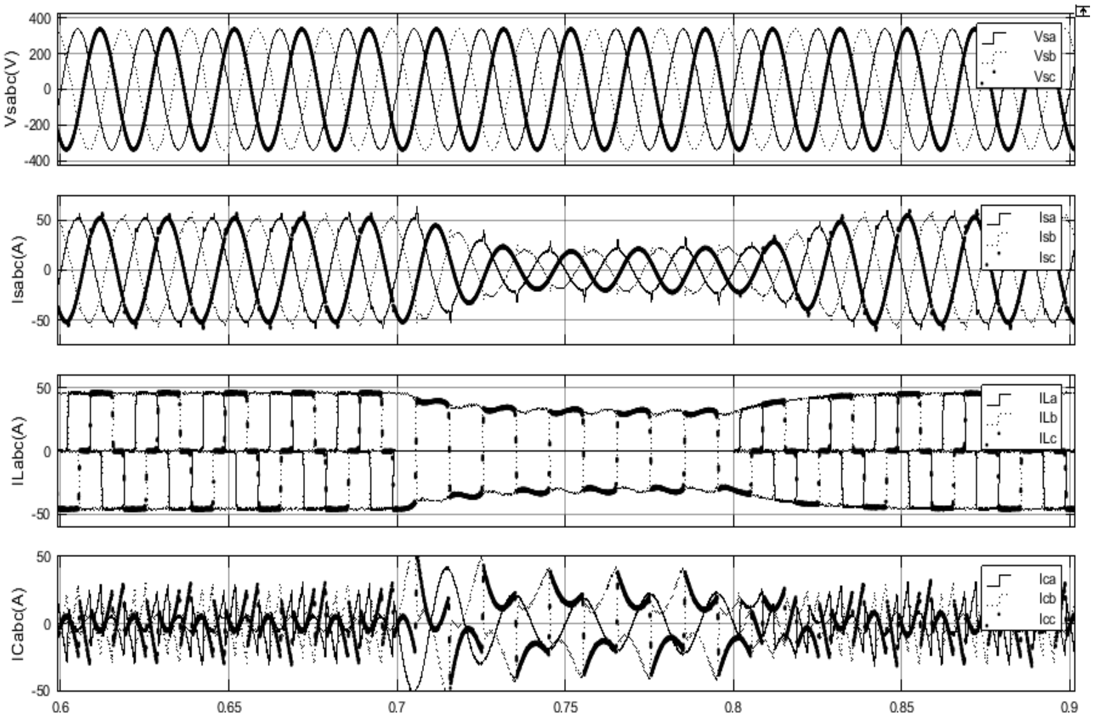


Figure 7. DSTATCOM performance for system configuration2

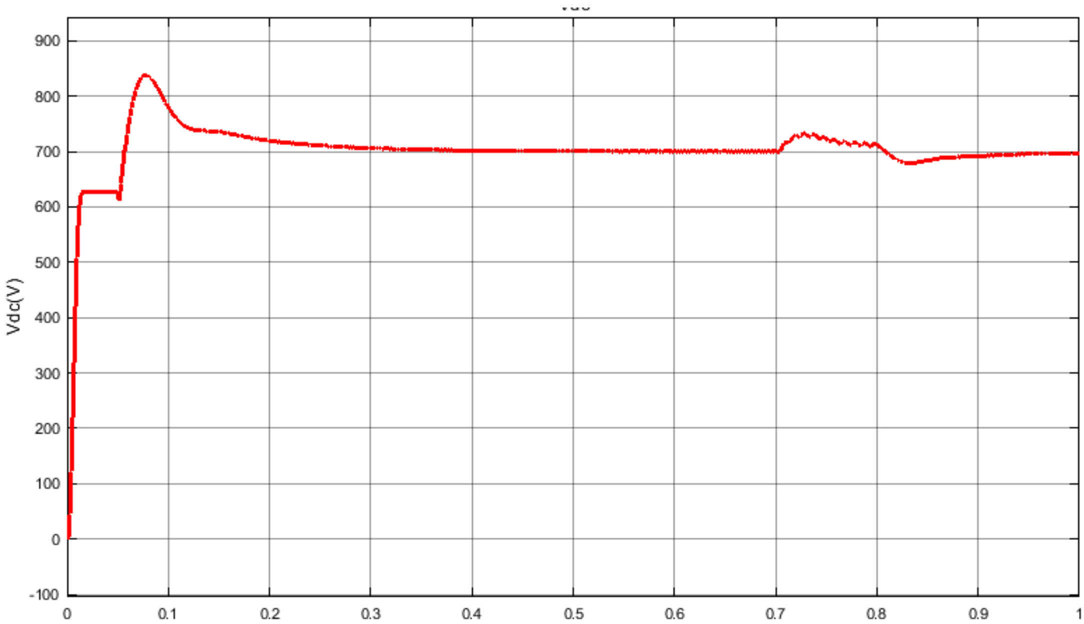


Figure 8. DC link voltage in PFC mode under variable nonlinear load for system configuration3

Table 1. The performance analysis for different system configurations

Sr.No.	System configuration type	Source current harmonics		Load current harmonics	DC link voltage settling time(s)
		Modified Icos ϕ	Existing Icos ϕ	Modified Icos ϕ	Modified Icos ϕ
1.	Configuration1	3.13%	3.78%	27.31%	0.30
2.	Configuration2	3.07%	3.22%	27.10%	0.27
3.	Configuration3	0.53%	2.02%	27.24%	0

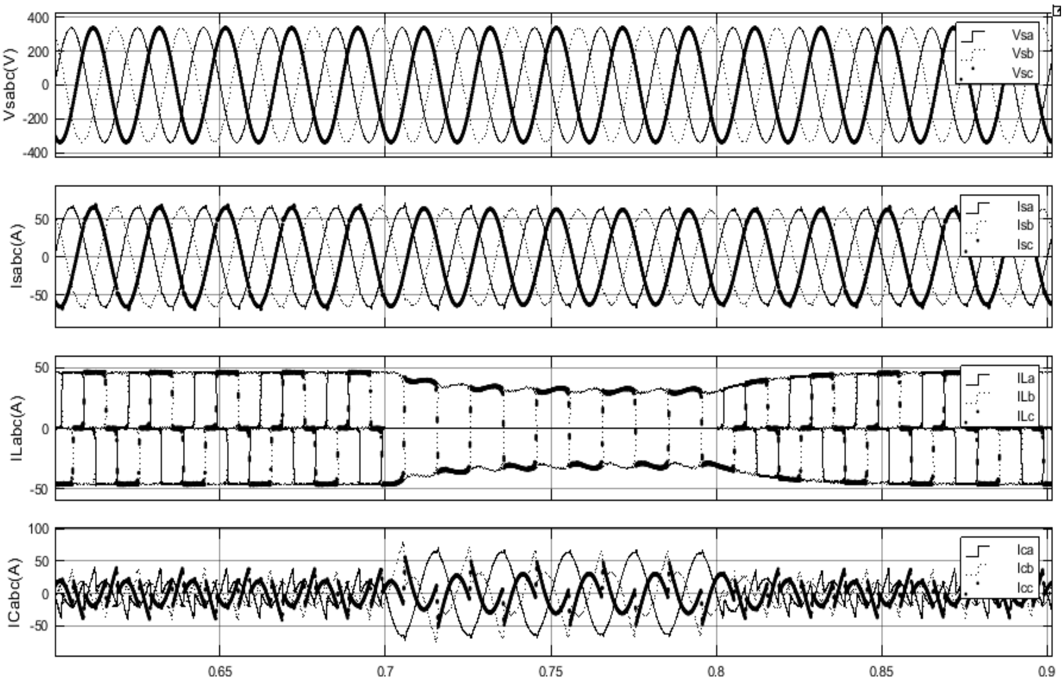


Figure 9. DSTATCOM performance for system configuration3

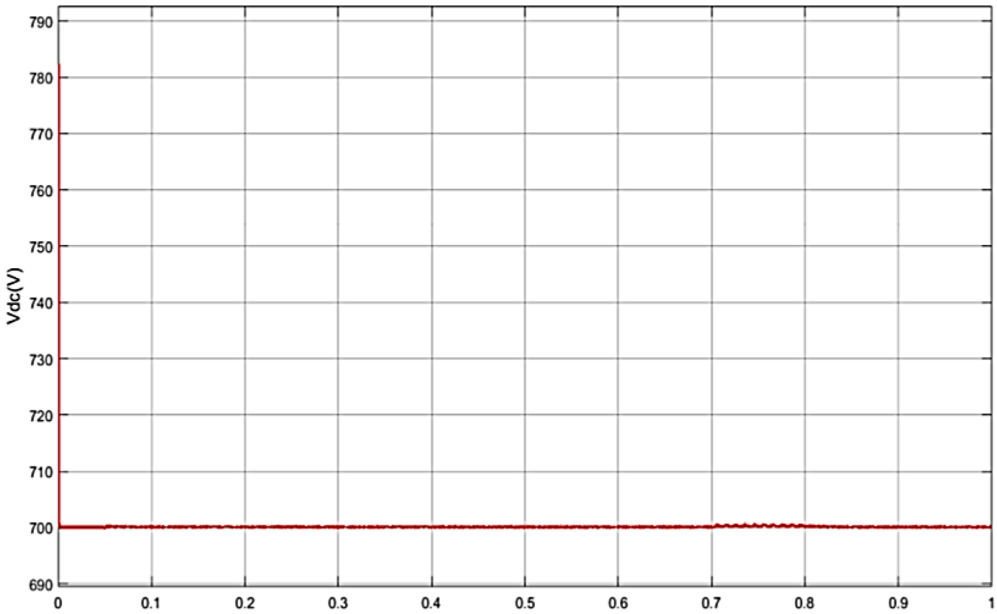
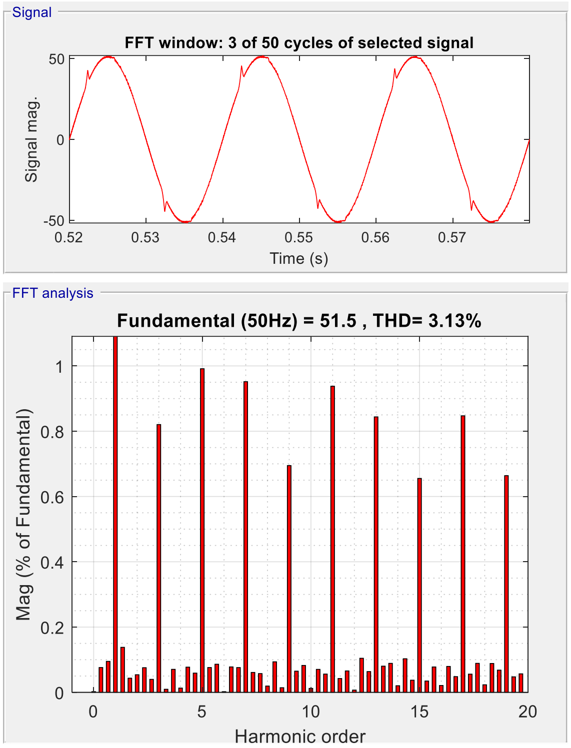


Figure 10. DC link voltage in PFC mode under variable nonlinear load for system configuration3

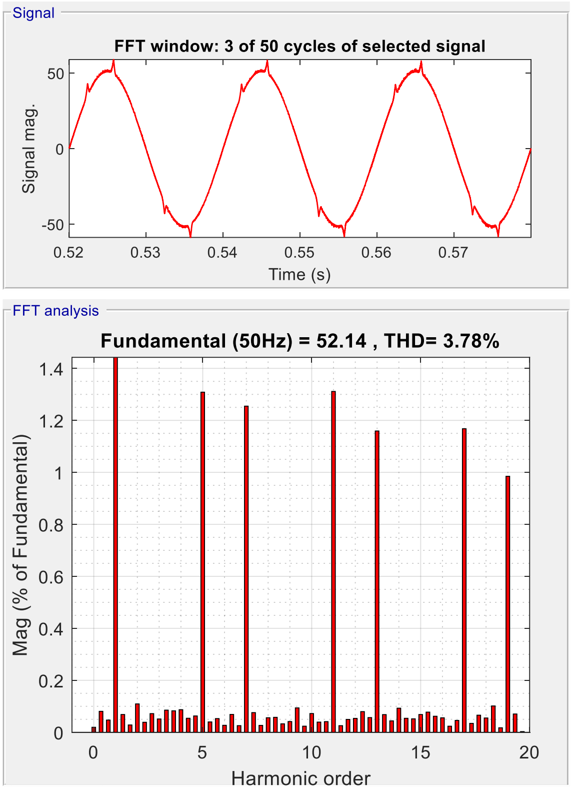
5. CONCLUSION

Three different systems configurations are simulated with DSTATCOM using proposed Icos ϕ in MATLAB/Simulink for DSTATCOM operation in PFC mode. For all three systems configuration DC link voltage of DSTATCOM is controlled in varying nonlinear load. The behavior of DSTATCOM with proposed Icos ϕ is found very effective for different systems configuration in terms of harmonic elimination of source current, load balancing and power factor correction. The modified Icos ϕ technique is found better than existing Icos ϕ in term of THD elimination of source current. These models can be used for teaching and research purpose for study the different types of power quality problems and also other configurations of system can be developed with DSTATCOM which are not considered in this paper.

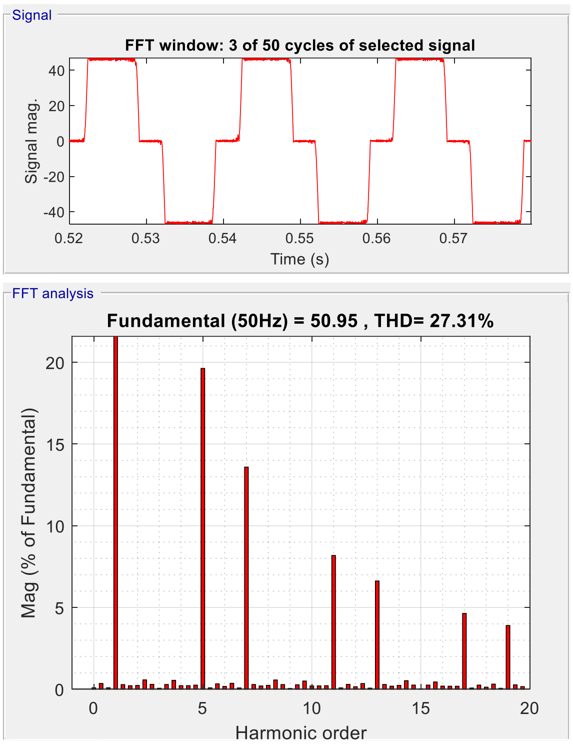
APPENDIX



(a)

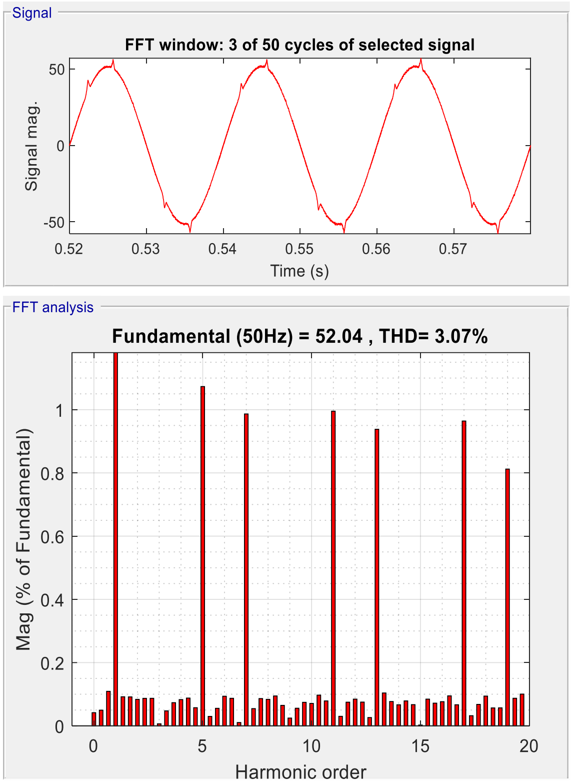


(b)

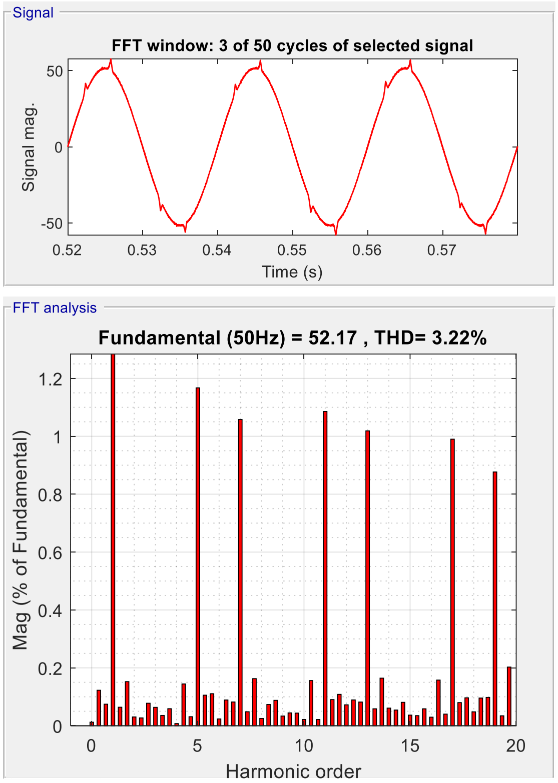


(c)

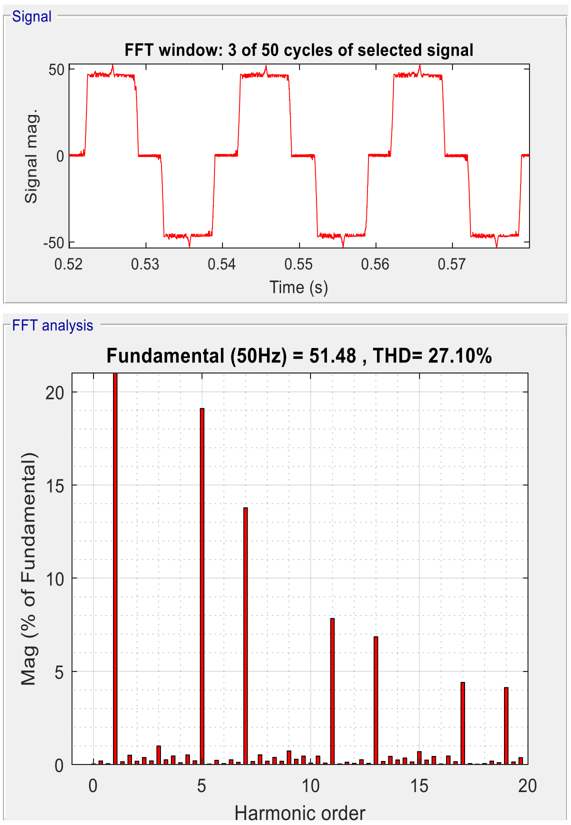
Figure 11. (a)-(c) shows the harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current for phase ‘a’ respectively for configuration1



(d)

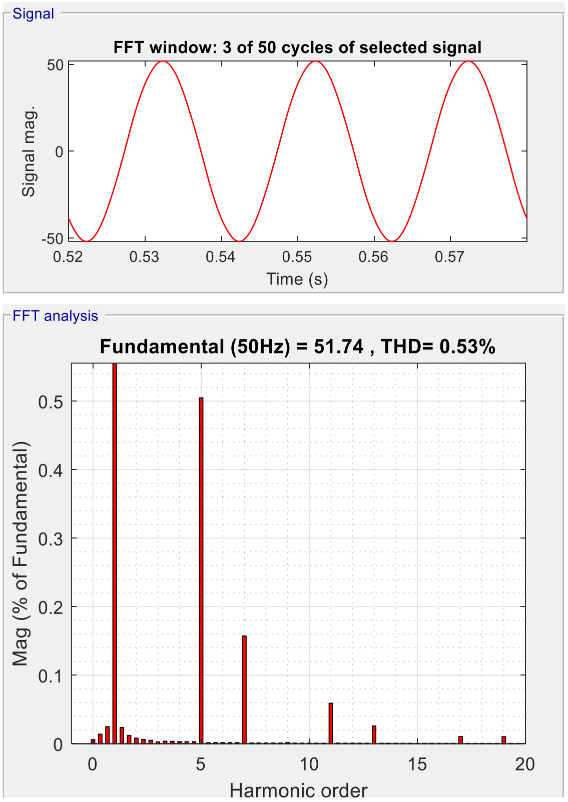


(e)

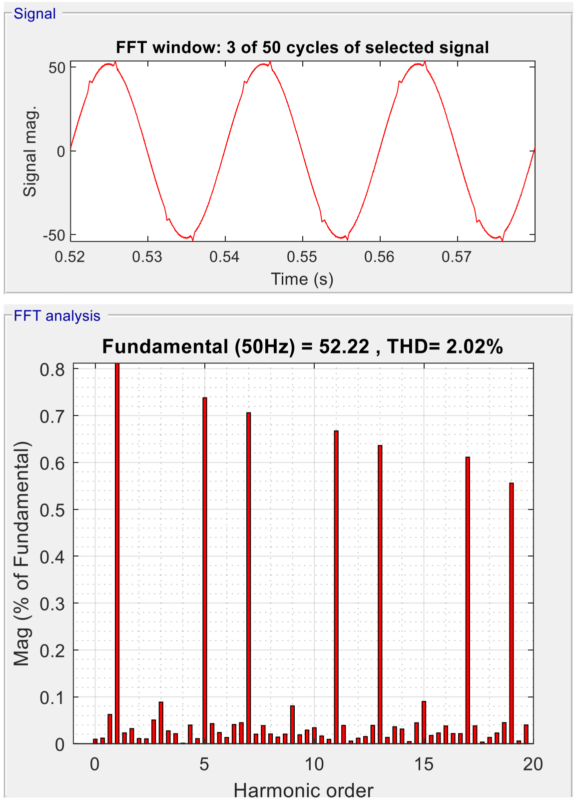


(f)

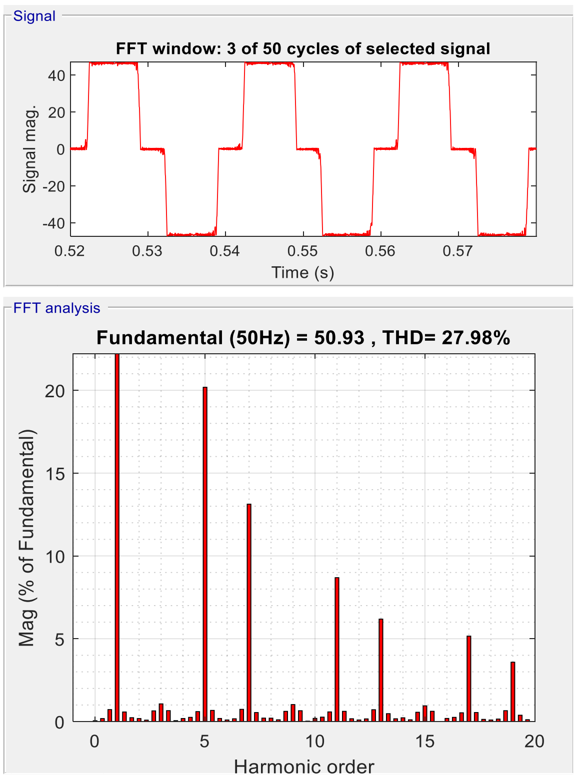
Figure 11. (d)-(f) shows the harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current for phase ‘a’ respectively for configuration2 (continue)



(g)



(h)



(i)

Figure 11. (g)-(i) shows the harmonic spectrum of source current with modified Icos ϕ, source current with existing Icos ϕ and load current for phase 'a' respectively for configuration3 (continue)

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