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Evaluation of Fundamental d-q Synchronous Reference Frame Harmonic Detection Method for Single Phase Shunt Active Power Filter

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ABSTRACT

Active Power Filter has become popular choice to address the harmonic pollution present in power system. It relies on fast and accurate detection of reference current to guarantee efficient compensation performance. In this paper harmonic extraction using d-q Synchronous Reference Frame (SRF) for single phase system and various aspects defining its performance is presented. The effect of the orthogonal signal generation on the harmonic current extraction is analyzed. Three different filtering approaches are compared based on their time and frequency domain characteristics. The effect of DC offset in the measured load current, introduced during measurement and data processing is derived. Accordingly a novel method to eliminate this DC offset is proposed with minimum compromise on the dynamics of the system. The discussions presented are validated using simulation results.

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1. INTRODUCTION

The harmonic pollution brought about by increase in usage of non linear loads has been a major power quality concern. These harmonic currents interact with other power system equipments like transmission/distribution lines, capacitors, transformers, motors and electrical equipments connected to it causing loss, heating, overloading, abnormal operation and resonance effect [1]. Active Power Filter (APF) is preferred over traditional passive filters due to their reliability, flexibility and harmonic mitigation performance. Shunt APF are widely used configuration for harmonic current problems due to its simplicity and effective compensation performance [2]. Several Single phase shunt APF can be used instead of a single large filter to deal with harmonics produced by nonlinear loads present in commercial areas. The harmonic spectrum of common nonlinear loads like, Switching Mode Power Supplies, Uniterruptable Power supply and Fluorescent Lamps consists of odd harmonics, dominated by 3rd, 5th and 7th harmonic components and compensating them would result in elimination of large chunk of harmonic currents [3][4]. A full bridge PWM VSI connected at point of common coupling is used as a current controlled current source to inject the harmonic components of opposite polarity to that present in the load current. For this the distortion present in load current has to be identified. The generalized block diagram of the single phase APF along with its constituent subsystem is shown in Figure 1.

A fast and accurate harmonic identification method will result in better compensation performance of the APF. The defect in harmonic extraction will be carried forward to inappropriate compensation in feed-forward harmonic estimation system like in Figure 1 where there is no control loop to correct the extracted harmonics by comparing with the harmonic present in the load current. Feed-forward harmonic extraction techniques are popular owing to simpler realization. Various harmonic detection algorithms has been proposed and evaluated in the literatures [5], [6]. Frequency domain methods based on Fourier analysis are limited in use due to drawbacks like slow response, computational burden for calculating coefficients and inefficiency in determining the interharmonic components. The time domain approaches are based on instantaneous estimation of reference signal hence are faster in response and need fewer calculations resulting in widespread use. Several methods are based on change of variables and transformations to reduce complexity and ease of implementation of control algorithms. The undesired/desired components are separated in the new co-ordinate axes using filtering approach and transformed back to original reference frame. The calculation is instantaneous but a time delay incurs due to filtering process. Harmonic detection method based on d-q Synchronous Reference Frame provides better performance in most of the abnormal condition. Furthermore it allows controlling of ac quantities as dc signals and offering simpler implementation.

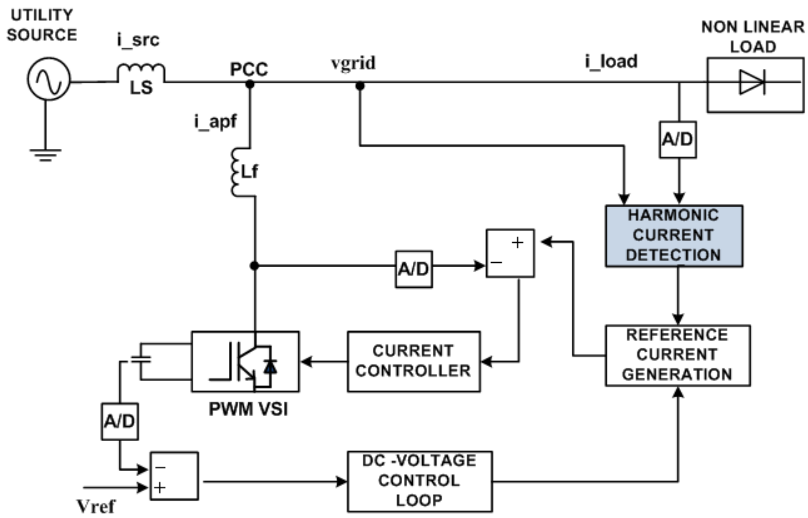


Figure 1. Generalized block diagram of APF connected to grid

Two issues can be identified to improve the performance of the harmonic detection mechanism. The filtering approach used in the d-q axis determines the accuracy and the dynamics of the system [5]. Another issue is the effect of DC offset introduced during sampling and processing of the detected load current. Digital devices like Digital Signal Processor (DSP) is widely used for implementing signal processing and control algorithms in power converter applications. The load current is measured, downscaled, filtered and an offset is added to convert it positive signal in the range (0, +3V) suitable for Analog to Digital (AD) conversion by the DSP. After AD conversion the digital data is transformed back to the original value using inverse transformation for calculation. It is difficult to remove the exact offset from digital data as added before AD conversion and thus it will result in errors in detected harmonic content. The DC offset can be removed before it enters the dq transformation or can be dealt after its effect is introduced in dq transformation. This paper proposes an efficient way to remove the DC offset before dq transformation without compromising much on the speed of the system response as compared to another alternate solution.

The organization of the paper is as follows. A brief review of fundamental d-q SRF method for single phase APF is presented in section II. The effect of orthogonal signal generation on the requirement of characteristics of filter is evaluated in section III. A suitable filtering approach is selected among three filtering techniques based on their speed and THD reduction capability in section IV. Section V examines and derives the effect of DC offset present in load current during harmonic detection process. A novel method to eliminate DC offset is proposed in section VI. Section VII verifies the suitability of the proposed method by simulation results. Finally, section VIII summarizes the work presented.

2. BRIEF REVIEW OF DQ SRF METHOD

The synchronous harmonic dq frame current extraction method provides selection of harmonic frequencies that need to be compensated but requires increased computational burden. A simpler method is to find the fundamental component of load current and then use it to find the other non active current component responsible for harmonics and reactive power as given in (1).

$$i_{na}(t) = i_l(t) - i_a(t) \tag{1}$$

$i_a(t)$, is active component responsible for real power consumed by the nonlinear load. In this way the APF is compensating everything albeit at a cost of increased power rating.

The d-q transformation is inherently developed for 3 phase system, where they are first transferred to two orthogonal components representing instantaneous active and reactive power component. If these orthogonal components are rotated at the fundamental frequency of the supply voltage then d-q transformation is obtained also known as Park Transformation. For single phase system to apply these transformations more information quantities are required. [7] created an imaginary load current by phase shifting the existing load current by 90° such that 2 orthogonal signals in α-β frame having identical characteristics were obtained (2). The dq transformation was applied on these orthogonal components using the rotation matrix (3). The resultant harmonic extraction procedure is shown in Figure 2. The required synchronizing signal for transformation can be obtained through Phase Locked Loop subsystem.

$$\begin{bmatrix} i_{l,\alpha} \\ i_{l,\beta} \end{bmatrix} = \begin{bmatrix} i_l(\omega t) \\ i_l(\omega t - 90) \end{bmatrix} \tag{2}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} \sin\theta & -\cos\theta \\ \cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{3}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{bmatrix} iL_d + i\tilde{L}_d \\ iL_q + i\tilde{L}_q \end{bmatrix} \tag{4}$$

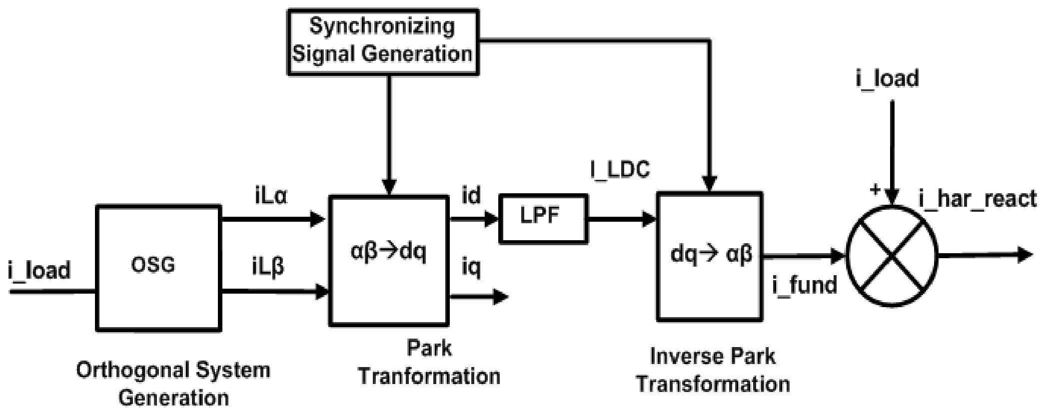


Figure 2. D-Q Synchronous Reference Frame method for single phase system

The DC term's in dq axis (4) are the fundamental active and reactive components while other frequency terms $i\tilde{L}_d$ and $i\tilde{L}_q$ are the harmonic active and harmonic reactive component responsible for distortion power. The filtering operation is used to separate these components as per the requirement. To implement the principle of (1), APF compensating all non active components, only the fundamental active component needs to be extracted using Low Pass Filter (LPF) from d axis. Q axis component can be neglected and not included in filtering operation. The fundamental component iLd*extracted from LPF undergoes inverse park transformation (d-q→α-β) using the inverse transformation matrix as in (5)

$$\begin{bmatrix} il_\alpha * \\ il_\beta * \end{bmatrix} = \begin{bmatrix} \sin\theta & \cos\theta \\ -\cos\theta & \sin\theta \end{bmatrix} \begin{bmatrix} i_{Ld} * \\ 0 \end{bmatrix} \tag{5}$$

Since the β component is the fictitious component it can be neglected and hence the fundamental component of load current and consequently the nonactive current component is obtained as in (6) and (7).

$$il_\alpha * = i_{fund} = i_{Ld} * sin\theta \tag{6}$$

$$i_{h,r}(t) = i_l(t) - il_\alpha^{\ *}(t) \tag{7}$$

3. ORTHOGONAL SIGNAL GENERATION(OSG)

Two approaches can be identified to generate orthogonal signals required for dq transformation: phase shifting every frequency components by 90° or time delaying each frequency component by a quarter of fundamental time period. These 2 orthogonal signals results in different mapping of harmonic components in stationary frame to rotating dq frame however maintaining same mapping for fundamental quantity.

The distorted current drawn by nonlinear loads are odd half wave symmetric and periodic in nature. From Fourier Analysis the load current is composed of fundamental and odd harmonics as given in

$$\begin{aligned} i_{load} = i_{L,\alpha} &= \sum_{h=2n+1, n=0,1,2..}^{\infty} A_h \sin(h\omega t - \gamma_h) \\ &= A_1 \sin(\omega t - \gamma_1) + A_3 \sin(3\omega t - \gamma_3) + A_5 \sin(5\omega t - \gamma_5) + A_7 \sin(7\omega t - \gamma_7) + ... \end{aligned} \tag{8}$$

The orthogonal component and subsequently the d axis component obtained after phase shifting each frequency component by 90° is given in (9) and (10)

$$i_{L,\beta} = -A_1 \cos(\omega t - \gamma_1) - A_3 \cos(3\omega t - \gamma_3) - A_5 \cos(5\omega t - \gamma_5) - A_7 \cos(7\omega t - \gamma_7) + ... \tag{9}$$

$$iL_d = A_1 \cos\gamma_1 + A_3 \cos(2\omega t - \gamma_3) + A_5 \cos(4\omega t - \gamma_5) + A_7 \cos(6\omega t - \gamma_7) + ... \tag{10}$$

Equation (11) and (12) shows the β axis component and the d axis component using the time delay approach.

$$i_{L,\beta} = -A_1 \cos(\omega t - \gamma_1) + A_3 \cos(3\omega t - \gamma_3) - A_5 \cos(5\omega t - \gamma_5) + A_7 \cos(7\omega t - \gamma_7) - .... \tag{11}$$

$$iL_d = A_1 \cos\gamma_1 + A_3 \cos(4\omega t - \gamma_3) + A_5 \cos(4\omega t - \gamma_5) + A_7 \cos(8\omega t - \gamma_7) + A_9 \cos(8\omega t - \gamma_9)..... \tag{12}$$

In time delay mechanism the harmonic components at n=1,5,9,13… are moved to $(n-1)^{th}$ component while the harmonic components at n=3,7,11,15… are mapped to $(n+1)^{th}$ frequency in d-q frame. In phase shifting method, all frequency components are mapped to $(n-1)^{th}$ frequency component in d-q coordinate. With time delay approach the first harmonic component that needs to be filtered occurs at f_4=4×50 Hz compared to 100Hz using the phase shifting method. Hence with time delay method offers accurate fundamental current extraction using same type of LPF and also reduces the stringent demand on filtering operation. Furthermore phase shifting all frequency components by 90° requires computationally complex Hilbert transform.

Equal time delay corresponds to a linear phase shift, n^{th} harmonic component undergoing a phase shift of n × 90°. This can be implemented using a circular buffer to store a quarter time period samples and release it. Since the main aim is to extract fundamental quantity the time delay is one-fourth of 50 Hz fundamental frequency which amounts to 5ms. In a discrete implementation with sampling period T_{samp} this equals to N sampling point delay given by (13)

$$N = \frac{T_{delay}}{T_{Samp}} = \frac{5e^{-3}}{5e^{-5}} = 100 \quad (13)$$

The equivalent transfer function representing time delay procedure can be written as (14) and bode plot is shown in Figure 3.

$$D(z) = z^{-N} \quad (14)$$

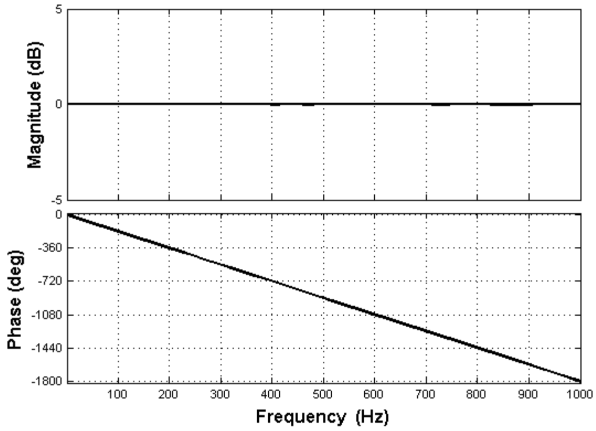


Figure 3. Bode plot of time delay transfer function

4. SELECTION OF LOW PASS FILTER

In [5] it was reasserted the importance of Numerical filtering in the accuracy and dynamics of the harmonic detection mechanism. A compromise between these two has to be made while selecting the characteristics of the filter. These are determined by the order and cutoff frequency of the filter used. Higher order filter and lower cutoff frequency improve attenuation of harmonics but at a cost of slowed down response in the event of load change. After transformation the signal at d axis is superimposed of DC component and other higher frequency modulated signal. Since we are extracting the DC signals, the phase characteristics are not of concern as compared to attenuation provided by the filters. The digital filter should maintain the amplitude, integrity and the variation in DC gain and oscillation will hamper the fundamental current detection. The filter is realized as a software block in DSP and 2 types of digital filter implementation are popular IIR filters and FIR filters.

4.1. Butterworth Low Pass Filter (BWLPF)

Low pass filters can be implemented using Butterworth filters [5], [6]. They are popular choice due to their flat gain at DC frequency and are implemented as Digital IIR filters after converting it to discrete time domain using bilinear transformation. Higher order filters are not suitable owing to dynamic response and implementation issues as poles move closer to the imaginary axis. Higher order higher cutoff frequency can be traded with lower order lower cutoff frequency. When filter order is determined the selection of cutoff frequency will also affect the stability and performance of the LPF. Lower cutoff frequency will move poles closer towards imaginary axis increasing oscillation and slowing down the transient response in trade of improved attenuation of ac quantities. The location of poles of 3rd order BWLPF (15) for different cutoff frequencies (ωc) is shown in Figure 4.

$$F(s) = \frac{1}{1 + (s/\omega_c) + 2(s/\omega_c)^2 + (s/\omega_c)^3} \quad (15)$$

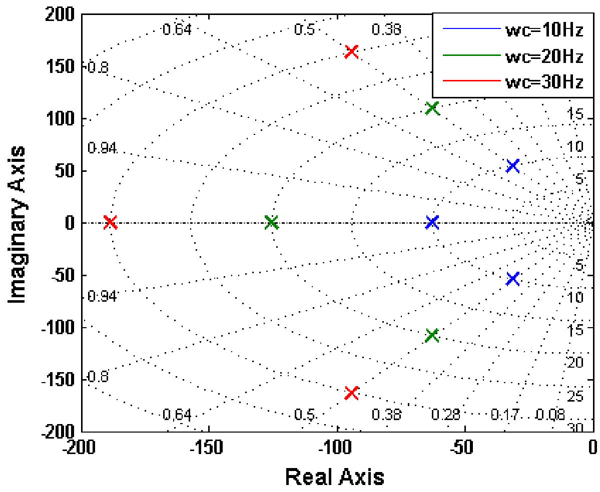


Figure 4. Location of poles for different cutoff frequencies of 2nd order BWLPF

4.2. Series Connection of Butterworth and Notch Filter

The cutoff frequency can be increased if the first harmonic component it has to filter is moved to higher frequency. If a Notch Filter is used to attenuate the harmonic contents at 4×f, the next frequency component the LPF needs to attenuate will occur at 8×f. Hence the flexibility in selection of cutoff frequency of the LPF can be made. A 3rd order BW LPF is replaced with a series combination of notch filter centered at 200Hz and a 2nd order low pass filter. The cutoff frequency of LPF is selected at 80Hz 1/5th below the first frequency the LPF has to filter. This combination will provide improved attenuation of 3rd and 5th harmonic components which are dominant and also improve the dynamic response of the system.

Notch filter passes all the frequencies except the frequencies in the stop band centered at a notch frequency. Digital Notch filter designed using pole zero placement in Z domain has simpler implementation. The zeros are placed in unit circle on the frequency where a notch is desired. The poles are placed on the same radial line where the zeros are positioned and their location determines the bandwidth. [8] Has provided the optimum pole location and gain of notch filter to attain unity gain at DC and nyquist frequency. The modified transfer function of the notch filter is given as:

$$N(z) = k\left[\frac{1-2\cos\omega_0 z^{-1} + z^{-2}}{1-(1+r^2)\cos\omega_0 z - 1 + r^2 z^{-2}}\right] \tag{16}$$

ω_0 is the notch frequency or angle at which zero is placed , k is the gain at DC and Nyqusit frequency and r is the distance between pole and origin, which also determines the notch bandwidth and transient response. The bode diagram of the notch filter for different value of r is shown in Figure 5.

The digital implementation of butterworth LPF is often based on bilinear transformation of the standard continuous time transfer function (17).

$$B(s) = \frac{1}{(s/\omega_c)^2 + (1.4141s/\omega_c) + 1} \tag{17}$$

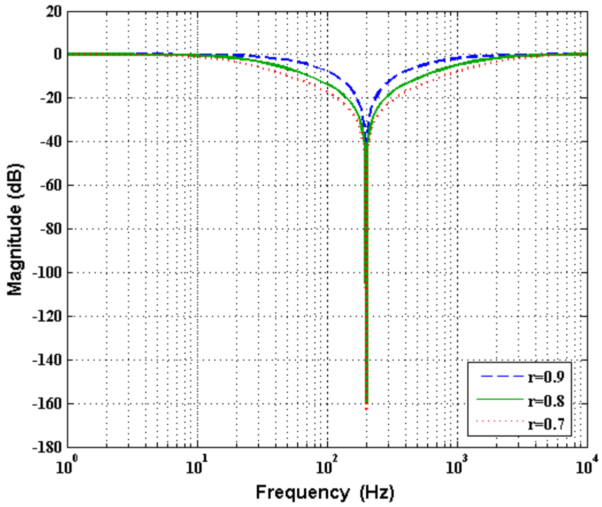


Figure. 5 The frequency response of Notch filter for different values of r

4.3. Moving Average Filter (MAF)

LPF implemented using Moving Average Filter can be used to obtain the DC values [9]. MAF is a simple FIR filter used to average out the higher frequency components to zero and retain the DC component acting as a Low Pass Filter [10]. The output of MAF is the average of last N samples given as:

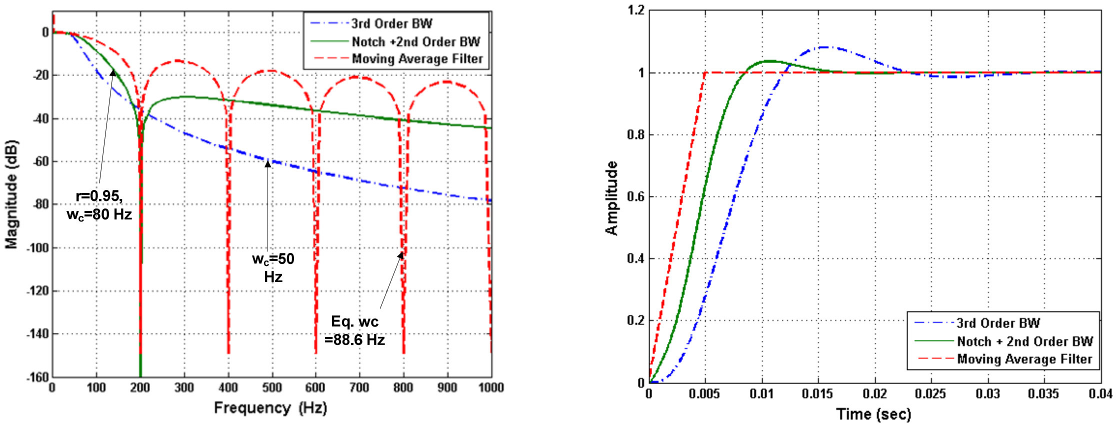
$$y[k] = \frac{1}{N}(x[k] + x[k-1] + x[k-2] + \bullet\bullet\bullet + x[k-N+1]) \tag{18}$$

And corresponding transfer function is:

$$\begin{aligned} H(z) &= \frac{1}{N}(1 + z^{-1} + z^{-2} + ... + z^{-N+1}) \\ &= \frac{1}{N}\frac{1-z^{-N}}{1-z^{-1}} \end{aligned} \tag{19}$$

To attenuate out the 200Hz component, the d axis load current has to be summed and averaged at the period of 5ms. This will average the 200Hz and its multiple frequency components to zero while the DC value is unaffected. The number of consecutive samples needed to be stored and averaged for sampling frequency of 20 kHz is given as:

$$N = \frac{T_{prd}}{T_{sam}} = \frac{5\times10^{-3}}{50\times10^{-6}} = 100 \tag{20}$$



(a) (b)

Figure 6. Bode plot(a) and step response(b) of 3 different filter structure

Figure 6(a) shows the frequency response of three filtering approach discussed above. The MAF gives much sharper attenuation at 200Hz and its multiples frequency, upto half the Nyquist frequency. The attenuation provided by first and second combination to even harmonics is also satisfactory. However the difference lies in the dynamic response provided by them which is shown in Figure 6(b). The Transient response of the MAF is fastest and lasts only for 5 ms a quarter of fundamental time period, while it is worst for the first case. MAF can be considered the best option for good attenuation and transient response, the only limitation being its inability to reject the interharmonics component which is not present in considerable amount. The frequency adaptiveness can be implemented by varying the buffer size using the frequency information from PLL. The comparison of above 3 filtering approach is summarized in table 1

Table 1. Summary of 3 filtering approaches in d axis.

Features	BWLPF	Notch and BW LPF	MAF
Speed of transient response	Slow	Medium	Fast
Overshoot and Oscillation	High	Medium	No
Attenuation (3^{rd} and 5^{th} harmonic)	Medium	Highest	Highest
Attenuation (Higher harmonics)	High	Medium	Highest
Attenuation (Interharmonics)	Yes	Yes	Very small
Precision of Filter Coefficient	Important	Important	Always stable
Effect on frequency variation	Low	Medium	High
Filter Implementation Difficulty	Medium	Medium	Low

5. EFFECT OF DC OFFSET ON COMPENSATION

Let a DC offset A_0 is present in the load current during measurement and data conversion process. Then measured load current ($i_{lm\alpha}$) is different to actual load current iload.

$$i_{lm,\alpha} = A_0 + \sum_{h=2n+1, n=0,1,2..}^{\infty} A_h \sin(h\omega t - \gamma_h) \tag{21}$$

The orthogonal component will too include the DC offset and using the dq transformation given in (3) the d axis component is obtained as:

$$i_d = A_0(\sin\omega t - \cos\omega t) + A_1 \cos\gamma_1 + higher\ frequency\ terms \tag{22}$$

The DC offset is converted to ripples at fundamental frequency in d axis. The low pass filter will reject higher frequency terms; the fundamental frequency component is passed through unattenuated.

However, the phase shift is not 0° for 50Hz component, hence fundamental component after LPF operation is obtained as:

$$i_{fd} = A_1 \cos\gamma_1 + A_0(\sin(\omega t - \delta) - \cos(\omega t - \delta)) \tag{23}$$

For MAF with 100 taps, the phase shift at 50 Hz, is around 45° as vivid from the bode plot in Figure 8.

$$i,_{fund} = A_0[(\sin\omega t \times \cos 45 - \sin 45 \times \cos\omega t) - (\cos\omega t \times \cos 45 + \sin 45 \times \sin\omega t)] + A_1 \cos\gamma_1 \tag{24}$$

Using (5) for estimation of fundamental current component we obtain:

$$i,_{fund} = -A_0 \sin\omega t[\frac{2}{\sqrt{2}}\cos\omega t] + A_1 \sin\omega t \cos\gamma_1 \tag{25}$$

After simplification we have,

$$i_{fund} = -\frac{A_0}{\sqrt{2}}(\sin 2\omega t) + A_1 \sin\omega t \cos\gamma_1 \tag{26}$$

As, q axis component is not used for inverse transformation, the DC component is transformed to component at twice the fundamental frequency. The reference current thus extracted using (21) and (26) in (1) is:

$$i_{ref} = A_0 + A_1 \cos\omega t \sin\gamma_1 + \frac{A_0}{\sqrt{2}}\sin 2\omega t + \sum_{h=2n+1, n=1,2..}^{\infty} A_h \sin(h\omega t - \gamma_h) \tag{27}$$

APF will generate and inject these components in the power system. Considering the inner current control loop is ideal, the APF completely eliminates actual harmonic and reactive component present in load current. The Source current after compensation is obtained as:

$$i_{src} = i_{load} - i_{apf} \tag{28}$$

$$i_{src} = -A_0 + A_1 \sin\omega t \cos\gamma_1 - \frac{A_0}{\sqrt{2}}\sin 2\omega t \tag{29}$$

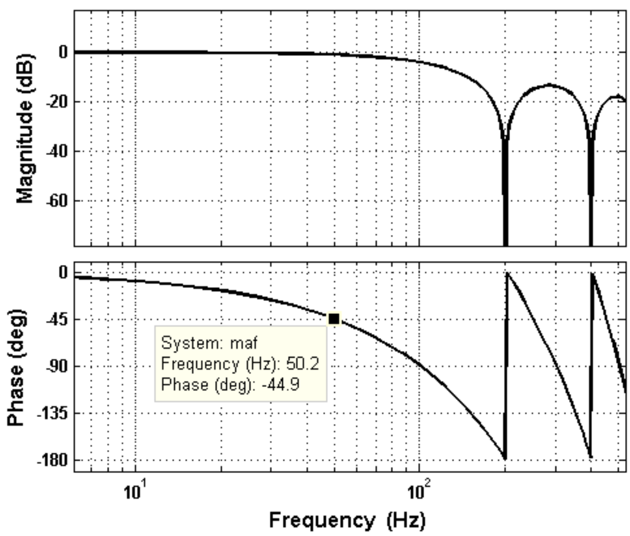


Figure 7. Bode plot of MAF with N=100

Then, THD of the source current after compensation is due to the DC offset present in the form of DC current and 100Hz component in (29) and given as:

$$THD\% = \sqrt{\sum_{h\neq 1}\left(\frac{I_h}{I_1}\right)^2} \times 100 \tag{30}$$

I_h and I_1 are RMS value of harmonic and fundamental component.

$$= \sqrt{\left(\frac{(A_0)^2 + (A_0/\sqrt{2})^2}{(A_1/\sqrt{2})^2}\right)} \tag{31}$$

$$= \frac{\sqrt{3}A_0}{A1} \times 100\% \tag{32}$$

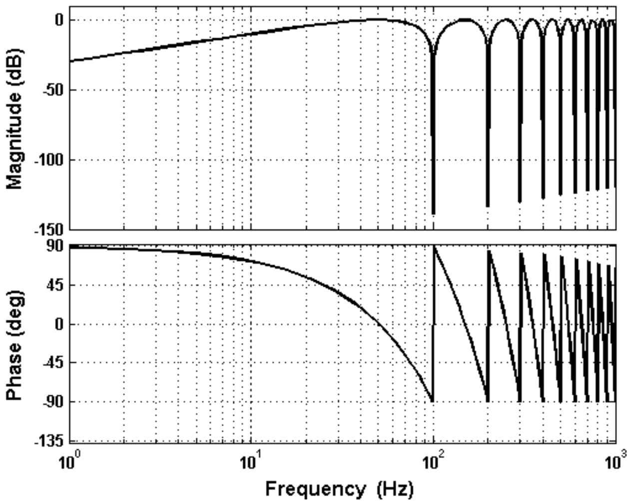


Figure 8. Bode plot of equivalent filter structure.

6. DC OFFSET REJECTION METHOD

The THD of the source current is affected by the introduced offset and hence has to be removed to improvise the compensation performance. Furthermore injection of DC current in power system can saturate distribution transformers, leading to overheating, trips and losses[11]. The elimination of DC offset can be exercised at two locations.

(1) Before, the DC offset enters the dq transformation, a low pass filter can be used to extract the DC component and subtract it from the instantaneous load current. The dq transformation is applied then.

(2) In the dq transformation extending the moving average filters to collect samples and take average every fundamental cycle to make sum of frequency component at 50Hz and its multiples to zero.

The second approach will completely eliminate DC offset but the transient response of the filter will increase to 20ms. To prefer the first method it should provide the overall transient response to be less than 25ms, including the 5ms delay offered by the OSG structure. The first method requires a high order and lower cutoff LPF to prevent the fundamental frequency component to pass through LPF while extracting the DC signal. Even if the DC offset changes very slowly compared to load current; the disturbances in load current affect the transient of DC component detection. Using a general IIR filter structure or Moving average filter will need transient response time of 20ms or greater just for DC component detection only. Hence a novel method is proposed which will remove the offset without compromise on the dynamics of the system. Since measured load current consists of DC offset, fundamental component and odd harmonic components, the addition of the load current and the half of fundamental time period, delayed load current will cancel out all frequency components that are odd multiples of fundamental component. This is equivalent to n^{th} odd harmonic undergoing n×180° phase shift. The current component obtained from time delaying the load current by half of the fundamental period is given as:

$$i_{L,\alpha}' = i_{L,\alpha}(\omega t - n\pi) = A_0 - \sum_{h=2n+1, n=0,1,2..}^{\infty} A_h \sin(h\omega t - \gamma_h) \tag{33}$$

Adding (21) and (33) all ac quantities are cancelled out leaving DC component:

$$i_{L,\alpha} + i_{L,\alpha}' = 2 \times A_0 \tag{34}$$

To remove the DC offset from entering the dq transformation, the new α current component obtained using (21) and (34):

$$i_{L,\alpha n} = (i_{L,\alpha} - i_{L,\alpha}') \times 0.5 \tag{35}$$

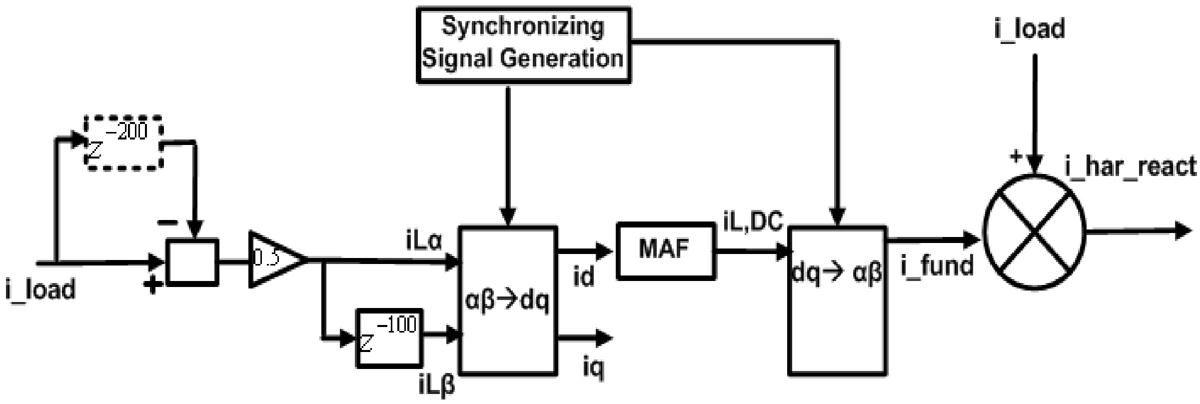


Figure 9. Improved Harmonic Detection Structure of single phase dq SRF method

(33) can be implemented by using a circular buffer to delay the measured value by N_f sampling point:

$$N_f = \frac{T_{delay}}{T_{samp}} = \frac{10ms}{50\mu s} = 200 \tag{36}$$

The equivalent filter operation is given in (37) and corresponding bode plot is given in Figure 9. The structure offers attenuation to DC component and even harmonics while the odd harmonics are passed unattenuated.

$$F_d(z) = \frac{(1 - z^{-N_f})}{2} \tag{37}$$

The final improved harmonic detection structure is shown in Figure 9. The transient response to fundamental current detection offered by the whole structure to the change in load current is equivalent to a fundamental time period and efficiently suppresses the DC offset present in it. The step response of both approaches is given in Figure 10 and shows that the proposed system quickly attains the steady state as compared to second approach.

7. SIMULATION RESULTS

The simulation is carried out in MATLAB/SIMULINK to analyze and validate the above discussions. A non linear load comprised of diode-bridge/uncontrolled rectifier with RLC at DC end is connected to grid supply. The APF structure is connected in parallel with the nonlinear load. The DC offset is added during current measurement and then fed to the reference current extraction block. Figure 11 shows the detected load current and the αβ load current components. The DC offset is absent in orthogonal signals used for dq transformation. Figure 13 shows the load current, and the extracted fundamental and harmonic current with and without DC offset removing structure. DC offset of 2A is added during measurement process and the load current changes at time, t=0.2s. The total delay of the structure is around, 1 cycle. The FFT analysis of the detected fundamental current is shown in Figure 14. Without filter significant amount of 2nd order harmonic is present in the detected fundamental current, hence degrading the THD(8.3%). Furthermore there is DC offset in the detected reference current too. The filter structure significantly improves the THD of the detected fundamental component by removing effect of DC offset; hence accurate harmonic compensation can be achieved.

To verify the transient speed of the first approach is better than the second one, the THD of detected fundamental current component via both approaches was calculated. The simulation result in Figure 15 show that the steady state performance of both approach are same while the transient of first approach is faster by around 4-5 ms.

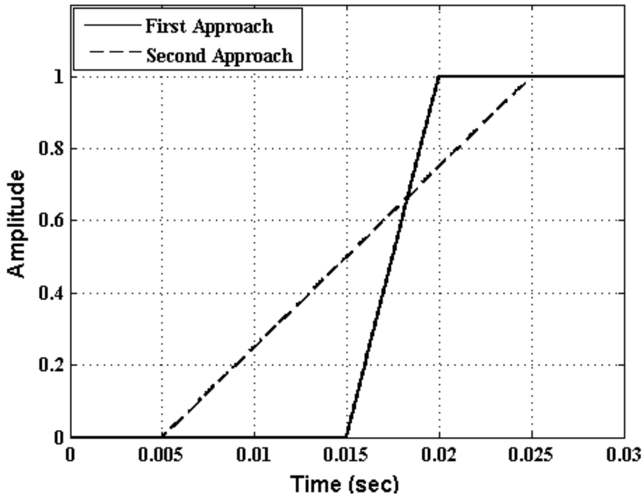


Figure. 10. Step response of the effective transient time for step change for 1st and 2nd approach.

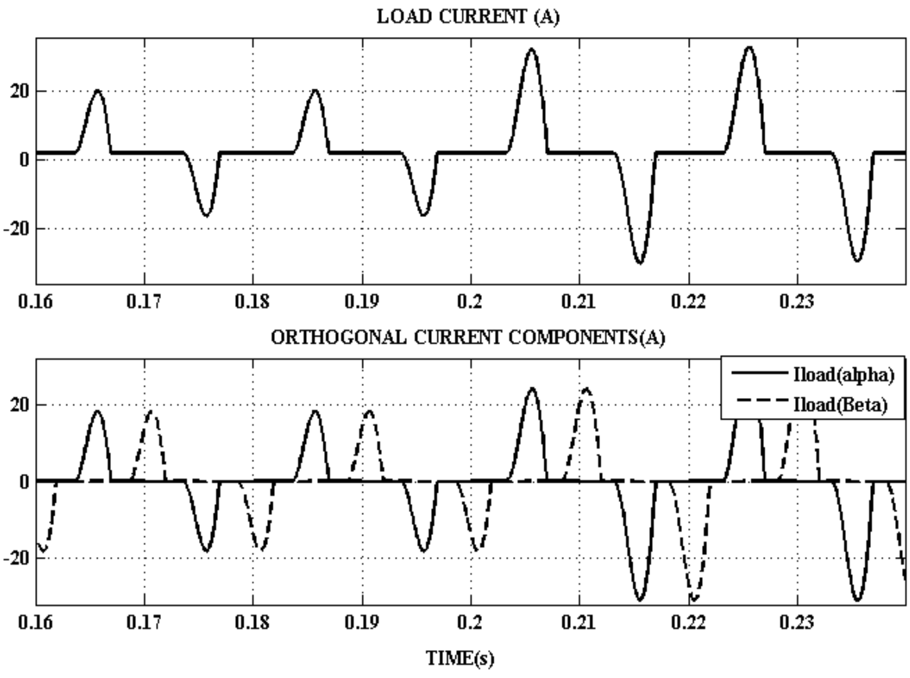


Figure 11. Measured Load current and current used for d-q transformation

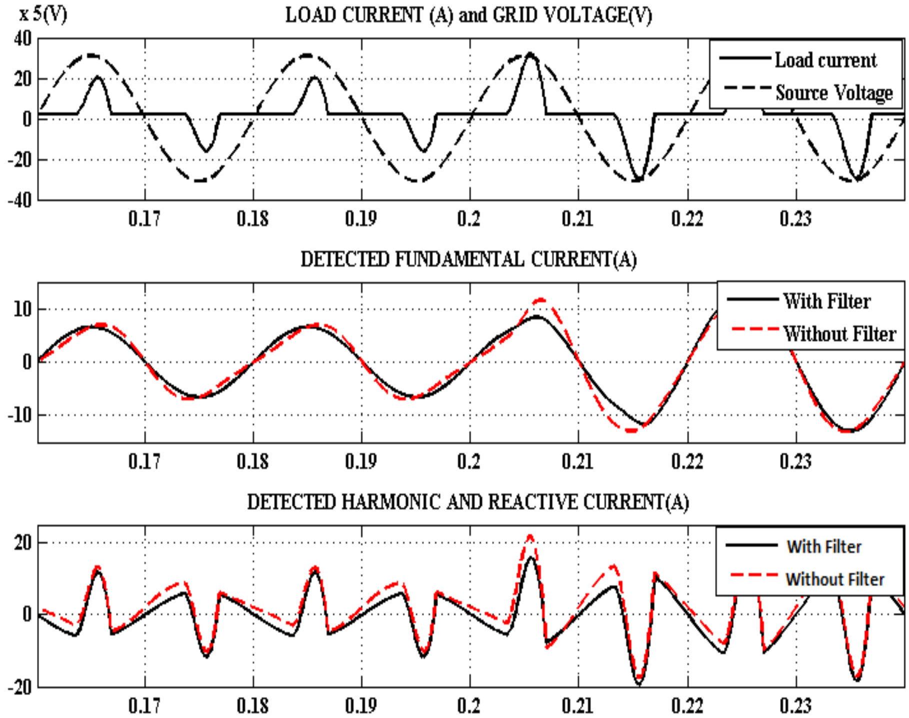
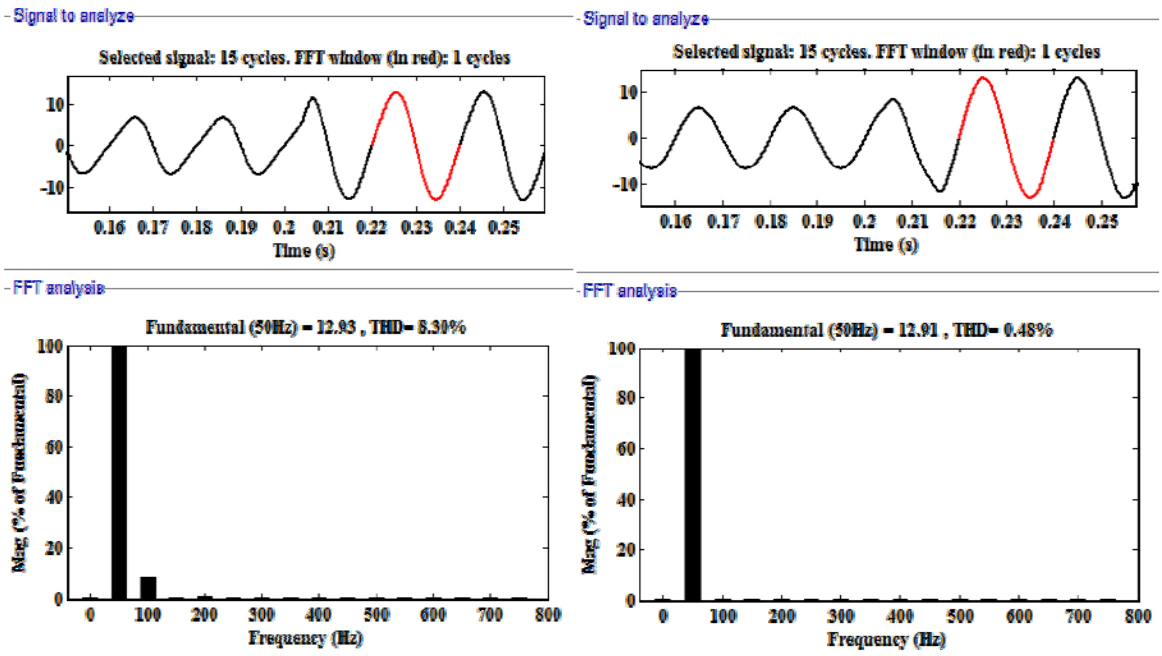


Figure 12. Load current and detected fundamental and reference current



(a) (b)

Figure 13. Harmonic Spectrum of detected fundamental (a) Without Filter (b) With Filter

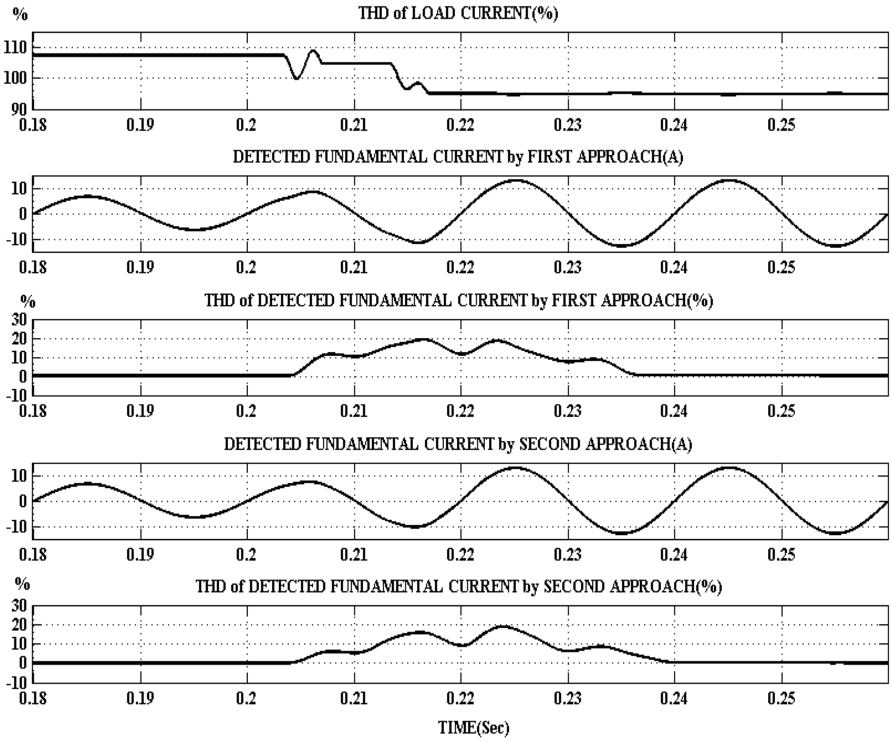


Figure 14. THD performance of two approaches in transient and steady state.

8. CONCLUSION

The performance of reference current extraction process is of critical importance to realize better compensation performance. In this paper various performance affecting criteria of fundamental dq SRF harmonic detection method for single phase active power filter is presented. Use of moving average filter provided fast and accurate detection of fundamental current and consequently the reference current. The DC offset introduced in measured load current degrades the THD of source current if not dealt with. This paper presents an effective method to reject the DC offset before dq transformation and its performance comparison is drawn with that of method using Moving Average Filter in d axis to deal with the effect of DC offset. The simulation results in SIMULINK prove the effectiveness and validity of the proposed method.

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