SSRG International Journal of Electrical and Electronics Engineering
ISSN: 2348 – 8379 / https://doi.org/10.14445/23488379/IJEEE-V9I2P103

Volume 9 Issue 2, 12-27, February 2022


*Original Article*

# Comparative Study of Synchronous Reference Frame and Instantaneous Active Reactive Power Reference Current Signal Generation Technique-Based Shunt Active Power Filter in Solar Photovoltaic Microgrid System

Sajjad R Talpur[1], Sajid H Qazi[2]

[1]*Student of Masters of Engineering in Electrical Power Department of Electrical Engineering Mehran UET SZAB Khairpur Mirs campus, Sindh, Pakistan*

[2]*Assistant Professor in Department of Electrical Engineering Mehran UET SZAB Khairpur Mirs campus, Sindh, Pakistan*

Received Date: 10 January 2022
Revised Date: 12 February 2022
Accepted Date: 25 February 2022

***Abstract -*** *In an AC power system, harmonics are the 'n' multiples of power system frequency of 50/60 Hz. As per the majority of research publications, the major portion of harmonics in AC power systems is due to nonlinear loads. As per distant past and recent past research work ac power system harmonics have been mitigated by the application of passive/active filters. But as of the recent past majority of research studies prove that the use of an active filter approach for a harmonic reduction in power system is more effective. Thereby this research paper also aims to implement a shunt active power filter with synchronous reference frame & instantaneous active-reactive power compensating current signal generation techniques at point of common coupling of solar photovoltaic based microgrid system at balanced and unbalanced nonlinear load conditions to evaluate the performance of shunt active filter models and to ascertain whether they comply with IEEE-519 standard in MATLAB simulation environment.*

**Keywords -** *Active power filter, Harmonic suppression, Instantaneous Active-Reactive Power, Synchronous Reference Frame, Solar photovoltaic microgrid system.*

## I. INTRODUCTION

The problem of harmonics in ac power systems enhanced from the mid-1970s with increased use of state-of-the-art electronic switch device-based loads, which proved to be flexible in attributes, technologically advanced and economical, but at the same time degraded the quality of electrical power supply to consumers and caused numerous problems in power system operation, control and protection [1][2][3][4][5].

Since the inception of harmonics on a major scale in ac (alternating current) power system by nonlinear (electronic switch device based) loads up till now, many research publications have proven that nonlinear load generated harmonics in the ac power system can be effectively suppressed to desired international standards IEEE-519 by implementing active power filters with numerous harmonic detection and control strategies [2][3][5][9][11].

In this research paper, shunt active power filter (SHAPF) shall be implemented with synchronous reference frame(SRF) and instantaneous active-reactive power(IPQT) reference current signal generation techniques at point of common coupling(PCC) of grid-connected solar photovoltaic(PV) based microgrid(MG) system to reduce total harmonic distortions(THD) from common point system voltage & current(VPCC&IPCC) at balanced and unbalanced nonlinear load conditions and satisfy IEEE-519 standard in MATLAB.

This research paper is arranged as follows; Part 2 includes a brief and comprehensive description of time domain-based reference current signal extraction techniques of shunt active power filter 'SRF' and 'IPQT' used for generating three-phase compensating current signals.

In part 3, a thorough description of MATLAB models of grid-connected Solar (PV) based microgrid systems and Shunt APF shall be presented.

In Part 4, simulation results shall be discussed, and a comparative analysis shall be carried out on SHAPFs SRF&IPQT models to ascertain which among the two models performed better.

Part 5 will include concluding remarks. This research paper shall be limited to harmonics generated by nonlinear loads since power system generated harmonics account for 1-2 % and therefore are neglected.[8]

## II. REFERENCE CURRENT SIGNAL GENERATION TECHNIQUES 'SRF' and 'IPQT'

The most widely used 3 phase time domain-based reference current signal generation techniques of SHAPF 'SRF' and 'IPQT' shall be thoroughly discussed along with their MATLAB models in this part of the research paper.[5][9][11]

### *A. Synchronous Reference Frame Technique*

It's a 3 phase reference compensating current signal extraction technique of SHAPF[11] that requires the input of 3 phase load currents IL(ABC) for ABC-DQ0 transformation and 3 phase supply-side voltages VS(ABC) for phase-locked loop(PLL) circuit[24] that generates angular frequency 'ωt', ωt shall serve as a second input for ABC-DQO transformation.

At first, this technique performs ABC-DQ0 transformation on harmonic polluted load currents IL(ABC), which is accomplished by Clarke's & Park's transformation algorithm indicated by (1) & (2).

$$\begin{bmatrix} I\alpha \\ I\beta \\ I0 \end{bmatrix} = [2/3] \begin{bmatrix} 1 & -1/2 & -1/2 \\ 0 & \sqrt{3}/2 & -\sqrt{3}/2 \\ 1/2 & 1/2 & 1/2 \end{bmatrix} \begin{bmatrix} Ia \\ Ib \\ Ic \end{bmatrix} \quad (1)$$

$$\begin{bmatrix} Id \\ Iq \\ I0 \end{bmatrix} = \begin{bmatrix} \cos(wt) & \sin(wt) & 0 \\ -\sin(wt) & \cos(wt) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \\ I0 \end{bmatrix} \quad (2)$$

$$Id = \overline{Id} + \widetilde{Id} \quad (3)$$

$$Iq = \overline{Iq} + \widetilde{Iq} \quad (4)$$

The transformed ID and IQ components of harmonic polluted IL(ABC) load current contain power frequency subcomponents($\overline{Id}$&$\overline{Iq}$) and harmonic rich sub-components($\widetilde{Id}$&$\widetilde{Iq}$) as shown in (3) and (4).

The fundamental frequency subcomponents($\overline{Id}$&$\overline{Iq}$) are filtered out from ID&IQ by using either a low pass filter or a high pass filter. Harmonic rich ($\widetilde{Id}$&$\widetilde{Iq}$) are then transformed into compensating/reference current signals $\widetilde{IC}$(ABC) using inverse parks and Clarke's transformation indicated by (5) & (6).

$$\begin{bmatrix} \widetilde{I\alpha} \\ \widetilde{I\beta} \\ I0 \end{bmatrix} = \begin{bmatrix} \cos(wt) & -\sin(wt) & 0 \\ \sin(wt) & \cos(wt) & 0 \\ 0 & 0 & 1 \end{bmatrix} \begin{bmatrix} \widetilde{Id} \\ \widetilde{Iq} \\ I0 \end{bmatrix} \quad (5)$$

$$\begin{bmatrix} \widetilde{Ia} \\ \widetilde{Ib} \\ \widetilde{Ic} \end{bmatrix} = \begin{bmatrix} 1 & 0 & 1 \\ -1/2 & \sqrt{3}/2 & 1 \\ -1/2 & -\sqrt{3}/2 & 1 \end{bmatrix} \begin{bmatrix} \widetilde{I\alpha} \\ \widetilde{I\beta} \\ I0 \end{bmatrix} \quad (6)$$

Harmonic rich compensating three-phase currents $\widetilde{IC}$(ABC) serve as an input to HBCC(hysteresis band current control) algorthm[7], which is a 2 state control circuit shown in Fig.1 that serves the purpose of generating an appropriate sequence of gate trigger signals for electronic switches(IGBTS/MOSFETS/thyristors) of VSC/ISC(voltage source/current source converter/inverter) of SHAPF.

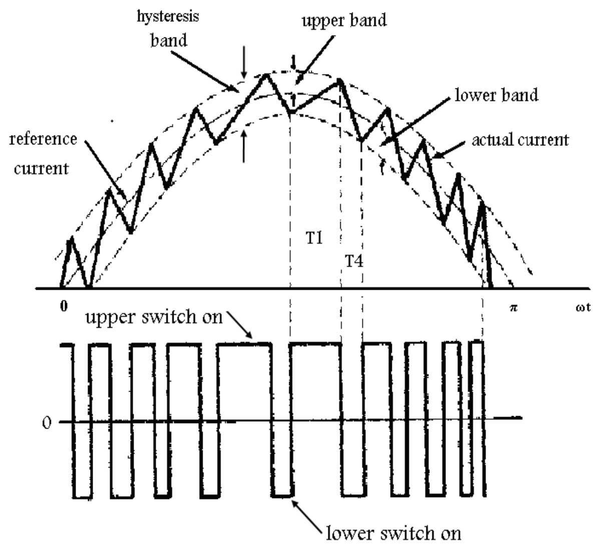


**Fig. 1 A two-state HBCC**

The VSC (voltage source converter/inverter) with the appropriate triggering of its switches generates harmonic rich three-phase filter currents IF(ABC) that are injected at a common point (PCC) of the power system to meet the harmonic demand of nonlinear loads.

In order to ensure proper working of HBCC, three-phase filter currents are fed back to it and compared with three-phase compensating currents signals $\widetilde{IC}$(ABC) that generates an error which, if breaches either upper band or lower band limit of HBCC, a gate signal is generated.

In order to account for losses occurring in the switch circuit of VSC and to maintain a constant dc input to it, additional Vdc regulator circuitry[23] is used that compares Vdc(ref) with Vdc(meas) that generates an error which is conditioned by PI controller and then added to harmonic rich $\widetilde{ID}$(transformed).

### *B. Instantaneous Active-Reactive power technique*

Instantaneous Active-Reactive power is a 3-phase reference compensating current signals generation technique of SHAPF [5], which requires the input of 3 phase supply-side voltages VS(ABC) and 3 phase load end currents IL(ABC).

At first, using Clarke's transformation shown in (1), both supply-side voltages VS(ABC) and load side currents IL(ABC) are transformed into stationary orthogonal components(αβ0).

$$\begin{bmatrix} P \\ Q \\ P0 \end{bmatrix} = \begin{bmatrix} V\alpha & V\beta & 0 \\ -V\beta & V\alpha & 0 \\ 0 & 0 & V0 \end{bmatrix} \begin{bmatrix} I\alpha \\ I\beta \\ I0 \end{bmatrix} \quad (7)$$

$$P = \overline{V\alpha} \times \overline{I\alpha} + \widetilde{V\beta} \times \widetilde{I\beta} \quad (8)$$

$$P = \overline{P} + \widetilde{P} \quad (9)$$

$$Q = -\widetilde{V\beta} \times \widetilde{I\alpha} + \overline{V\alpha} \times \overline{I\beta} \quad (10)$$

$$Q = \widetilde{Q} + \overline{Q} \quad (11)$$

$$P0 = V0 \times I0 \quad (12)$$

The transformed VS(αβ0)&IL(αβ0) are used in (7)&(12) to calculate harmonic polluted P and Q indicated in (8) and (10). As shown in (8)&(10), harmonic polluted P and Q consists of fundamental frequency components ($\bar{P}$&$\bar{Q}$) and harmonic rich ($\tilde{P}$&$\tilde{Q}$) components. The fundamental frequency components are filtered from P&Q by using either a low pass filter or a high pass filter.

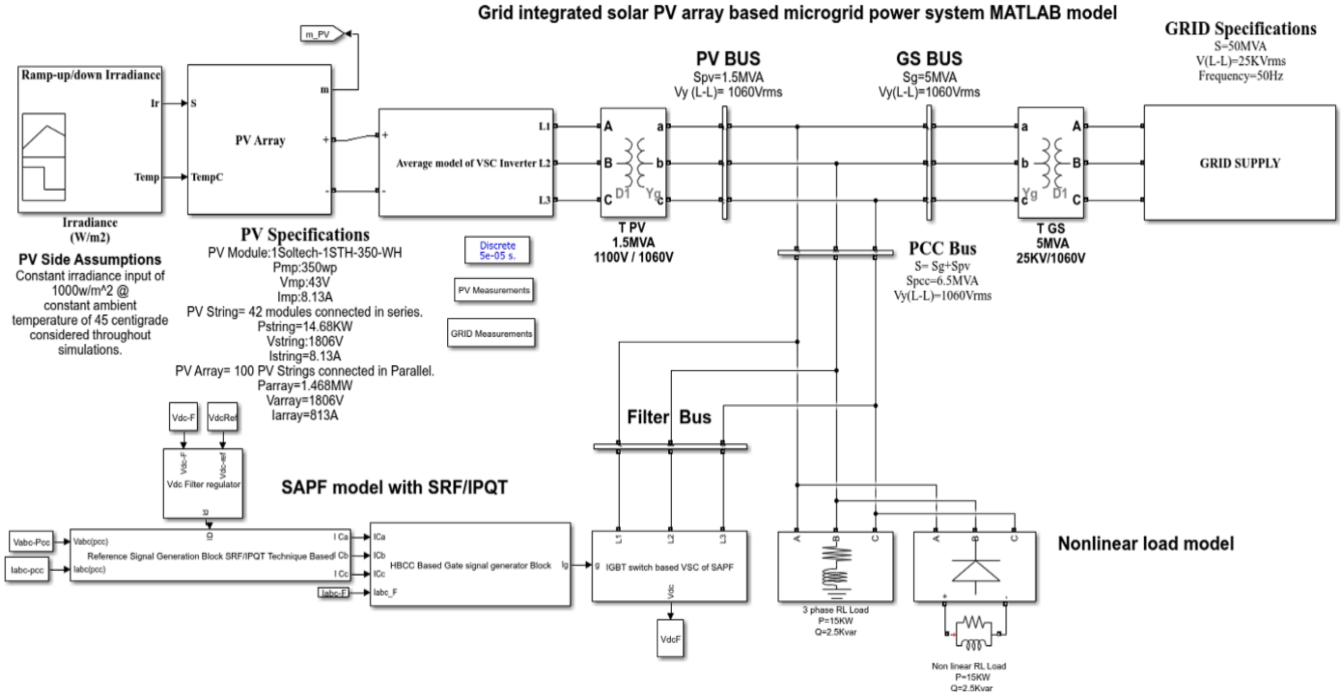


**Fig. 2 Matlab models**

In order to account for losses occurring in the switch circuit of SHAPF(VSC) and to maintain a constant dc input to it, additional Vdc regulator circuitry is used that compares Vdc(ref) with Vdc(meas) that generates an error which is conditioned by PI controller which gives 'Ploss' factor that is then added to harmonic rich $\widetilde{P}$.

The harmonic rich stationary orthogonal currents I($\widetilde{\alpha\beta}$0) are calculated by using harmonic rich $\widetilde{P}$&$\widetilde{Q}$ and V(αβ) as shown in (13)&(16).

$$\begin{bmatrix} \widetilde{I\alpha} \\ \widetilde{I\beta} \end{bmatrix} = \frac{1}{V\alpha^2 + V\beta^2} \begin{bmatrix} V\alpha & -V\beta \\ V\beta & V\alpha \end{bmatrix} \begin{bmatrix} \widetilde{P} \\ \widetilde{Q} \end{bmatrix} \quad (13)$$

$$\widetilde{I\alpha} = \frac{\widetilde{P} \times V\alpha - \widetilde{Q} \times V\beta}{V\alpha^2 + V\beta^2} \quad (14)$$

$$\widetilde{I\beta} = \frac{\widetilde{P} \times V\beta + \widetilde{Q} \times V\alpha}{V\alpha^2 + V\beta^2} \quad (15)$$

$$I0 = p0/v0 \quad (16)$$

The harmonic rich compensating currents $\widetilde{IC}$(ABC) are then calculated by using inverse clarke transformation indicated in (6). The harmonic rich compensating currents $\widetilde{IC}$(ABC) are then used in a two-state HBCC algorithm in a similar fashion as in the SRF technique's case for generating an adequate sequence of gate triggering signals for electronic switches(IGBT/MOSFET) of VSC of SHAPF.

The VSC(voltage source converter/inverter) with the appropriate triggering of its switches generates harmonic rich three-phase filter currents IF(ABC) that are injected at a common point(PCC) of the power system to meet the harmonic demand of nonlinear loads.

## III. MATLAB MODELS OF SOLAR(PV) MICROGRID SYSTEM AND SHUNT APF

Grid-connected Solar PV array-based microgrid power system model along with shunt active power filter model (SRF/IPQT) and nonlinear load model in MATLAB is shown in fig 2.

### *A. MATLAB Models of Solar (PV) MG System and Nonlinear Load*

As depicted in Fig.2, the MATLAB model of the microgrid system has the capacity to deliver 6.5MVA at 1060V(L-L) rms to a nonlinear load.

The supply-side of the microgrid system comprises a solar PV array that is designed to deliver 1.5MW at 1.806-2.006KV (dc) and 813Amps(dc) under max PowerPoint with constant ambient conditions (irradiance input 1000w/m^2, temp 45 centigrade and 1.5 air mass factor). Now, as system side harmonics are to be neglected, therefore an average MATLAB model of DC to AC converter has been used in solar PV array side. A control/gate signal generator block has been designed for the average model of DC/AC converter that delivers gate trigger signals in a sequence to DC/AC converter, which ensures regulation of Vdc input. Solar PV array side (Dy1) 3 phase transformer delivers 1.5MVA at 1060Vpcc(L-L) rms at point of common coupling (PCC).

The grid supply side comprises a 3 phase (3 wire) feeder having the capability to deliver 50MVA at 25KV(L-L) rms that are connected with (Dy1) 3 phase grid side transformer that delivers 5MVA at 1060Vpcc(L-L) rms at point of common coupling (PCC).

At the point of common coupling, a nonlinear load model that comprises of 3 phase diode rectifier-based R-L load connected in parallel with 3 phase Y connected series R-L load that at balanced and unbalanced load condition taps a total of 30KW and 5Kvar at 1060v(L-L) rms from PCC busbar. Total load power consumption is divided equally amongst both load models. Load unbalanced condition in the system is created by selecting different values of R-L in Y connected load per phase.

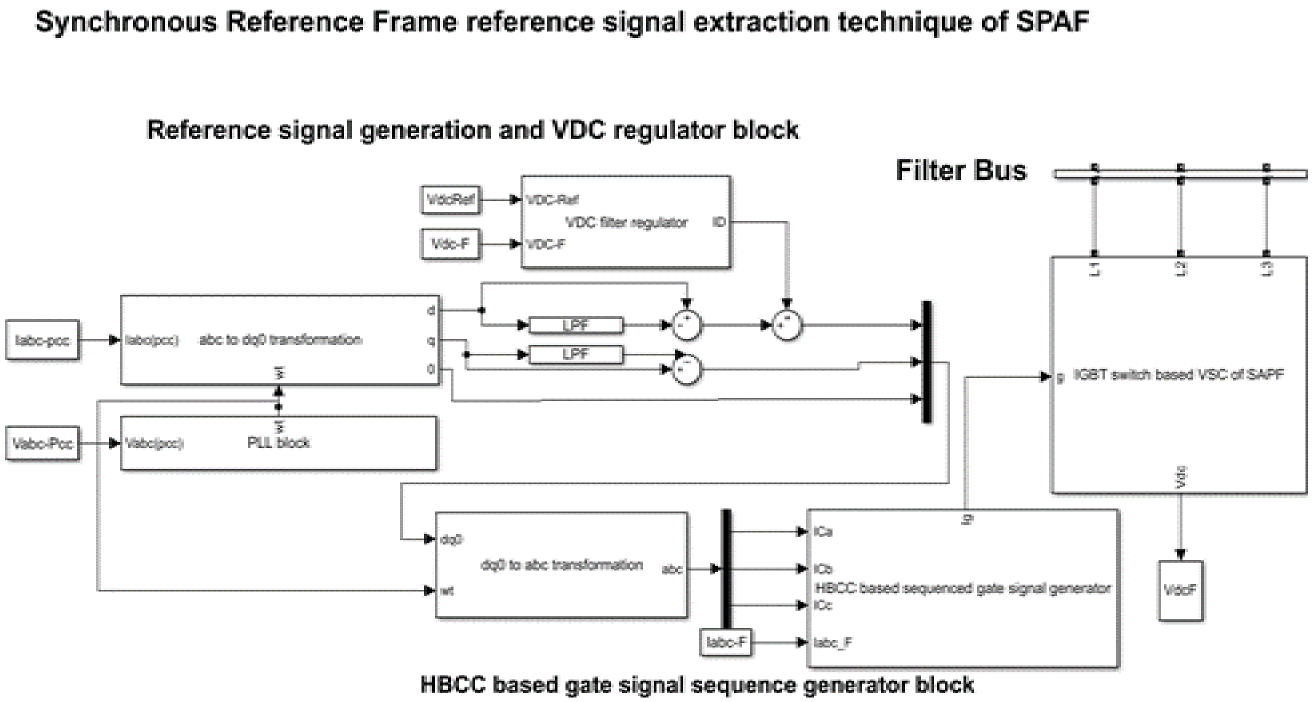


**Fig. 3 Matlab model SHAPF(SRF)**

### *B. MATLAB Model of Shunt Active Power Filter (SRF/IPQT)*

MATLAB models of shunt active power filter with synchronous reference frame reference signal generation technique and instantaneous active-reactive power technique are shown in Fig.3&Fig.4.

The SHAPF(SRF) MATLAB model shown in Fig.3 comprises of reference/compensating current signal generation (ILABC to Idq0 & $I\tilde{d}\tilde{q}\tilde{0}$ to $\widetilde{IC}$(ABC transformation) block, V(DC) regulator block, HBCC block and VSC inverter block. The functions of reference/compensating current signal (ILABC to Idq0 & $I\tilde{d}\tilde{q}\tilde{0}$ to $\widetilde{(IC)}$(ABC transformation) block, V(DC) regulator block, HBCC block and VSC inverter block have already been discussed comprehensively in sec II subsection A.

The SHAPF(IPQT) MATLAB model shown in Fig.4 comprises of reference/compensating current signal generation (ABC-αβ0,αβ0-PQ0, PQ0-αβ0 and αβ0-ABC transformation) block, V(DC) regulator block, HBCC block and VSC inverter block. The function of reference/compensating current signal generation(ABC-αβ0,αβ0-PQ0, PQ0-αβ0 and αβ0-ABC transformation) block, V(DC) regulator block, HBCC block and VSC inverter block have already been discussed comprehensively in sec II subsection B.

Thereby detailed discussion of Synchronous Reference Frame based Shunt Active Power Filter /Instantaneous Active-Reactive Power technique based Shunt Active Power Filter shall have abstained in section III.

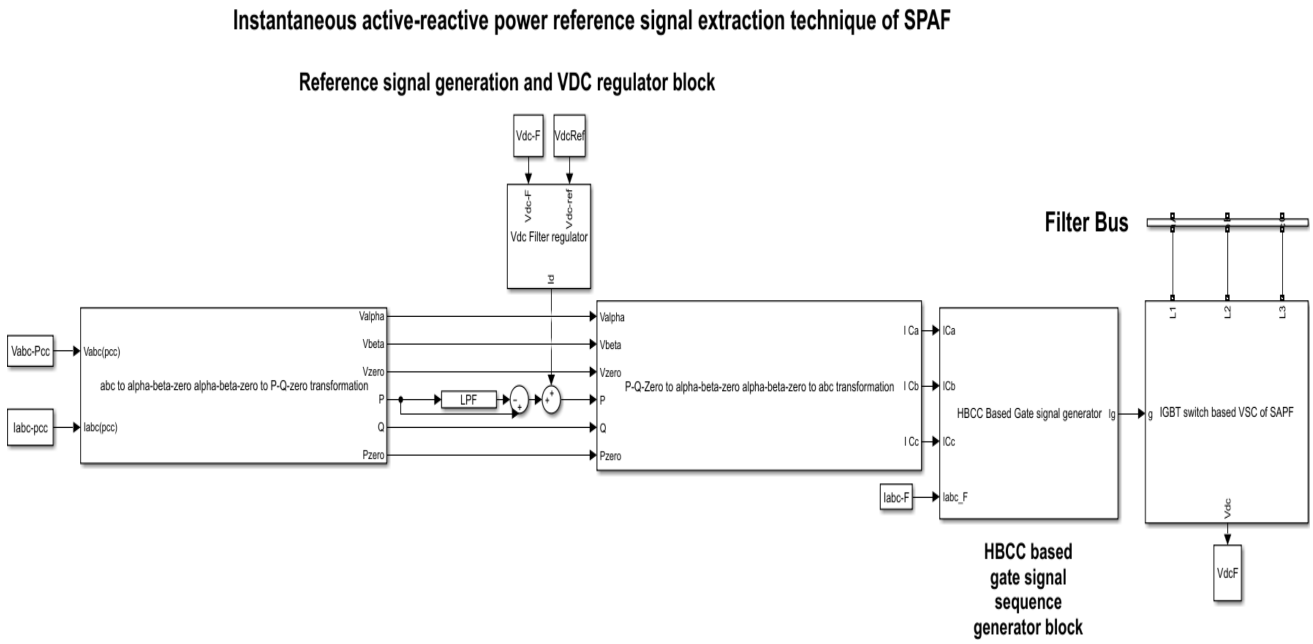


**Fig. 4 Matlab model SHAPF(IPQT)**

## IV. SIMULATION RESULTS AND COMPARATIVE ANALYSIS

The proposed power system model's simulation results at balanced and unbalanced load conditions are discussed in separate subsections as follows.

### *A. Simulation Results at Balanced load*

Simulation results at balanced load condition without compensation are depicted in Fig5. As depicted in Fig.5 at balanced load condition, V(ABC)PCC and I(ABC)PCC have values 1006V(L-L) rms and 70.04A(L-L/L-N) rms.

Total harmonic distortion (THD) in V(ABC)PCC & I(ABC)PCC is 20.40% and 15.38%. Dominating harmonic components in V(ABC)PCC are 5th (12.68%), 7TH (9.4%) and 11th (4.5%) harmonic.

Dominating harmonic components in I(ABC)PCC are 5th (13.3%) and 7TH (7.04%) harmonic.

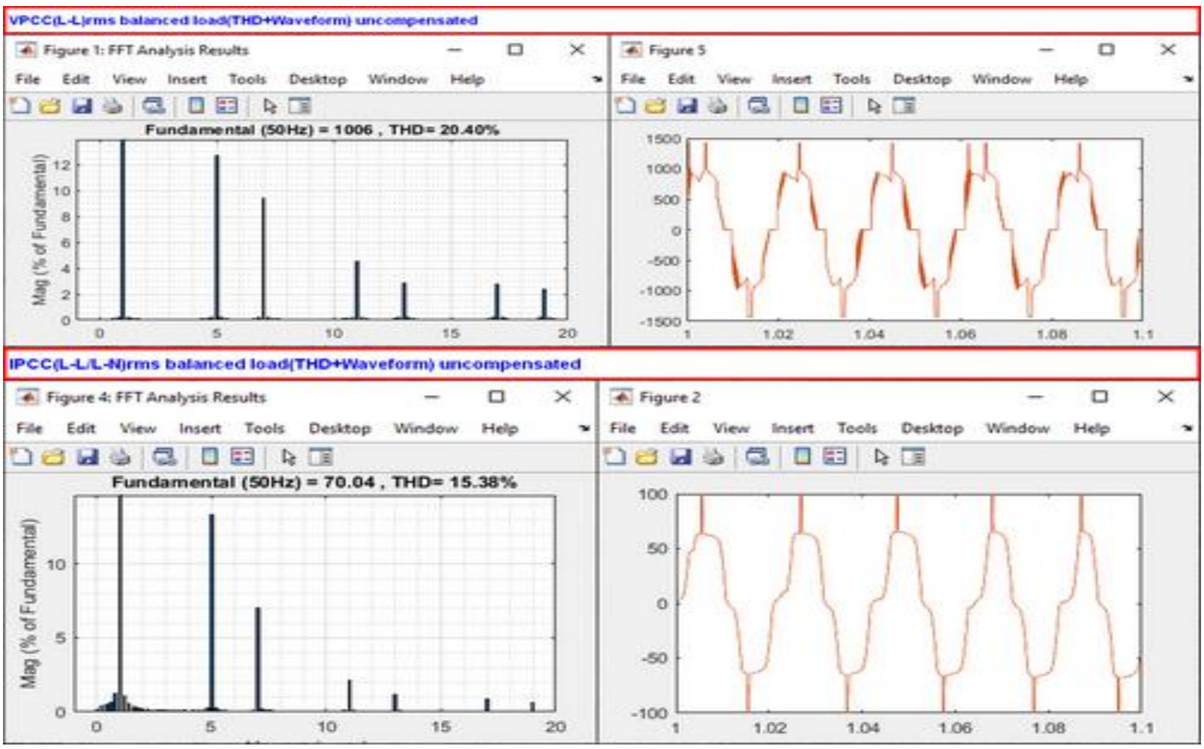


**Fig. 5 VPCC&IPCC(THD+WAVEFORM)**

Simulation results at balanced load condition after compensation with SHAPF'S SRF model are depicted in Fig6.

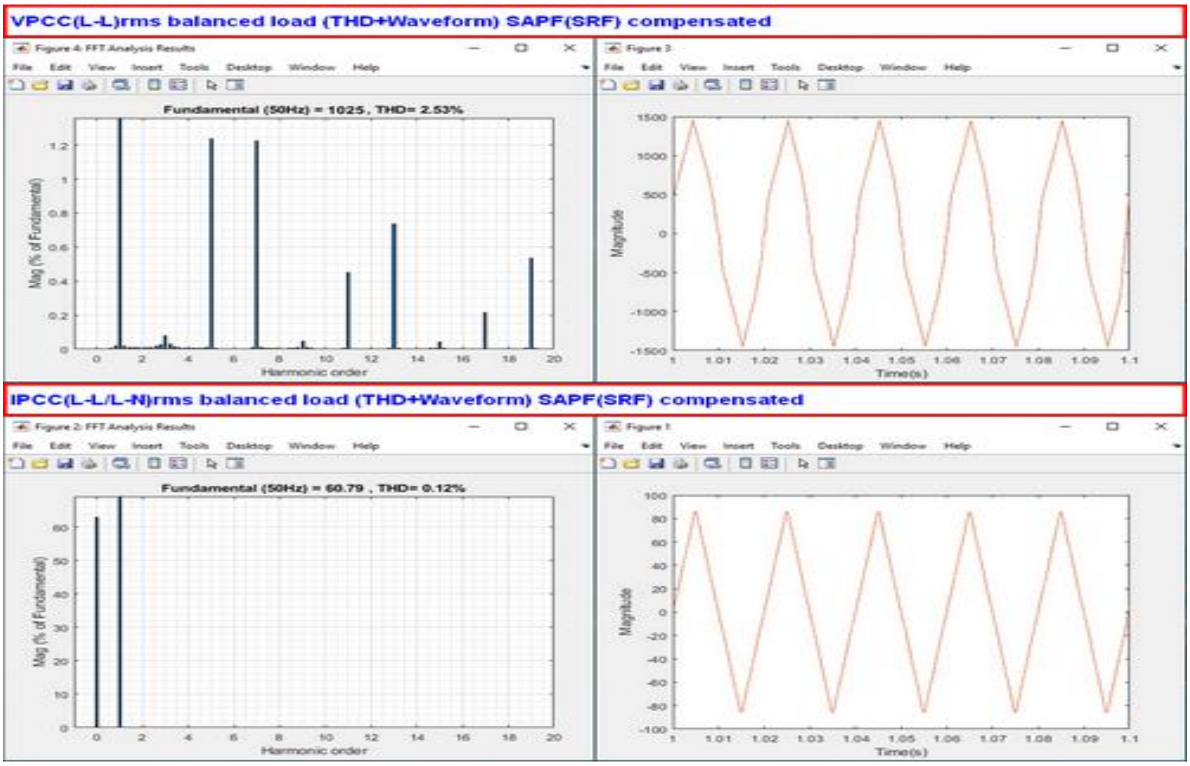


**Fig. 6 VPCC&IPCC(THD+WAVEFORM) SHAPF SRF Compensated**

As shown by Fig6 magnitude of V(ABC)PCC & I(ABC), PCC stands at 1025V(L-L) rms and 60.79A(L-L/L-N) rms, a decent increase in V(ABC)PCC and a considerable dip in I(ABC)PCC.

Total harmonic distortion (THD) values of V(ABC)PCC and I(ABC)PCC after compensation by SHAPF(SRF) at balanced load are 2.53% and 0.12%, a considerable decrease in THD values of V(ABC)PCC&I(ABC)PCC along with the satisfaction of IEEE-519 standard.

Simulation results at balanced load condition after compensation with SHAPF'S IPQT model are depicted in Fig7.

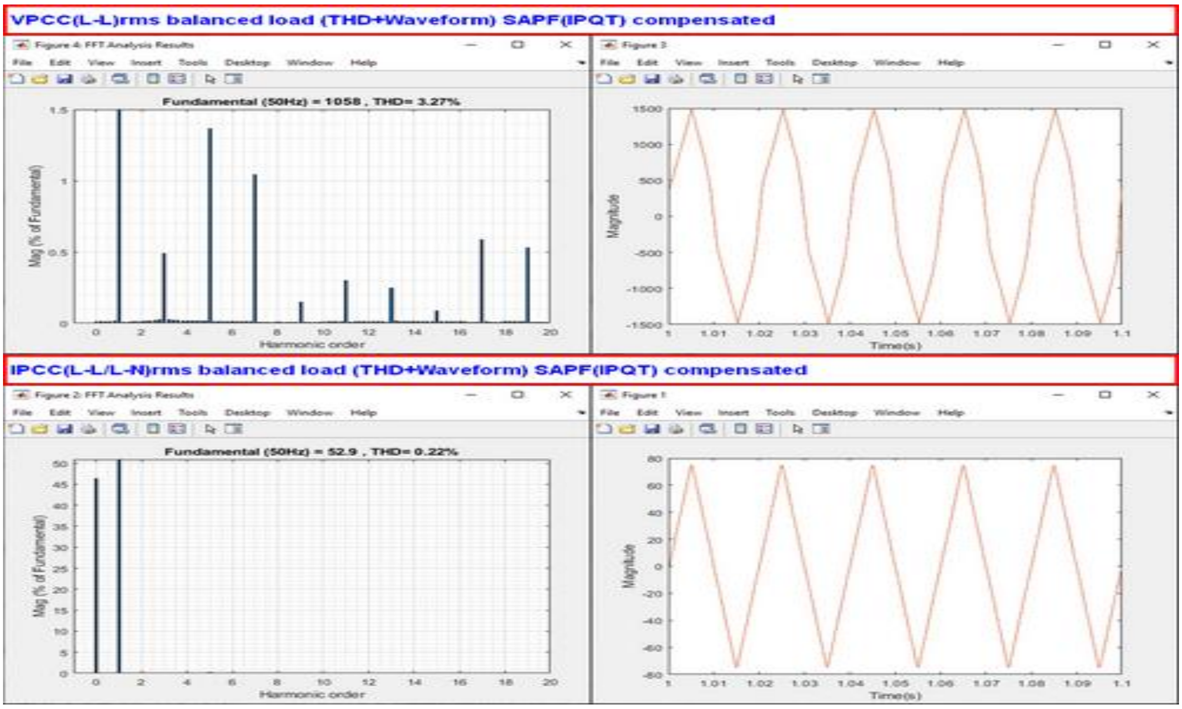


**Fig. 7 VPCC&IPCC(THD+WAVEFORM) SHAPF(IPQT)Compensated**

As depicted in Fig7. after application of shunt active power filter with IPQT at balanced load, V(ABC)PCC and I(ABC)PCC have magnitude 1058V(L-L) rms and 52.9A(L-L/L-N) rms, a considerable increase in V(ABC)PCC and decrease in I(ABC)PCC.THD values of V(ABC)PCC and I(ABC)PCC have reduced to 3.27%&0.22%, which satisfies the IEEE-519 standard.

***B. Simulation Results at Unbalanced load***

Simulation results at unbalanced load conditions without compensation are depicted in Fig8,9&10.

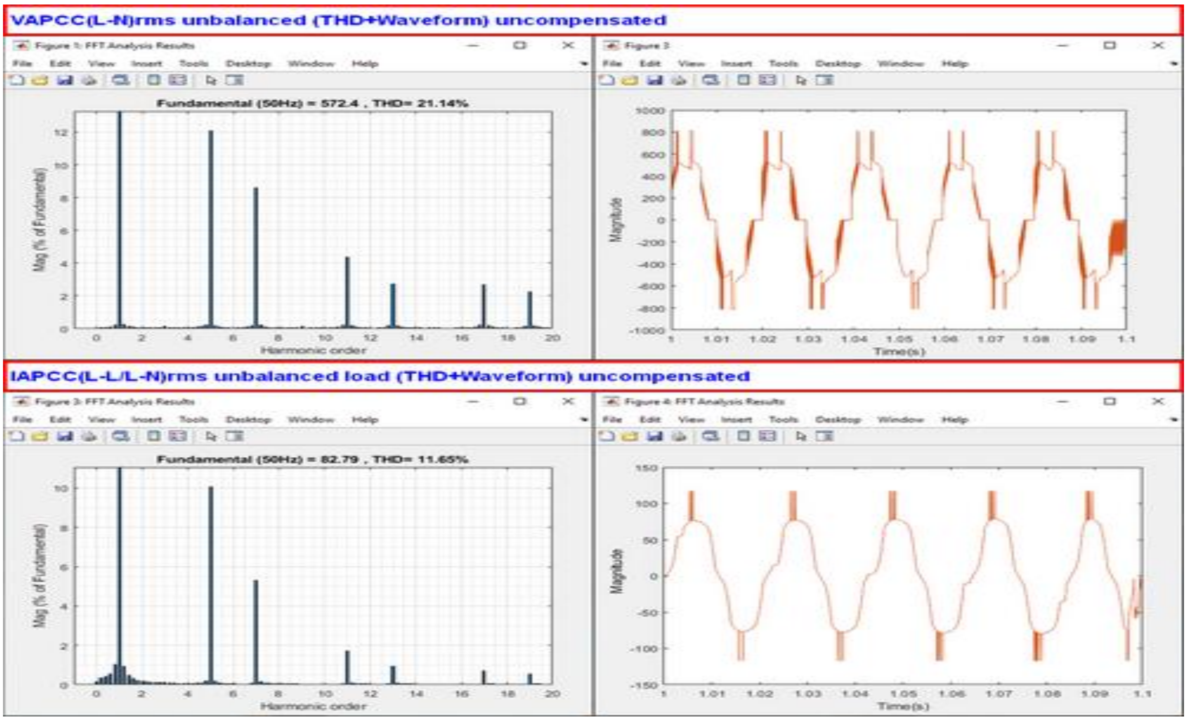


**Fig. 8 VPCC&IPCC(A) (THD+WAVEFORM) Unbalanced load Uncompensated**

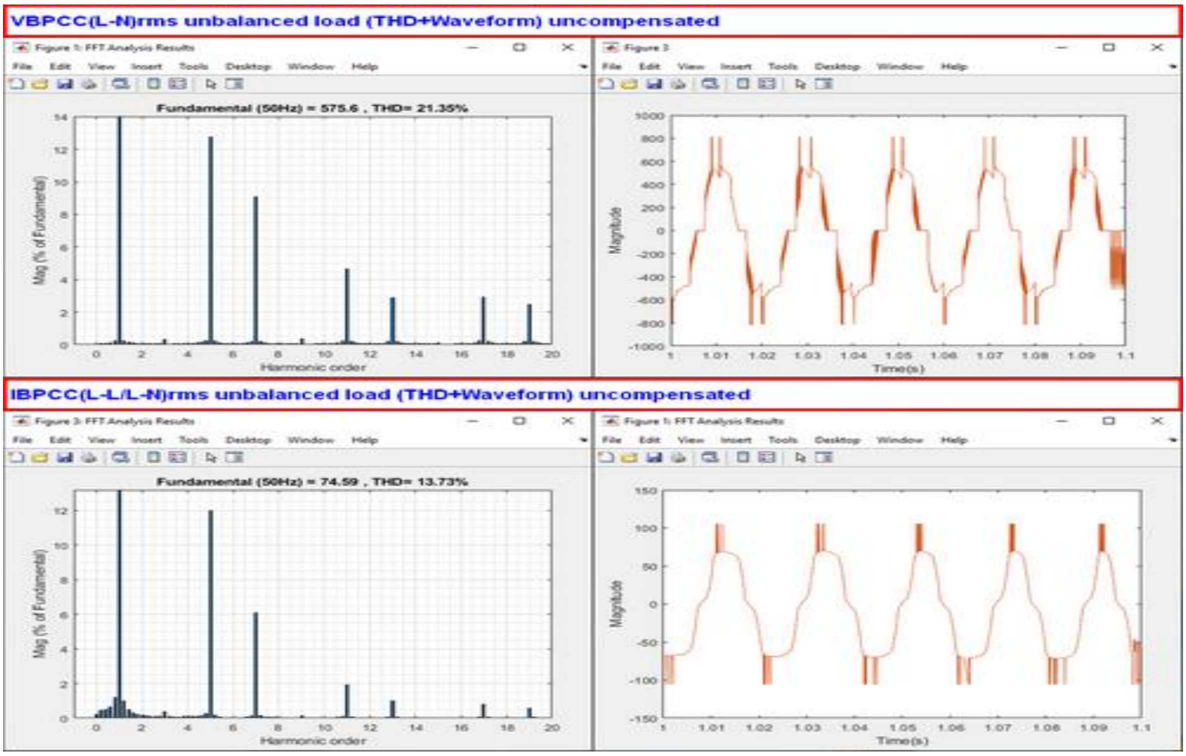


**Fig. 9 VPCC&IPCC(B) (THD+WAVEFORM) Unbalanced load Uncompensated**

At unbalanced load conditions per phase, values of voltage and current shall be considered at PCC.

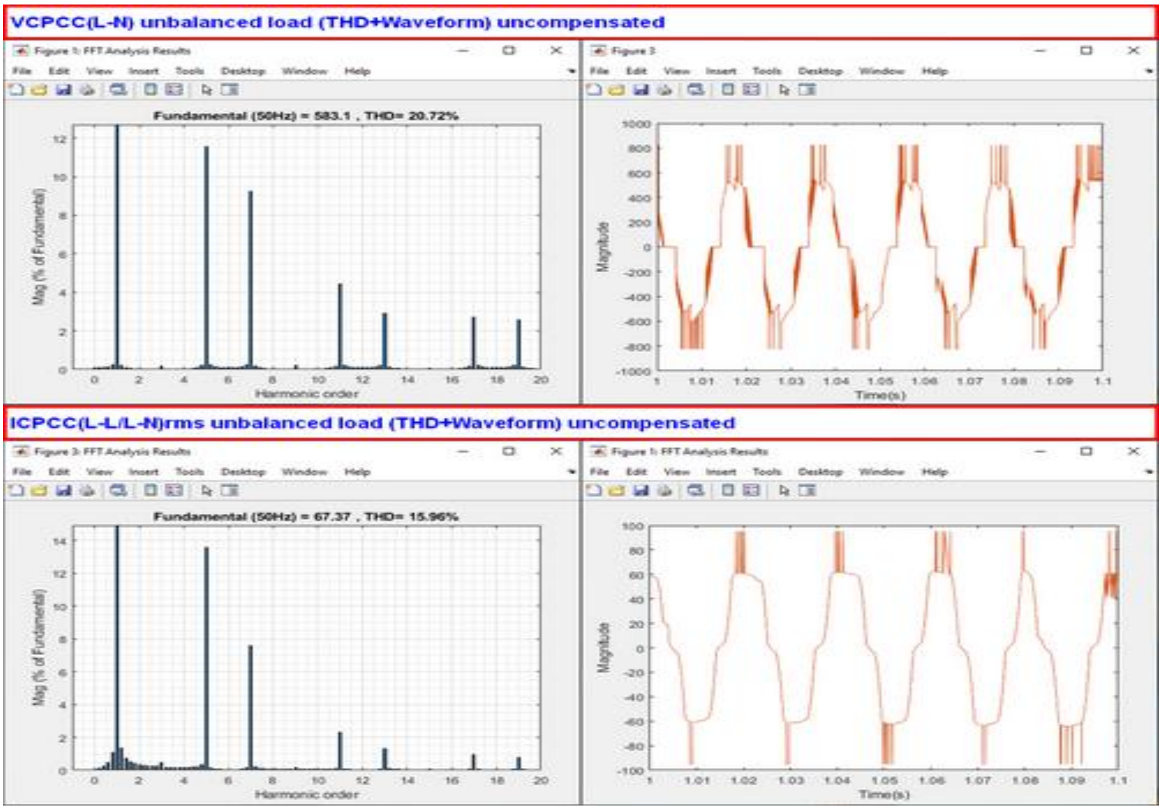


**Fig. 10 VPCC&IPCC(C) (THD+WAVEFORM) Unbalanced load Uncompensated**

As depicted in Fig8 magnitude and THD values of VA(PCC)rms(L-N) &IA(PCC)rms(L-L/L-N) are 572.4V(L-N) rms&21.14% and 82.79A(L-L/L-N) rms&11.65%. Dominating harmonic components in VA(PCC) are 5th (12.06%), 7TH (8.6%) and 11th (4.3%) harmonic. Dominating harmonic components in IA(PCC) are 5th (10.05%) and 7TH (5.3%) harmonic.

As depicted in Fig9 magnitude and THD values of VB(PCC)rms(L-N) &IB(PCC)rms(L-L/L-N) are 575.6V(L-N) rms&21.35% and 74.59A(L-L/L-N) rms&13.73%. Dominating harmonic components in VB(PCC) are 5th (12.73%), 7TH (9.06%) and 11th (4.6%) harmonic. Dominating harmonic components in IB(PCC) are 5th (11.97%) and 7TH (6.08%) harmonic.

As depicted in fig10 magnitude and THD values of VC(PCC)rms(L-N) &IC(PCC)rms(L-L/L-N) are 583.1V(L-N) rms&20.72% and 67.37A(L-L/L-N) rms&15.96%. Dominating harmonic components in VC(PCC) are 5th (11.54%), 7TH (9.24%) and 11th (4.4%) harmonic. Dominating harmonic components in IC(PCC) are 5th (13.6%) and 7TH (7.6%) harmonic.

Simulation results at unbalanced load conditions with SHAPF SRF compensation are depicted in Fig11,12&13.

As depicted in fig 11, the magnitude and THD of IAPCC&VAPCC after compensation by SHAPF(SRF) is 63.81A&0.11% and 596.9V&2.54%. A considerable decrease in THD values of IAPCC&VAPCC along with the satisfaction of IEEE-519 standard. Moreover, there is also a considerable decrease and increase in magnitudes of IAPCC&VAPCC.

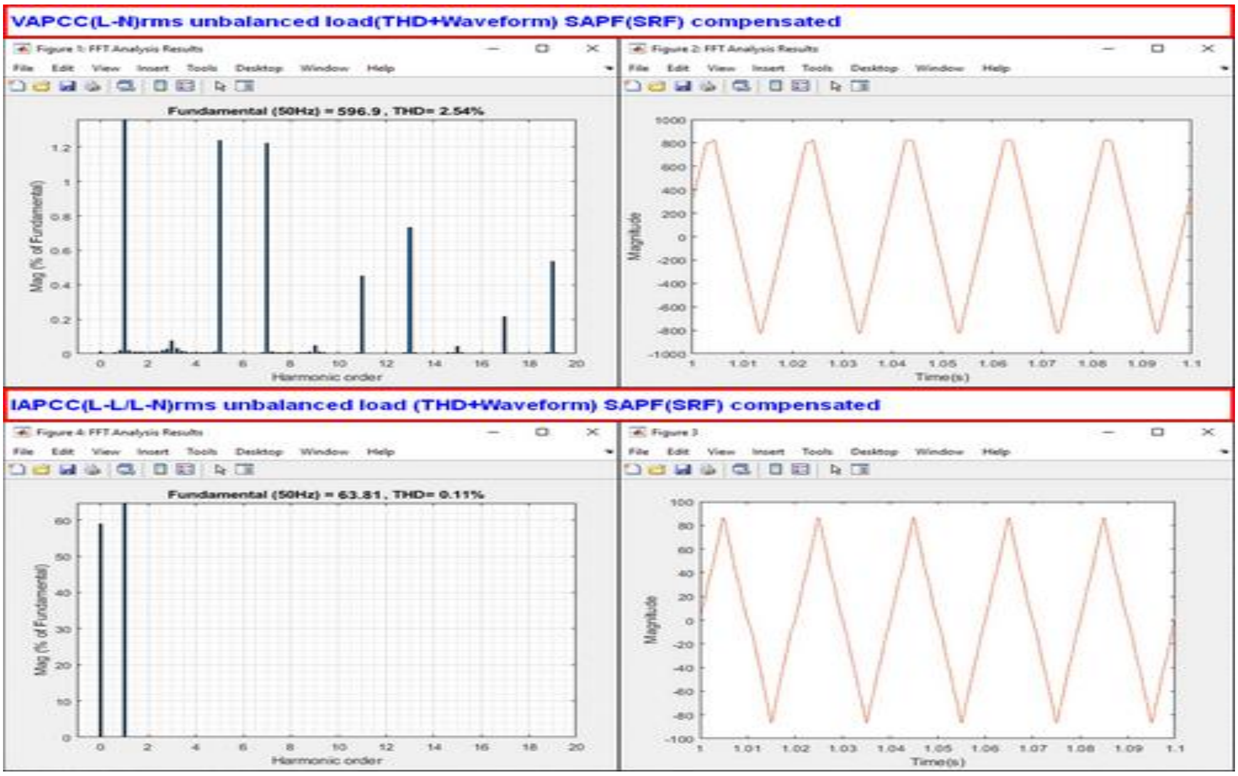


**Fig. 11 VPCC&IPCC(A) (THD+WAVEFORM) Unbalanced load SHAPF SRF Compensated**

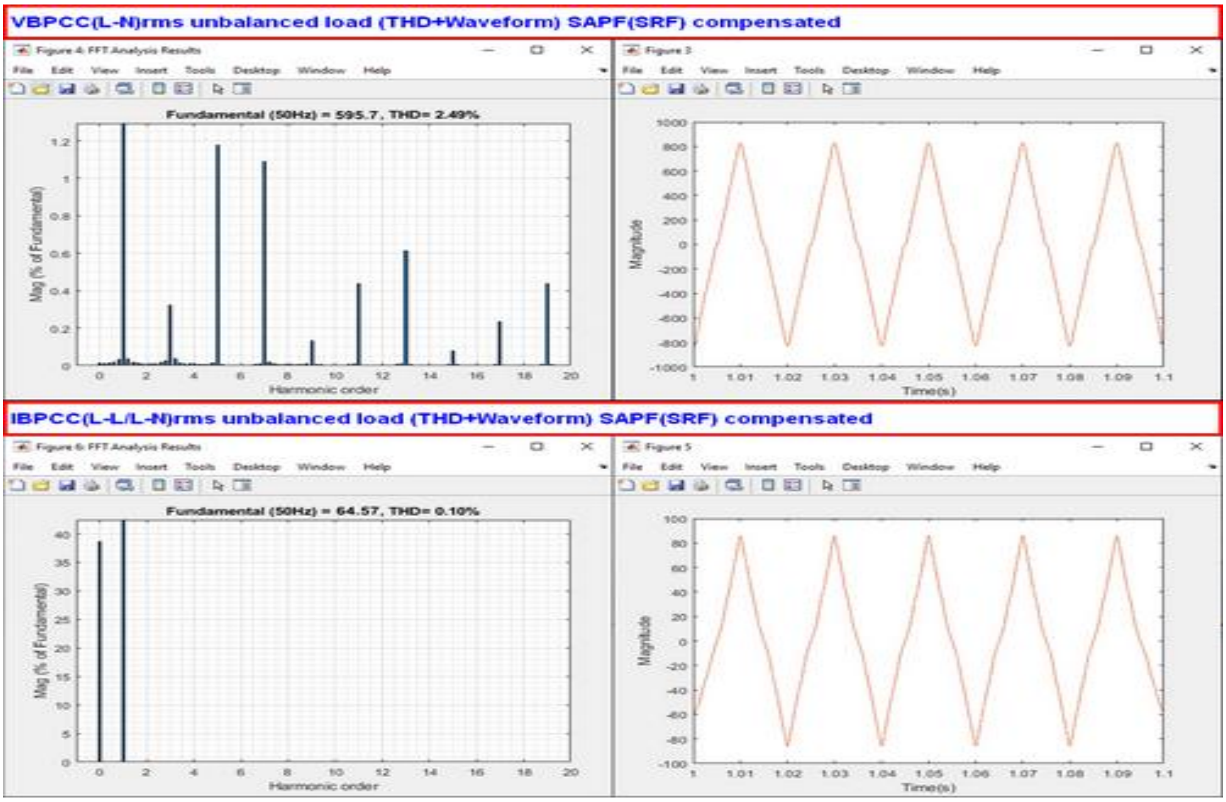


**Fig. 12 VPCC&IPCC(B) (THD+WAVEFORM) Unbalanced load SHAPF SRF Compensated**

As depicted in fig 12, the magnitude and THD of IBPCC&VBPCC after compensation by SAPF(SRF) is 64.57A&0.10% and 595.7V&2.49%. A considerable decrease in THD values of IAPCC&VAPCC along with the satisfaction of IEEE-519 standard. Moreover, there is also a considerable decrease and increase in magnitudes of IBPCC&VBPCC.

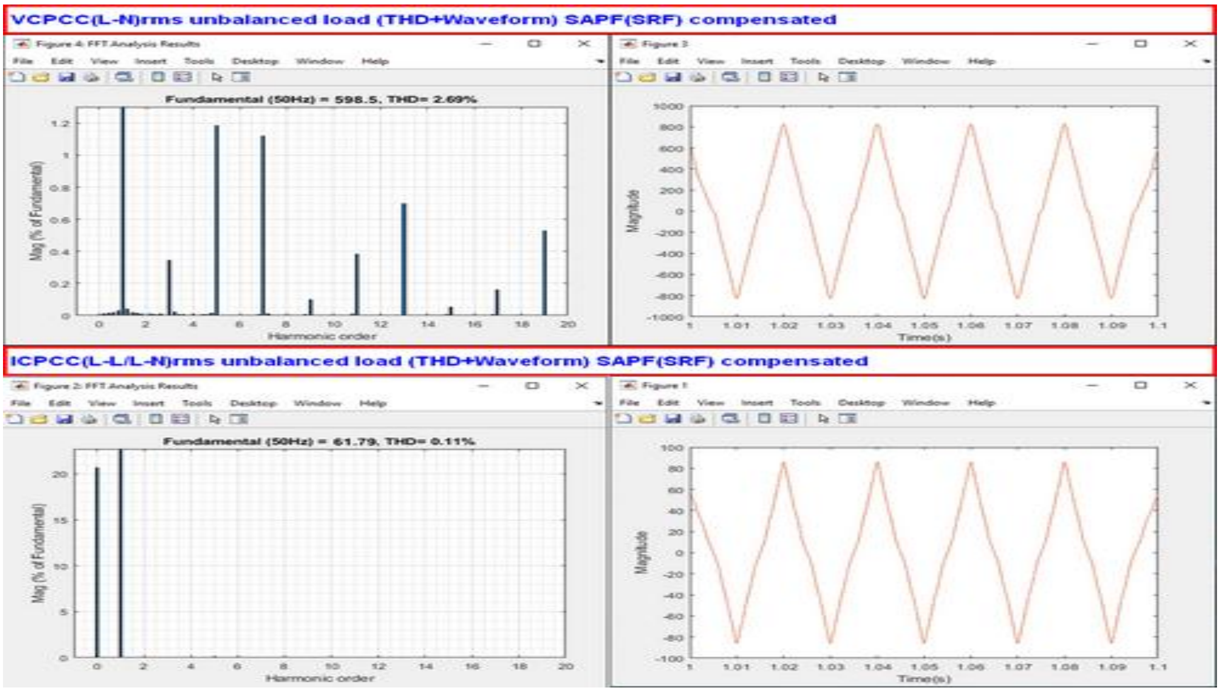


**Fig. 13 VPCC&IPCC(C) (THD+WAVEFORM) Unbalanced load SHAPF SRF Compensated**

As depicted in fig 13, the magnitude and THD of ICPCC&VCPCC after compensation by SAPF(SRF) is 61.79A&0.11% and 598.5V&2.69%. A considerable decrease in THD values of ICPCC&VCPCC along with the satisfaction of IEEE-519 standard. Moreover, there is also a considerable decrease and increase in magnitudes of ICPCC&VCPCC.

Simulation results at unbalanced load conditions with SHAPF IPQT compensation are depicted in Fig14,15&16.

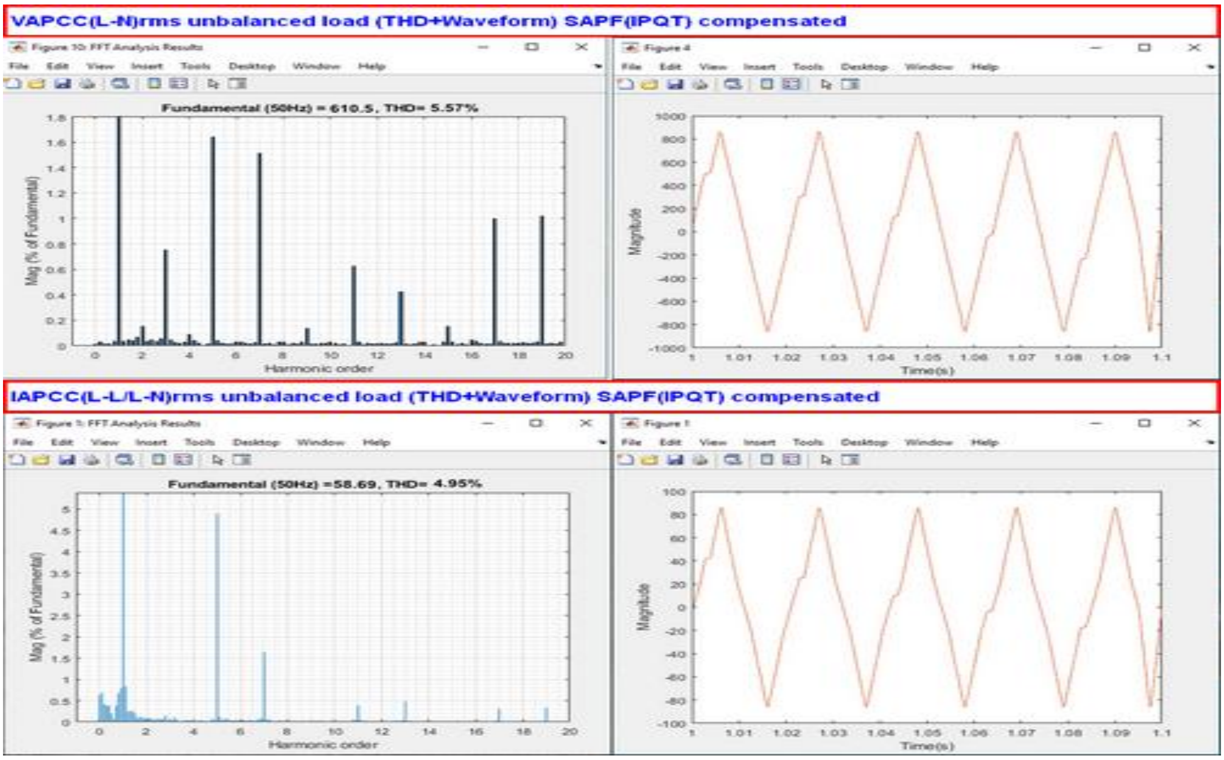


**Fig. 14 VPCC&IPCC(A) (THD+WAVEFORM) Unbalanced load SHAPF IPQT Compensated**

As depicted in fig 14, the magnitude and THD of IAPCC&VAPCC after compensation by SHAPF(IPQT) is 58.69A&4.95% and 610.5V&5.57%. A decent decrease in THD values of IAPCC&VAPCC, but IAPCC marginally satisfies IEEE-519 standard, whereas VAPCC fails to satisfy IEEE-519 standard.

However, there is a considerable decrease and increase in magnitudes of IAPCC&VAPCC.

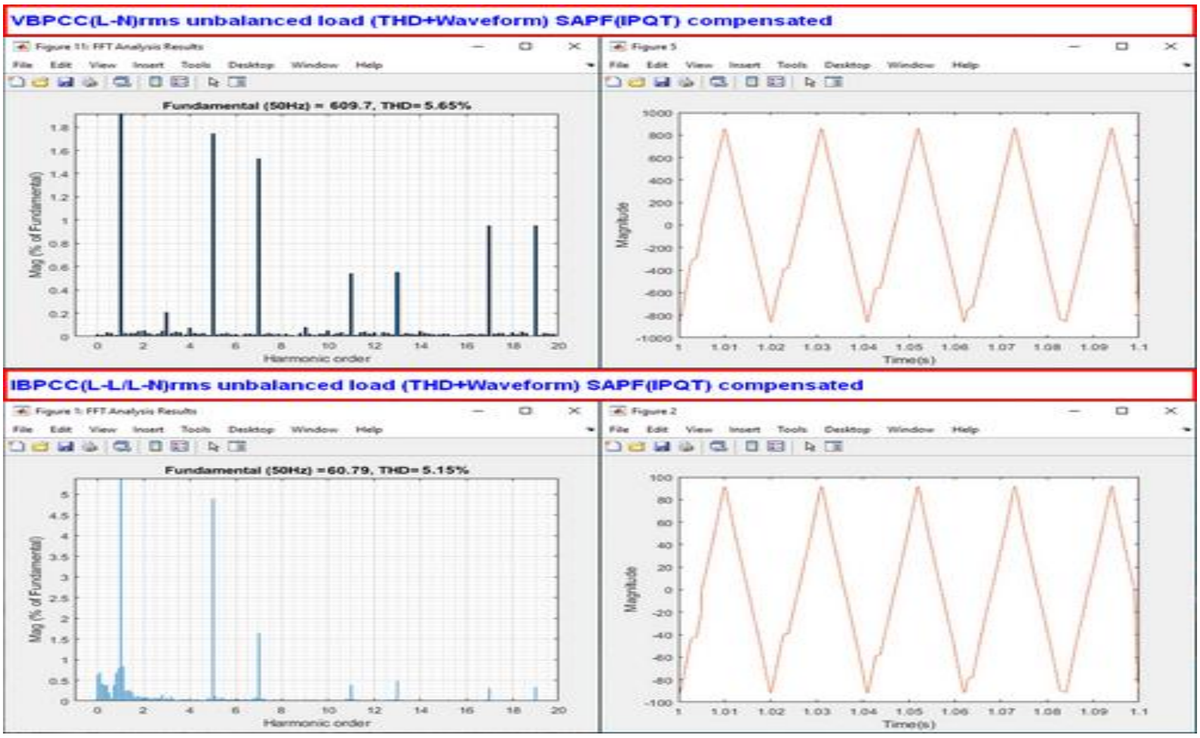


**Fig. 15 VPCC&IPCC(B) (THD+WAVEFORM) Unbalanced load SHAPF IPQT Compensated**

As depicted in fig 15, the magnitude and THD of IBPCC&VBPCC after compensation by SHAPF(IPQT) is 60.79A&5.15% and 609.7V&5.65%. A decent decrease in THD values of IBPCC&VBPCC, but both IBPCC&VBPCC fail to satisfy the IEEE-519 standard by the smallest margins. However, there is a considerable decrease and increase in magnitudes of IBPCC&VBPCC.

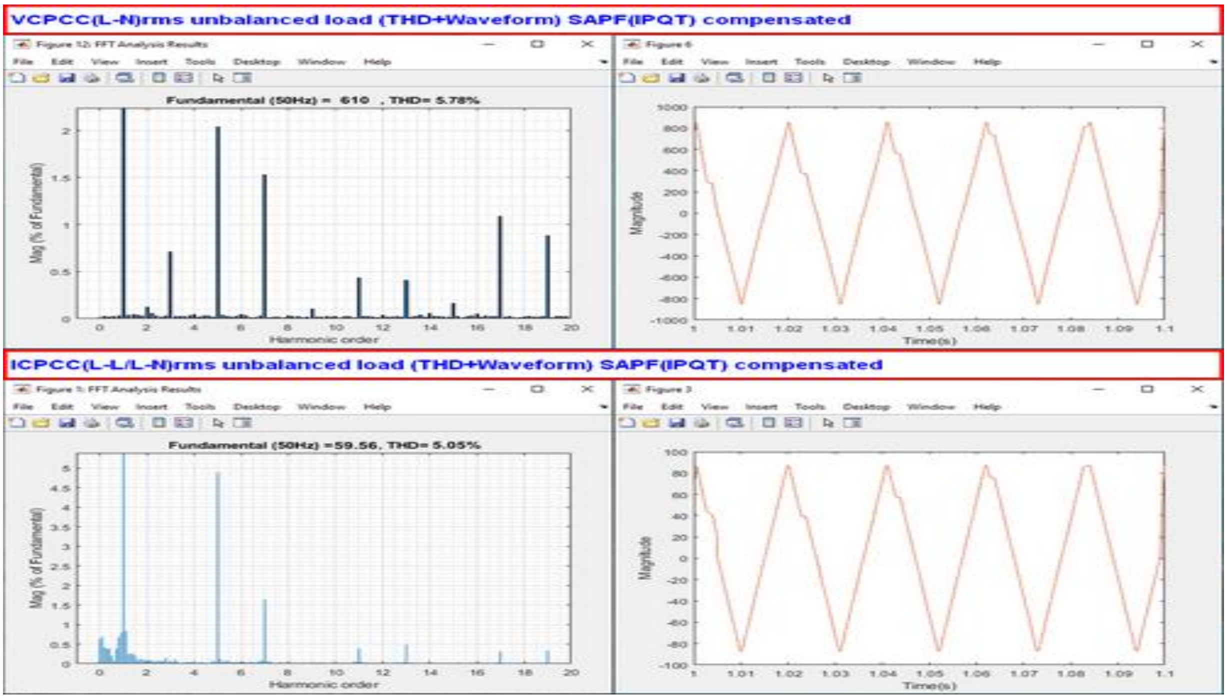


**Fig. 16 VPCC&IPCC(C) (THD+WAVEFORM) Unbalanced load SHAPF IPQT Compensated**

As depicted in fig 16, the magnitude and THD of ICPCC&VCPCC after compensation by SHAPF(IPQT) is 59.56A&5.05% and 610V&5.78%. A decent decrease in THD values of ICPCC&VCPCC, but both ICPCC&VCPCC fail to satisfy the IEEE-519 standard by marginally. However, there is a considerable decrease and increase in magnitudes of ICPCC&VCPCC.

*C. Comparative Analysis & Discussion of Simulation Results*

Total Harmonic Distortion (THD) values of VPCC and IPCC at balanced load condition in proposed MATLAB model of power system without and with compensation by shunt active power filter are shown in following fig17,18&19.

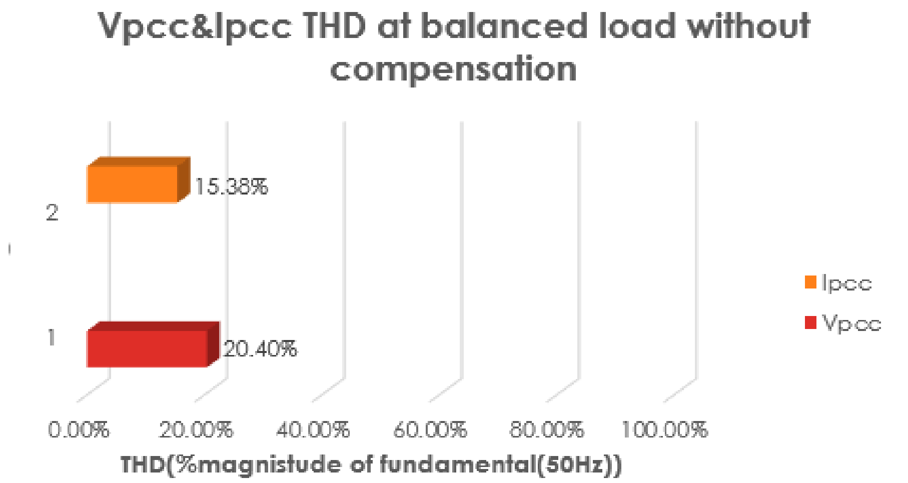


**Fig. 17 VPCC&IPCC THD Balanced load Uncompensated**

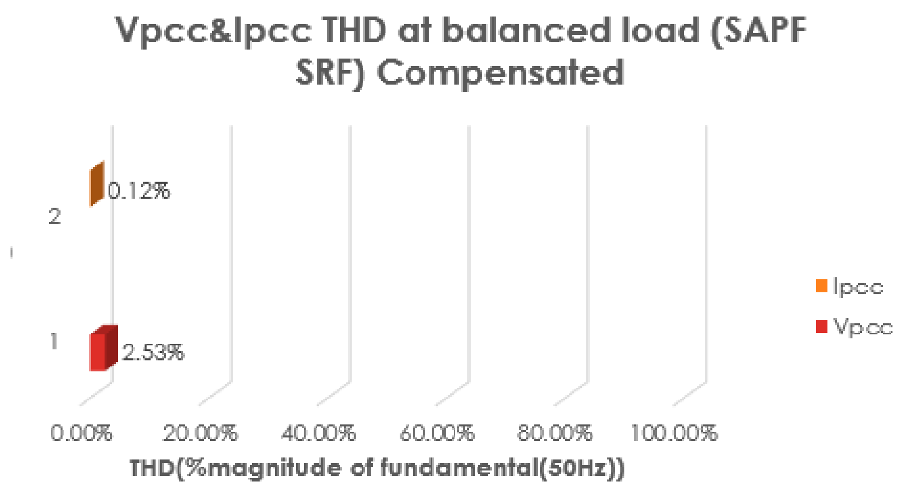


**Fig. 18 VPCC&IPCC THD Balanced load SHAPF SRF Compensated**

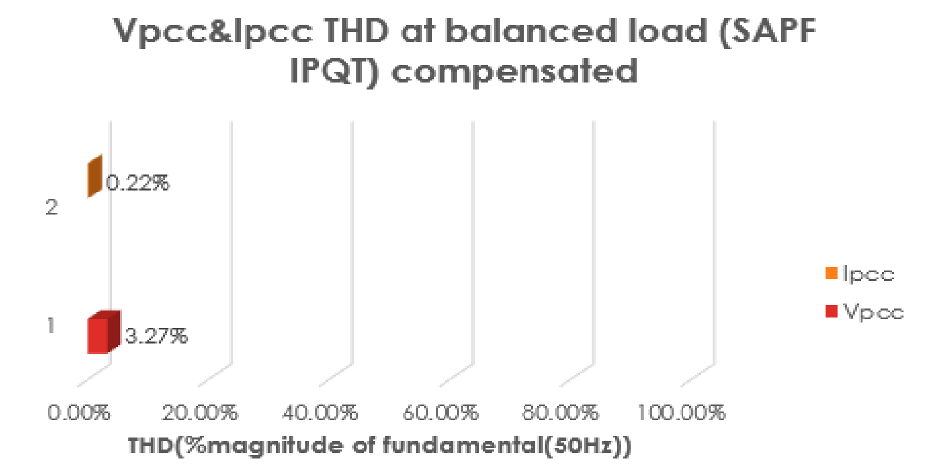


**Fig. 19 VPCC&IPCC THD Balanced load SHAPF IPQT Compensated**

As indicated in fig 17, THD values of VPCC and IPCC at balanced load condition without compensation are 20.40% and 15.38%.

After implementation of shunt active power filter with synchronous reference frame technique at balanced load condition THD values of VPCC and IPCC drop to 2.53% and 0.12%, as shown in fig 18.

In a similar fashion, after implementing a shunt active power filter with instantaneous active, reactive power technique at balanced load condition, THD values of VPCC and IPCC drop to 3.27% and 0.22%, as depicted in fig 19.

So evidently from figures of MATLAB simulation results; shunt active power filter implemented with SRF and IPQT at balanced load condition in proposed MATLAB model of power system reduces THD from VPCC and IPCC significantly and also satisfies IEEE-519 standard.

Total Harmonic Distortion (THD) values of VPCC and IPCC at unbalanced load condition in proposed MATLAB model of power system without and with compensation by shunt active power filter are shown in following figures:

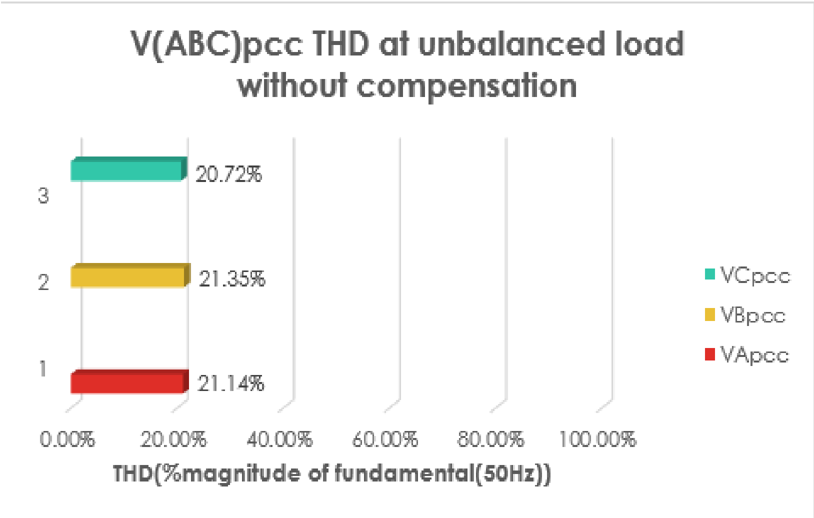


**Fig. 20 V(ABC)PCC THD Unbalanced load Uncompensated**

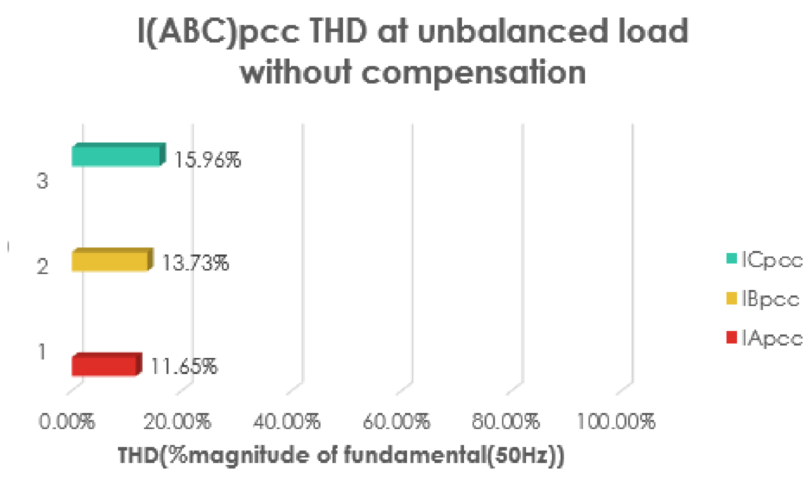


**Fig. 21 I(ABC)PCC THD Unbalanced load Uncompensated**

As shown in fig 20&21 at unbalanced load condition without compensation THD values for V(ABC)PCC are 21.14%, 21.35% and 20.72% and I(ABC)PCC are 11.65%, 13.73% and 15.96%.

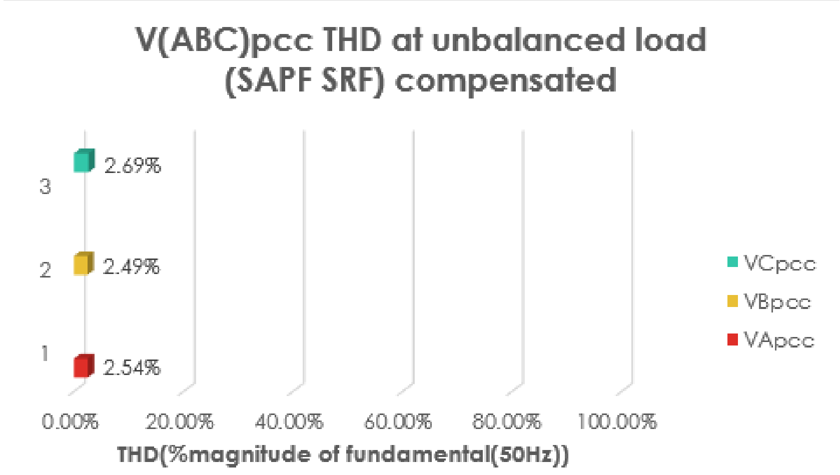


**Fig. 22 V(ABC)PCC THD Unbalanced load SHAPF SRF Compensated**

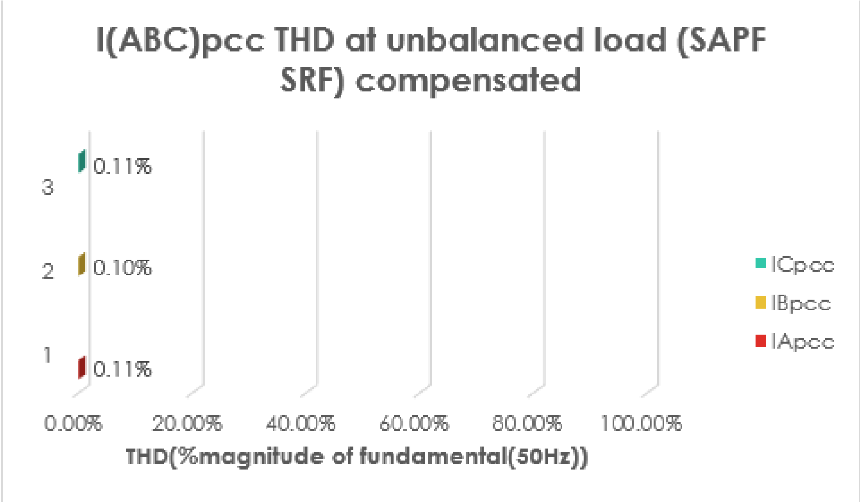


**Fig. 23 I(ABC)PCC THD Unbalanced load SHAPF SRF Compensated**

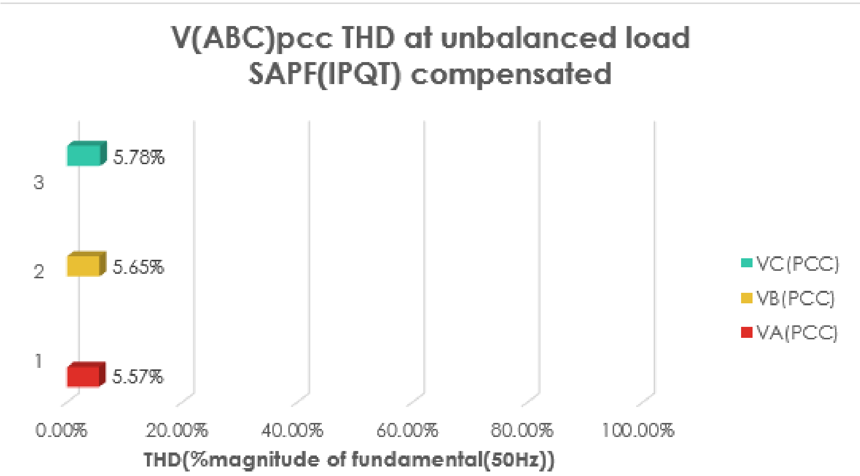


**Fig. 24 V(ABC)PCC THD Unbalanced load SHAPF IPQT Compensated**

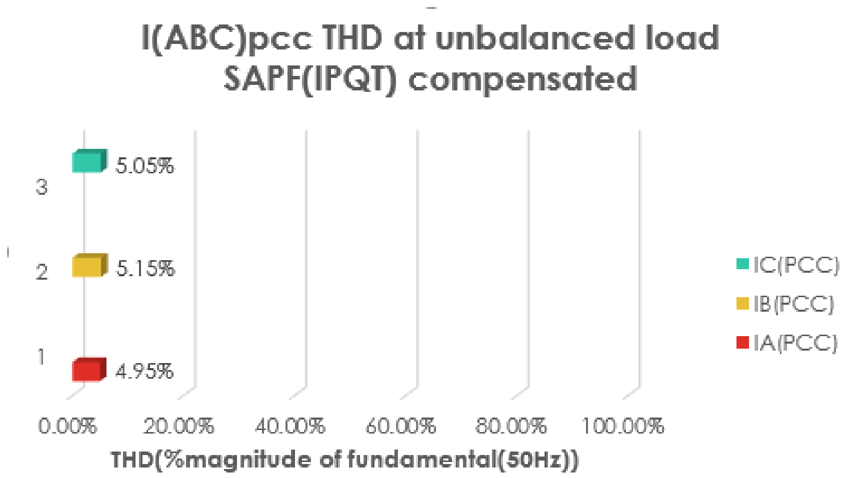


**Fig. 25 V(ABC)PCC THD Unbalanced load SHAPF IPQT Compensated**

As illustrated in Fig 22&23 at unbalanced load condition with harmonic compensation by SHAPF(SRF); THD values of V(ABC)PCC are 2.54%, 2.49 and 2.69% and I(ABC)PCC are 0.11%,0.10% and 0.11%. So evidently, it is safe to say that shunt active power filter connected with proposed power system model with synchronous reference frame technique shrinks harmonics from V(ABC)PCC&I(ABC)PCC remarkably and also maintains IEEE-519 standard.

Figs 24&25 indicate an unbalanced load condition with harmonic suppression by SHAPF(IPQT); THD values of V(ABC)PCC are 5.57%, 5.65% and 5.78%, and I(ABC)PCC are 4.95%, 5.15% and 5.05%. As witnessed from figs, 24&25 shunt active power filter used with instantaneous active, reactive power technique fails to reduce THD from both V(ABC)PCC& I(ABC)PCC below 5% and thereby fails in maintaining IEEE-519 standard.

Comparatively speaking, implementation of SHAPF with SRF&IPQT reference current signals generation techniques at PCC of MG power system at balanced and unbalanced nonlinear load conditions; SHAPF(SRF) successfully reduced THD's from VPCC&IPCC below 5% along with decent reactive power compensation at both balanced and unbalanced load conditions and also ensured load balancing at unbalanced load condition.

SHAPF(IPQT) successfully reduced THD's from VPCC&IPCC below 5% at balanced load conditions but failed to reduce THD's from VPCC&IPCC below 5% at unbalanced load. However, SHAPF(IPQT) significantly provided reactive power compensation at both balanced and unbalanced load conditions also ensured load balancing at unbalanced load conditions.

## V. CONCLUSION

In the end, brief essence of research work is that shunt active power filter's implementation with SRF&IPQT techniques at PCC of solar PV based MG power system at balanced and unbalanced load conditions reduced not only total harmonic distortion from V(ABC)PCC&I(ABC)PCC below 5% but also ensured reactive power compensation and load balancing at specified load conditions.

Performance-wise shunt active power filter with synchronous reference frame technique reduced THD from V(ABC)PCC&I(ABC)PCC below 5% comfortably at both load conditions but shunt active power filter with instantaneous active-reactive power technique only reduced THD from V(ABC)PCC&I(ABC)PCC below 5% at balanced load condition and failed to reduce THD from V(ABC)PCC&I(ABC)PCC below 5% at unbalanced load condition marginally.

So, shunt APF with SRF technique is the best choice for maintaining THD in voltages and currents at PCC below 5% at balanced and unbalanced load conditions in the proposed power system's MATLAB model.

Future work to be done on current research work includes;

Consideration of power system generated harmonics in MATLAB model of solar PV based MG system.

Considering variable inputs (solar irradiance, ambient temp & air mass factor) to solar PV side of PV based MG system.

Implementation of shunt APF with various frequency/time domain-based reference current signal generation techniques in solar PV based MG system and evaluating its performance at specified load conditions.

**APPENDIX A**

| S.No | Acronym | Description |
|---|---|---|
| 1 | APF | Active Power Filter |
| 2 | SRF | Synchronous Reference Frame |
| 3 | P-Q | Active-Reactive Power |
| 4 | IPQT | Instantaneous Active Reactive Power Technique |

| | | |
|---|---|---|
| 5 | VPCC | Voltage at Point Of Common Coupling |
| 6 | IPCC | Current at Point Of Common Coupling |
| 7 | THD | Total Harmonic Distortion |
| 8 | IGBT | Insulated Gate Bipolar Junction Transistor |
| 9 | MOSFET | Metal Oxide Field Effect Transistor |
| 10 | RL | Resistive Inductive load |
| 11 | Y | Three phase Star connection |
| 12 | PLL | Phase-locked loop |
| 13 | PI | Porportional Integrator controller |
| 14 | IL | Load Current |
| 15 | PCC | Point of Common Coupling |
| 16 | VSI | Voltage Source Inverter |
| 17 | HBCC | Hysterisis Band Current Controller |
| 18 | IF | Filter current |
| 19 | VSC | Voltage Source Converter |
| 20 | PV | Photo Voltaic |
| 21 | HPF | High Pass Filter |
| 22 | LPF | Low Pass Filter |
| 23 | VMP | Max Power Point Volts (dc) |
| 24 | IMP | Max Power Point Amps (dc) |
| 25 | MPPT | Max Power Point Tracking |


## ACKNOWLEDGMENT

The lead author is thankful for following faculty members of the Electrical Department MUET SZAB Khairpur Mir's campus for their cooperation and support in regard to this research paper:

1. Assistant Prof. Dr Sajid Hussain Qazi (Supervisor) and the author is also grateful to the following faculty members of Electrical Department MUET SZAB Khairpur Mir for Support/encouragement in regard to this research paper:
2. Associate Prof. Dr Mazhar Lund (Chairman Elec. DPT)
3. Assistant Prof. Irfan Ahmed Bajkani.


## REFERENCES


[1] E. W Kimbark, Direct-Current Transmission, New York, John Wiley & Sons Publishing. 1(1971).

[2] E.C Strycula, Gyugy, Active Ac Power Filters, Proc Iee Uias Annual Meet (1976) 529-535.

[3] R.P Stratford, D.E Steeper, Reactive Compensation And Harmonic Suppression for Industrial Power Systems using Thyristor Converters, Ieee Trans On Ind Appl,12(1976) 232-254.

[4] Ieee Working Group on Power System Harmonics, Power System Harmonics: An Overview, Ieee Trans on Power Apparatus Syst, Pas-102(8) (1983) 2455-2460.

[5] H. Akagi, Y. Kanazawa and A. Nabae, Instantaneous Reactive Power Compensators Comprising Switching Devices Without Energy Storage Components, Ieee Transactions on Industry Applications, Ia-20(3) (1984) 625-630.

[6] Ieee Load Characteristics Task Force, The Effects of Power System Harmonics on Power System Equipment and Loads, Ieee Trans on Power Apparatus Syst, Pas-104(9) (1985) 2555-2563.

[7] W.M Grady, M.J Samotyj and A.H Noyola, Survey of Active Power Line Conditioning Methodologies, Ieee Transactions on Power Delivery, 5(3) (1990) 1536-1542.

[8] J.F Chicharo, H. Wang, Power System Harmonic Signal Estimation and Retrieval For Active Power Filter Applications, Ieee Transaction on Power Electronics 9(6) (1994) 580-586.

[9] A Cavallini, G.C Montanari, Compensation Strategies for Shunt Active-Filter Control, Ieee Transactions on Power Electronics, 9(6) (1994) 587-593.

[10] M. Aredes, E.H Watanabe, New Control Algorithms for Series and Shunt Three-Phase Four-Wire Active Power Filters, Ieee Transactions on Power Delivery, 10(3) (1995) 1649-1656.

[11] S. Bhattacharya and D. Divan, Synchronous Frame-Based Controller Implementation For a Hybrid Series Active Filter System, Ias '95 Conference Record Of The 1995 Ieee Industry Applications Conference Thirteenth Ias Annual Meeting, (1995) 2531-2540.

[12] M. Aredes, J. Häfner and K. Heumann, Three-Phase Four-Wire Shunt Active Filter Control Strategies, Ieee Transactions on Power Electronics,12(2) (1997) 311-318.

[13] H. Akagi, Control Strategy and Site Selection of A Shunt Active Filter for Damping of Harmonic Propagation in Power Distribution Systems, Ieee Transactions on Power Delivery, 12(1) (1997) 354-363

[14] B. Singh, K. Al-Haddad and A. Chandra, A Review of Active Filters for Power Quality Improvement, Ieee Transactions on Industrial Electronics, 46(5) (1999) 960-971

[15] H. Akagi, H. Fujita and K. Wada, A Shunt Active Filter Based on Voltage Detection for Harmonic Termination of A Radial Power Distribution Line, Ieee Transactions on Industry Applications, 35(3) (1999) 638-645.

[16] M.K Mishra, A. Joshi and A. Ghosh, A New Algorithm for Active Shunt Filters using Instantaneous Reactive Power Theory, Ieee Power Engineering Review, 20(12) (2000) 56-58.

[17] Chandra Et Al., An Improved Control Algorithm of Shunt Active Filter for Voltage Regulation, Harmonic Elimination, Power-Factor Correction, and Balancing of Nonlinear Loads, Ieee Transactions on Power Electronics, 15(3) (2000) 495-507.

[18] M. El-Habrouk, M. Darwish and P. Mehta, Active Power Filters: A Review, Ieee Proceedings Electric Power Applications, 147(5) (2000) 403-413.

[19] A M Al-Zamil and D A Torrey, A Passive Series, Active Shunt Filter for High Power Applications, Ieee Transactions on Power Electronics,16(1) (2001) 101-109.

[20] M I M Montero, E.R Cadaval and F B González, Comparison of Control Strategies for Shunt Active Power Filters in Three-Phase Four-Wire Systems, Ieee Transactions on Power Electronics, 22(1) (2007) 229-236.

[21] Lascu Et Al., Frequency Response Analysis Of Current Controllers For Selective Harmonic Compensation in Active Power Filters, Ieee Transactions On Industrial Electronics, 56(2) (2009) 337-347.

[22] S. Rahmani, K. Al-Haddad And N. Mendalek, Experimental Design Of A Nonlinear Control Technique For Three-Phase Shunt Active Power Filter, Ieee Transactions On Industrial Electronics, 57(10) (2010) 3364- 3375.

[23] S. Mikkili And A.K Panda, Real-Time Implementation Of Shunt Active Filter Pq Control Strategy For Mitigation Of Harmonics With Different Fuzzy Mfs, Journal Of Power Electronics Society,12(5) (2012) 821–829.

[24] A. Sharma and A. Upadhyay, Harmonic Mitigation Using Inverter Based Hybrid Shunt Active Power Filter, International Journal of Electronics and Electrical Engineering, 7(8) (2014) 787-798.

[25] Qazi Et Al., Comparison Of Reference Signal Extraction Methods for Active Power Filter to Mitigate Load Harmonics From Wind Turbine Generator, Ieee Conference On Energy Conversion (Cencon-2015). Johor Bahru, Malaysia (2015).