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Abstract

The article describes the current control scheme for Shunt Active Power Filter (SAPF) meant for setting up on a power system. There is also a supplementary function in the active power filter for eliminating harmonics, correct power factor, and asymmetrical balance load studied in this paper. A brief explanation of the execution of the classical current detection algorithms for active power filters provided. After understanding various severe power excellence problems and a range of commission needs a current control scheme put forth. The system gives shortest time delay when compared with other methodologies. A range of commissioning current references, thus, is precisely and efficiently attained by following the suggested current control approach.The proposed system can assured that to achieve a variety of compensation purposes. The simulation outcomes we arrived with MATLAB / Simulink are proof that our method gives outstanding performance apart from being more effective compared to the existing methods.

Subject Classification: *32A50, 43-XX*

Keywords: *Shunt Active Power filter, Synchronous Reference Frame, Instantaneous Reactive Power Theory, Point of standard coupling, Synchronous current detection*

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1. Introduction

Increased deployment linked with those power distributing frames to DC supply/inverter and converter dependent applications, lead to downgrading in power supply networks concerning voltage/current harmonics, power factor besides resonance issues. Modest and cheap passive filters are highly efficient. But, the source impedance decides their performance thereby causing unnecessary problems with the electrical power network [1,2,3]. Moreover, they are also heavy and not suitable for N-LL applications. When there are N-LL current source loads, the best option for downsizing the current harmonics in both low and high power applications is the SAPF [4,5]. Either in series or in combinations of both (unified power quality Conditioners) and hybrid configurations, the Active power filter can be connected [6,7]. Since the current harmonics compensation is the widely preferred one for industrial applications, the SAPF is considered the most popular choice compared to the [8,9] series active filters as they are tiny, versatile, come with more choice and robust. Studies have been conducted on SAPF and thereby leading to new developments and innovations [10].

Figure. 1 shows the primary commission motto for a plant with an N-LL using a SAPF. The SAPF consists of a three phase Voltage Source Inverter (VSI) containing just a dc link capacitor. Where the former one is linked to the load at the Point of Common Coupling (PCC) via the input

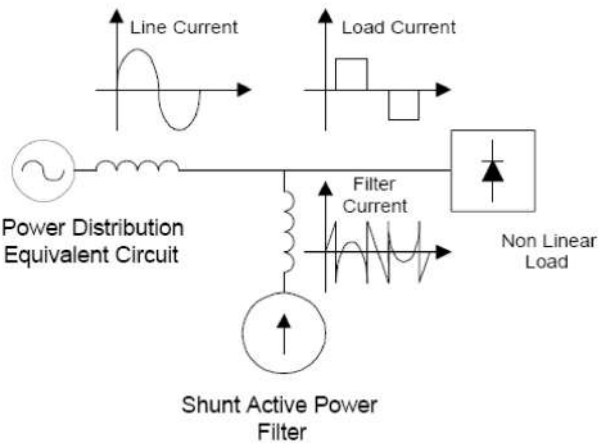

Figure 1

Principle of Shunt Compensation

inductor. Like a controlled current source, the SAPF works, thereby the load harmonic current. A sinusoidal current is obtained from the mains at the PCC. The SAPF will require an active fundamental current part to keep its DC connection capacitor activated at a voltage more significant than the threshold to line voltage. The reference current is not sinusoidal, so receiving a 0 - steady-state error is severe.

2. Principle of Shunt Compensation System

We keep the SAPF in link with the supply grid at Point of Common Coupling (PCC) via filter inductance. While switching the power inverter, harmonics are created, which is suppressed by the filter. We achieve the current harmonic commission by inoculating equivalent yet reverse present harmonic parts at PCC so that the previous alteration is canceled and power quality is also improved [11,12].

The immediate source current is shown in Figure 1.

$$I_S(t) = I_L(t) - I_C(t) \tag{1}$$

The immediate source voltage is

$$V_S(t) = V_m \text{ Sin } \omega t \tag{2}$$

The load current has the basic components and current harmonic parts, shown as [3]

$$\begin{aligned} I_L(t) &= \sum_{n=1}^{\infty} I_n \sin(n\omega t + \phi_n) \\ &= I_1 \sin(\omega t + \phi_1) + \left[\sum_{n=2}^{\infty} I_n \sin(n\omega t + \phi_n) \right] \end{aligned} \tag{3}$$

The immediate load power (P_L) can be calculated from the source voltage and load current, and the computation is given as

$$\begin{aligned} P_L(t) &= I_S(t) * V_S(t) = \begin{matrix} V_m Sin^2 \omega t * Cos\phi_1 + V_m I_1 Sin\omega t * \\ Cos\omega t * Sin\phi_1 + V_m Sin\omega t * \left(\sum_{n=2}^{\infty} I_n Sin(n\omega t + \phi_n) \right) \end{matrix} \\ &= P_F(t) + P_R(t) + P_H(t) \end{aligned} \tag{4}$$

The given load power has basic active power, reactive power, and harmonic power. From Eq. (4), we arrive the real basic power obtained from the load as

$$P_F(t) = V_m I_1 Sin^2 \omega t * Cos\phi_1 \tag{5}$$

In case the active power filter offers the total reactive and harmonic power, the source current $i_s(t)$ would be in line with the utility voltage and sinusoidal. The triple phase source currents post-commission is given as

$$I_A^* = I_m \text{Sin } \omega t \tag{6}$$

$$I_B^* = I_m \text{Sin } (\omega t - 120^\circ) \tag{7}$$

$$I_C^* = I_m \text{Sin } (\omega t + 120^\circ) \tag{8}$$

We derive the maximum value of the reference current Iref with the regulation of the DC-bus capacitor voltage of the inverter.

3. Reference Current Estimation

In the 3-phase 3 wire scheme, the direct load currents of phase "*a*" "*b*", "*c*" (i_a, i_b, and i_c) can be taken apart into +ve sequence and -ve sequence parts in accordance to the proportioned weigh laws stated by Fortes cue discretely.

$$i_x(n) = \sum_{k=1}^{\infty}\left[I_{1k}Sin\left(\frac{2\pi nk}{N}+\phi_{1k}-\frac{2l\pi}{3}\right)+I_{2k}Sin\left(\frac{2\pi nk}{N}+\phi_{2k}+\frac{2l\pi}{3}\right)\right] \tag{9}$$

It is just the +ve sequence, -ve sequence, active power, and reactive power of the basic current are monitored, and decomposing of the hormonic is unnecessary. Thereby, the current fundamental part is expressed as:

$$i_{x1}(n) = I_{11}Sin\left(\frac{2\pi}{N}n+\phi_{11}-\frac{2l\pi}{3}\right)+I_{21}Sin\left(\frac{2\pi}{N}n+\phi_{21}+\frac{2l\pi}{3}\right) \tag{10}$$

Here, the former component of (2) is directed to the +ve sequence part line with the phase voltage, called as the active power component of the +ve sequence necessary current; the second part of (2) is directed to the +ve sequence component orthogonal to the line voltage, called as the reactive power part of the +ve-sequence fundamental current; the third component of (2) is directed to the -ve sequence part in line with the line voltage, called as the active power component of the -ve sequence necessary current; the final segment of (2) is directed to the -ve sequence component orthogonal to the line voltage, called as the reactive power part of the -ve sequence fundamental

$$
\begin{aligned}
i_{x1}(n) \; = \; & I_{11}Sin\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)Cos\phi_{11} \\
& +I_{11}Cos\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)Sin\phi_{11} \\
& +I_{21}Sin\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)Cos\left(\phi_{21}-\frac{2l\pi}{3}\right) \\
& +I_{21}Cos\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)Sin\left(\phi_{21}-\frac{2l\pi}{3}\right) \qquad (11)
\end{aligned}
$$

Current.

Where '$Sin\frac{2\pi}{N}n$' is in line with the +ve sequence necessary voltage of phase "a" which finds the exact computing of active and reactive power parts. The system performance is regulated by the low-pass filter [13]. For a range of commission reasons, the separator conveniently gets various constituents that are greater to the algorithm according to the immediate reactive power theory. We created a Phase Locked Loop (PLL) system that is apt for time-domain analysis in an inaccurate utility circumstances. This was adjusted to the regulator effects like gain deterioration, line harmonics, and frequency turbulences. We did the entire incorporation of the PLL in software with no aid from hardware filters at all, as shown in Figure 2.

As mentioned above, we did a complete installation of the PLL in software devoid of hardware filters. If the reference Ude*is 0, the θ^* derived is in sync with the +ve sequence part of first voltage [14,15]. When $u_{de}^*$is not set to zero, there is a fixed phase difference amid the θ^* and the +ve sequence part of necessary voltage, thereby rendering the management of the displacement factor efficiently. Further, this phase variance not going

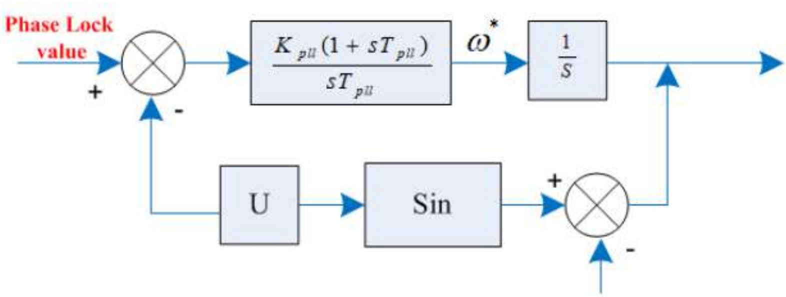

Figure 2

Proposed PLL System

to influence the strength of the chosen harmonics detection [16,17,18]. We gained the phase voltages U_{as}, U_{bs}, U_{cs} from sampled line-to-line voltages. The transformation of the obtained stationary reference frame voltages into voltages U_{de}, U_{qe} (in a frame of reference synchronized to the utility frequency) with the help of the 3/2 and e / s alterations. The angle θ* employed in the above conversions is gained by assimilating a frequency command ω^*. In case of frequency command ω^* is equal to the utility frequency, the voltages U_{de} and U_{qe}, look like dc values relying on the angle θ*.

In our proposed system, we have deployed a PI regulator forgetting that value of θ*(or ω^*) that carries the feedback voltage U_{de} to a commanded value U_{de}*. Alternatively, the regulator ends up in a rotating frame of reference with respect to which the transformed voltage U_{de} has the desired dc value U_{de}*. The rotating frame's incidence is similar to the rate of the utility voltage. The Extent of the controlled quantity U_{de} governs the phase difference between the utility voltages and sin (θ*) or cos (θ*).This approach leads to not just the utility frequency ω^* but also lets one to lock at an arbitrary phase angle θ* corresponding to the utility angle θ. The angle Δθ is controlled by the commanded values U_{de}*.

The phase voltage is stated by per-unit; the base numbers for per-unit value are the peak value of +ve sequence fundamental phase voltage. Then, three-phase voltages can be expressed as $Sin\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)$, respectively. The immediate power of the significant current can be attained by multiplying current $i_{x1}(n)$ by phase voltage. Likewise, the instantaneous power of harmonics can be accomplished by increasing flow. $i_{xk}(n)$ $i_{xk}(n)$ $Sin\left(\frac{2\pi}{N}n-\frac{2l\pi}{3}\right)$ We could observe that the -ve sequence or +ve sequence component has alone part out of which the three-phase sum up to zero. Without any energy storage, we can compensate for this using a compensator. The least frequency constituent is two times the primary frequency; the dc component can be attained by a low pass filter with a limit frequency smaller than two times the basic rate or by a sliding window with *N*/2 samples.

$$X_{x1} = I_{11}Cos\phi_{11} + I_{21}Cos\left(\phi_{21} + 4l\pi/3\right) \tag{12}$$

with a similar methodology, the below equations can also be obtained

$$Y_{x1} = I_{11}Sin\phi_{11} + I_{21}Sin\left(\phi_{21} + 4l\pi/3\right) \tag{13}$$

From equations (6) and (7),

$$\begin{pmatrix} X_{11} & Y_{11} \\ X_{21} & Y_{21} \end{pmatrix} = \begin{pmatrix} I_{11}Sin\phi_{11} & I_{11}Cos\phi_{11} \\ I_{21}Sin\phi_{21} & I_{21}Cos\phi_{21} \end{pmatrix} \tag{14}$$

Where X_{11} and Y_{11} denote the highest values of the reactive power part and active power part of +ve sequence underlying current. X_{11} and Y_{11} are the highest values of the active power part and active power part of —ve sequence primary flow of phase **"a."** Therefore,

$$i_{x11} = X_{11}Cos\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) + Y_{11}Sin\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) \tag{15}$$

$$i_{x21} = X_{21}Cos\left(\frac{2\pi}{N}n + \frac{2l\pi}{3}\right) + Y_{21}Sin\left(\frac{2\pi}{N}n + \frac{2l\pi}{3}\right) \tag{16}$$

$$i_{x1} = X_{x1}Cos\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) + Y_{x1}Sin\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) \tag{17}$$

$$i_{xk} = X_{x1}Cos\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) + Y_{xk}Sink\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right) \tag{18}$$

The segregation of different results is composed by Equations (14)–(16). This is achieved based on various compensation purposes generating a range of effects. In case SAPF is deployed to recompense harmonics and the —ve sequence part of the primary current, the +ve sequence constituent of the underlying present i_{x11} can be taken from (9), and the current reference can be given as $i^*_{cx}(n) = i^*_x(n) - i_{x11}(n)$ by deducting i_{x11} from the load current. Post the compensation when the line current is predicted as a regular three-phase necessary current, and the power factor is 1, the active power component of the +ve sequence fundamental current i_{px11} can be drawn by considering $X_{11} = 0$ in (9), and the current reference can be gained as $i^*_{cx}(n) = i_x(n) - i_{px11}(n)$ by deducting i_{px11} from the load current. Likewise, when we set Y_{11} to 0, the reactive power part of the +ve sequence underlying current is derived. The -ve sequence part of the fundamental present is derived from (15). If APF is utilized for compensating the selected order harmonics, we can calculate the by (17). The "active power" part and "reactive power" part of harmonics does not require a division, hence the factors $Cosk\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right)$ and $Sink\left(\frac{2\pi}{N}n - \frac{2l\pi}{3}\right)$ can be substituted with $Sin\left(\frac{2nk\pi}{N}\right)$ and $Cos\left(\frac{2nk\pi}{N}\right)$, separately. Followed by

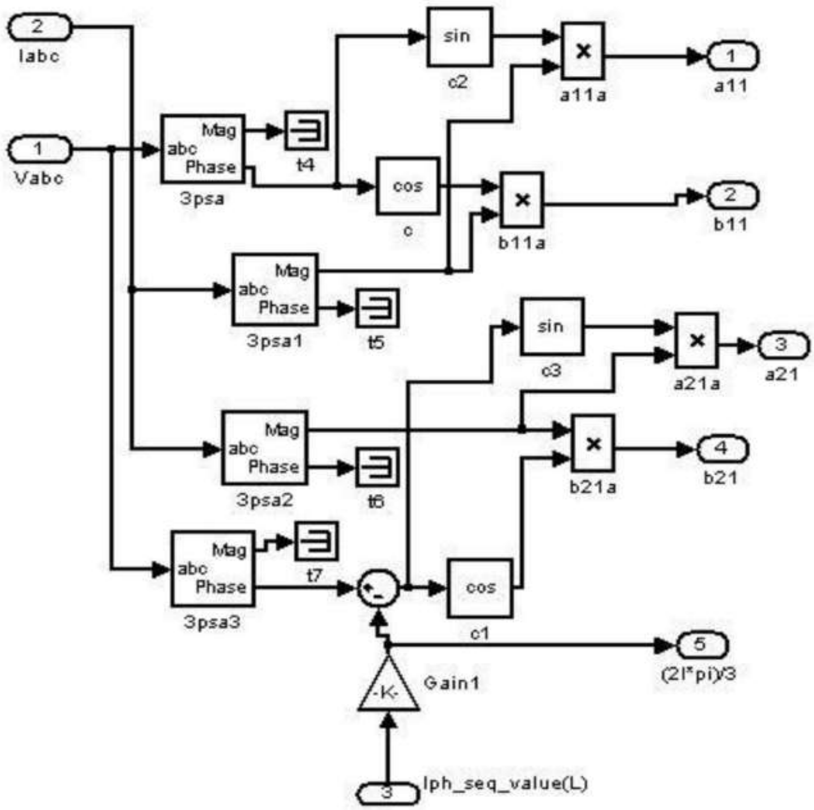

Figure 3
Proposed current control scheme

the simplification of programming. According to the detection methods, various compensation goals could be attained with specific combinations.

4. Proposed Control Scheme

A Phase Loop Lock, a sine wave generator and the separator form the principal constituents of our control scheme. We applied the current control scheme based on the strategy arrived by us for finding the reference recreating current. Figure. 3 shows current control scheme.

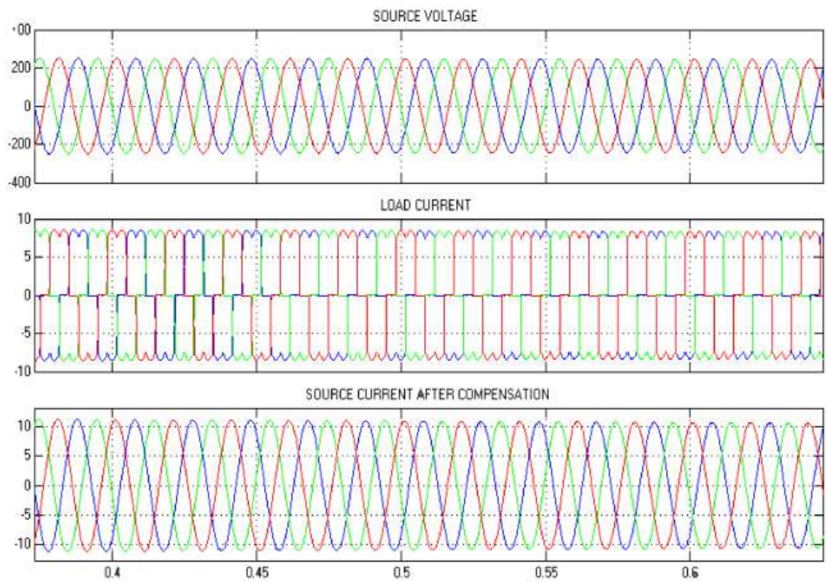

Figure 4

Source voltage, load current and source current after compensation

5. Simulation setup for Sinusoidal, Balanced Source Voltages

The main aim of the recreation is for showcasing the benefits of the SAPF control strategy suggested here. The source voltages are sinusoidal and stable, having a magnitude of 230 V, frequency of ω=100π and the source offers an unnecessary nonlinear load.

The stable and sinusoidal three-phase voltages measured are,

$$V_a = 230 \sin(\omega t)$$

$$V_b = 230 \sin(\omega t - 120^o)$$

$$V_c = 250 \sin(\omega t + 120^o)$$

The bridge rectifier load we incorporated here also dons the role of a nonlinear unbalanced load. To have clarity, we have plotted the simulation results separately. The source voltage, load current, and the source current after compensation depicted in Figure 4 and figure 5 depicts the outcomes recreated using the filter current created by the controller.

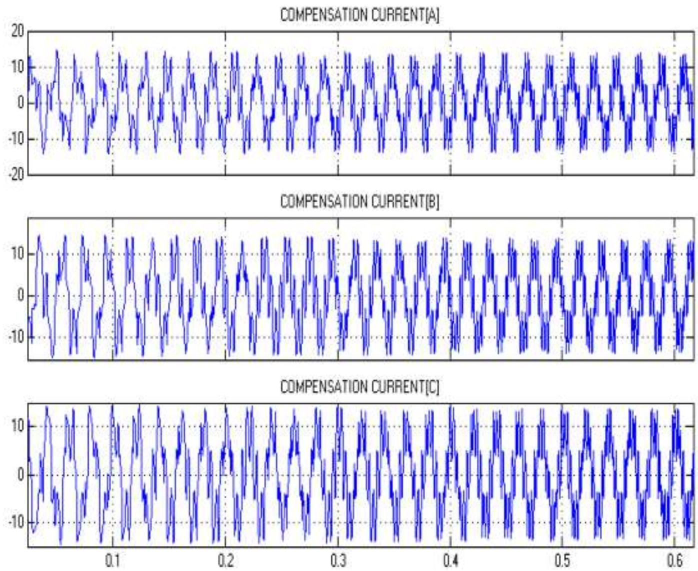

Figure 5

Filter Current

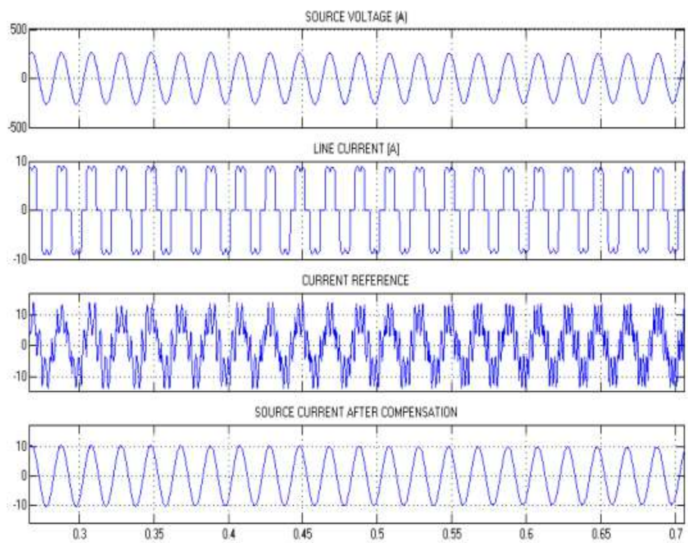

Figure 6

Source voltage, line current, current reference and Source current after compensation for phase A.

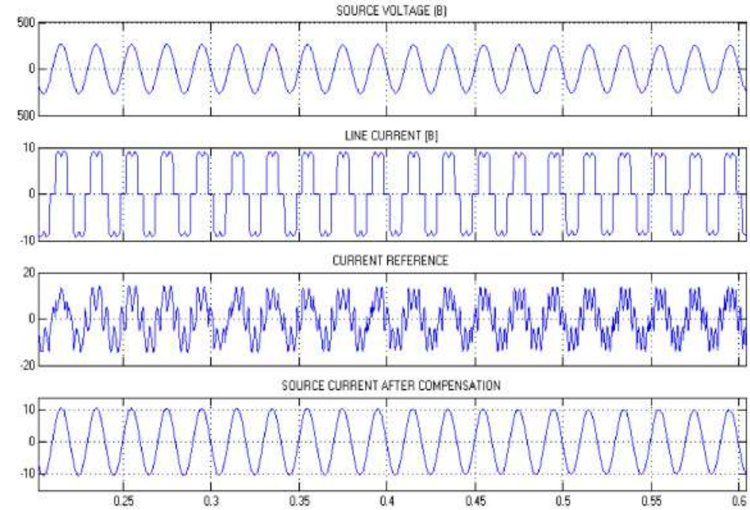

Figure 7

Source voltage, line current, current reference and Source current after compensation for phase B

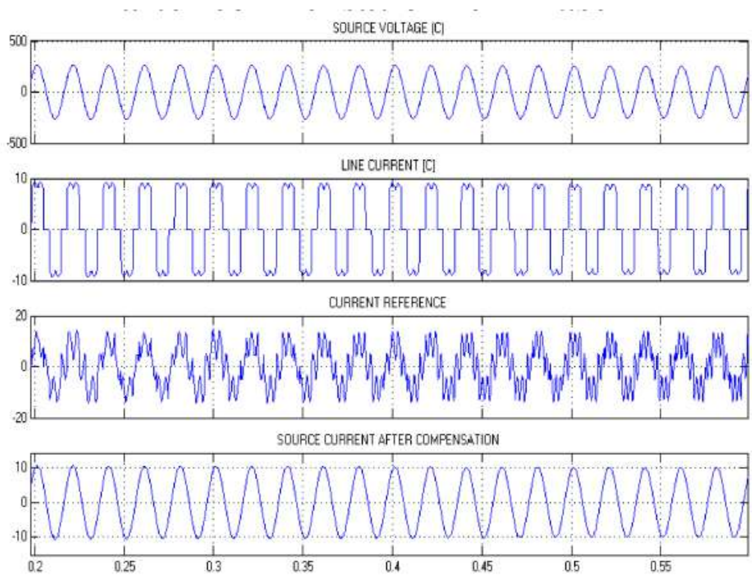

Figure 8

Source voltage, line current, current reference and Source current after compensation for phase C

The inoculation of commission current into the common coupling point in which the compensation of every phase's source currents occurs is shown in Figure 6-10.

The harmonic content of source current before commission is shown in Fig. 9 and implementation of compensated source current by SAPF has shown in Fig. 10.

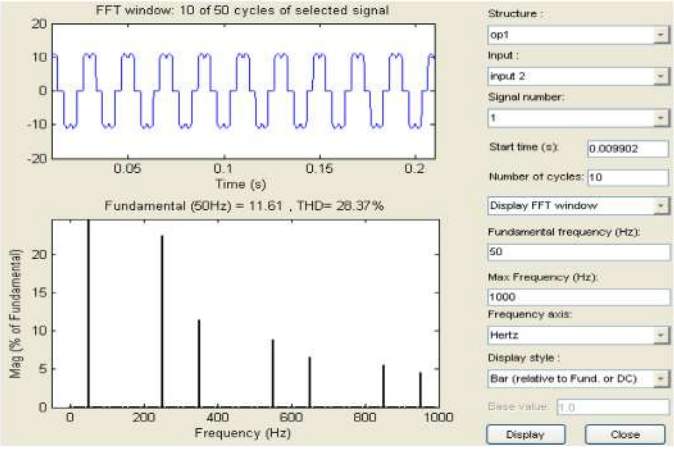

Figure 9

Without Harmonic Compensation

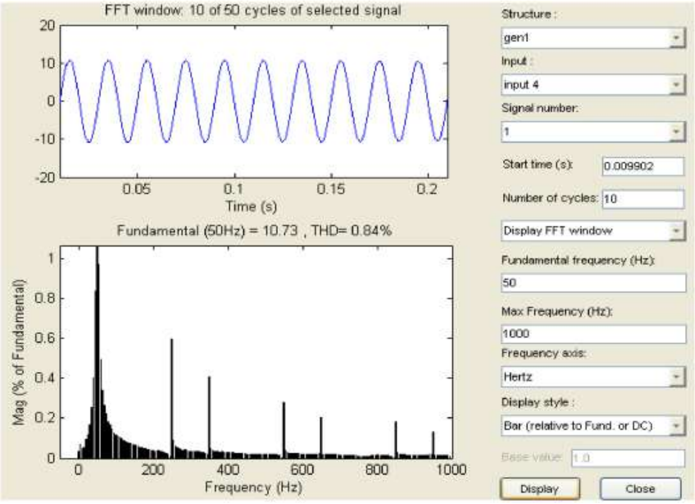

Figure 10

With Harmonic Compensation

Table 1
THD Comparison

CASE	THD %
With no Harmonic Compensation	28.37
Harmonic Compensation	0.84

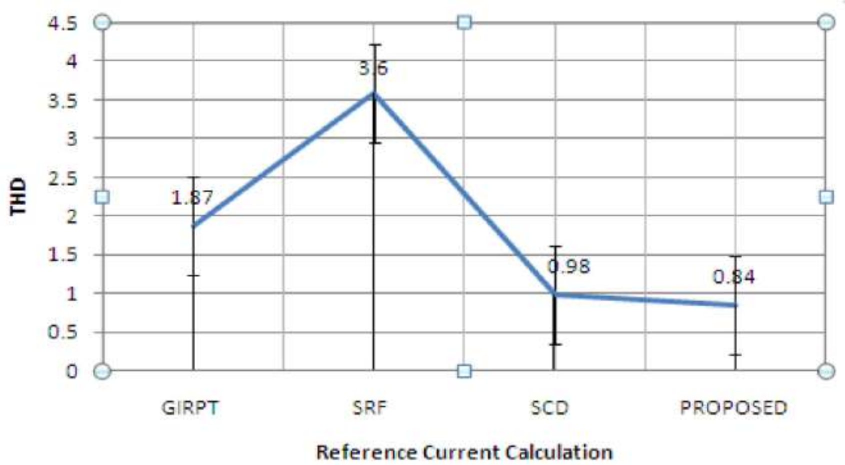

Figure 11
Comparison of % THD

6. Analysis of Simulation Results

The outcomes recreated obtained for a stable state is taken into account. From figure. 8 and figure. 10, we understand that harmonic currents are injected by SAPF into the line so that the input supply is made sinusoidal.

Figure 11 depicts the comparison of THD for the three studied and accessible approaches viz. Generalized Instantaneous Reactive Power Theory-based methods, Synchronous Reference Frame method, and the Synchronous Current Detection methods. Based on the outcomes (Fig. 10 and Fig. 16), we conclude that for stable source voltages, the THD for our approach is considerably lower than of the above-discussed methods. Even the setback as the result of the suggested plan is shy of 50% of the prime cycle; this is subsequently is shy of 50%of DFT and similar to the proposed method in accordance to the IRPT.

7. Conclusion

The outcomes recreated by using our proposed methodology are analyzed against the above-discussed methods. From the comparison we understand that the proposed method has a delay which is just shy of 50% of the prime cycle, this is subsequently is shy of 50% of DFT and also the algorithm created using IRPT. Based on the simulation and comparison studies, we find that the current control scheme proposed here is much superior in terms of affability, fidelity, and ease in operation. Also, as the reference commission currents are calculated in the 'a-b-c' reference setting, reference setting conversion is not needed. Hence, there is reduced complication in understanding the SAPF control circuit. In spite of that, it keeps an excellent filter performance. Post injection of compensation currents by SAPF, we infer that the source currents turn perfect and stay at par with the +ve sequence fundamental source voltages. Hence, the anticipated utility source power factor at the definite sequence fundamental frequency is obtained, and the harmonic currents kept under control. The Total Harmonic Distortion (THD) analysis divulges that our methodology has a source current THD lower than the previous methods. The commission methodology of SAPF put forth is verified via MATLAB/Simulink generating better understanding with the anticipated SAPF targets.

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