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Overview of Reference Current Extraction Techniques in Single Phase Shunt Active Power Filter

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ABSTRACT: This manuscript gives a complete survey on commonly used reference current extraction techniques in Single-Phase Shunt Active Power Filter (SAPF). A single-phase shunt active filter usage is increased considerably over the past few years in commercial and educational buildings to improve power quality leads to achieve customer satisfaction. The performance of a shunt active power filter depends largely on the extraction of harmonic current. To reproduce the exact inverse image of harmonics currents, various reference current extraction techniques like PI control algorithm, PQ Theory, DQ Theory, and other techniques are discussed. And the primary advantages and disadvantages of power filters are compared. Eventually, the selection of DC-Link capacitor voltage and capacitance rating and filter inductance of the SAPF was expansively appraised in detail. Almost all these research work-related papers have been thoroughly examined, classified and listed for quick reference. It will offer a clear vision of the state-of-the-art investigation advances in this field and then some suggestions are put forward for future research. In further, it can be extended to the three-phase system to improve the power quality in various aspects.

Keywords: DC Link capacitor voltage control, Harmonics, Reference current extraction, Single phase shunt active filter.

Abbreviations: PI Controller, Proportional Integral Controller; SAPF, Shunt active power filter; THD, Total harmonic distortion, VSI, Voltage source inverter; STF, self-tuning filter.

I. INTRODUCTION

The active power filter concept was initially proposed in 1971 by Sasaki and Machida as a means of removing current harmonics [1-5]. The SAPF operate in different operating conditions and higher frequencies effectively, which leads to giving enhanced performances. The general aim of a SAPF is to reduce harmonic distortions caused by non-linear loads and improve power factors for reactive loads. With the increase in the harmonics, distortion causes few problems like vibration and overheating of electrical equipment, blown capacitors, and malfunctioning of electronic circuits and power system protection devices. Hence to overcome the above adverse effect an active power filter is proposed. Due to superior mitigation capabilities, SAPF technology continues to advance.

SAPFs are in different forms such as the way it connected to the power system, based on power rating and speed of response. The single-phase active power filter is typically used in lower power ratings. It is suitable for educational buildings and commercial with computers load [6, 7]. The efficient performance of a shunt active power filter mainly depends upon three areas. The first one is used to estimate the reference current; the second is the type of current controller used, and the third one is the selection of parameters in SAPF [8].

The performance of the reference current extraction algorithm mainly depends on the fastness and accuracy of harmonic current extraction. And the rapid development of digital signal processing technology will greatly improve the speed of harmonic current extraction with accuracy.

In this regards to increase the performance of the SAPF with unique benefits, researchers have been proposed various extraction technique such as DC-Link PI control technique [1,7-17], Sliding mode control [18-20], Repetitive based control [21, 22], Sensor less control [23-25], PQ theory [26-33], DQ theory [34-39] and One Cycle Control [40, 41]. The literature explored in this paper involves publications from IEEE, IET, and Elsevier, etc. From the literature, the DC-link PI control based extraction with a self-tuning filter (STF) algorithm shows good performance in all aspects such as to estimate the reference harmonic current accurately even with distorted utility voltage. By comparing with the conventional harmonic extraction algorithm, the DC-link PI control based algorithm can identify and compensate the specific harmonic, better processing speed and reduce the processor workload. This manuscript aims to review and discuss different extraction techniques features and its drawbacks, and the selection of DC-Link capacitor voltage and capacitance rating and filter inductance of the SAPF was expansively appraised in detail. The findings of the study will help the researchers to select the most suitable extraction technique in SAPF applications.

This manuscript is offered in three parts. Initially starting with a classification of power filter, the following sections deal with the reference current extraction techniques used, and selection of parameters of single-phase SAPF with some suggestions are put forward for the future research, finally, the concluding observations are drawn.

II. CLASSIFICATION OF POWER FILTERS

The application of additional components in the power system for the mitigation of harmonic, this approach is termed as power filters. Generally, the power filters are classified into two types such as 1) classification based on power rating and speed of response 2) classification based on power connection as shown in Fig. 1. Power filter based on power connection classified into three categories such as passive, active and hybrid filters. In the first category, the passive filter was introduced as shown in Fig. 1 (b). The damping resistors, inductors, and capacitors are connected either in series or in a parallel arrangement to design a passive filter for harmonic compensation.

Table 1: Comparison of Power Filters.

Type of Filter	Advantages	Disadvantages
Passive filter	• Harmonic reduction and reactive power compensation is possible • The absence of undesirable harmonics	• It causes unwanted resonance problem • Incapable of adjusting to the varying conditions in the system and their size • Frequency tuning is less accurate and needs more calculations • Heavy and bulky. • Harmonic suppression is fixed
Active filter	• Compensate all harmonics with precise control techniques • Block resonance • Tuning is simple and more accurate • It can be used when harmonic components vary randomly. • Harmonic suppression is adjustable • Small size	• High initial and running cost • Required high rating of power converters • Due to the usage of power electronic devices, the inherent harmonics are developed • Power converter switching loss is significant due to high voltage and high current.
Hybrid filter	• Effectually reduce the overall cost and capacity of the power converter. • compensating both current and voltage harmonics • No resonance problem • Better reactive power management	• It required an additional transformer to couple the passive filter with the active filter • Harmonic suppression is fixed • Relatively poor dynamic performance and are less suitable for highly dynamic types of load.

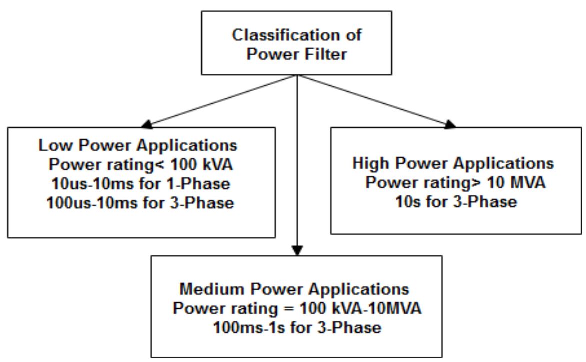

Fig. 1 (a) Classification based on power rating and speed of response.

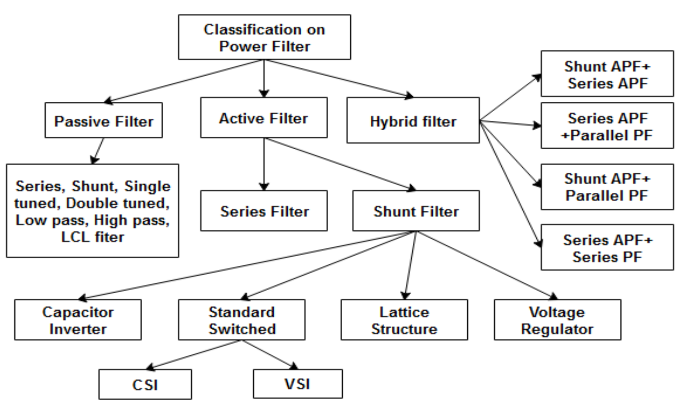

Fig. 1 (b) Classification based on power connection.

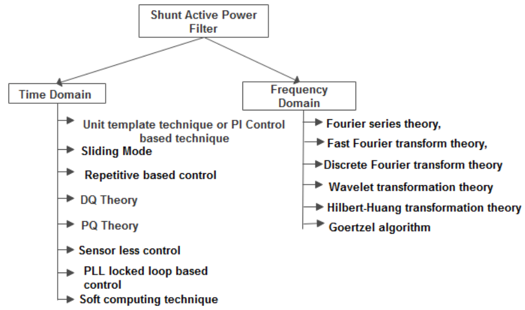

Fig. 2. Reference Current Estimation Techniques for SAPF.

The different designing methods reported in the literature comprises series, shunt, single tuned, double-tuned, low pass, high pass, LCL and LLCC filter. In the second category, the active power filters were developed; they are the grouping of power electronic switching devices and passive energy storage elements, namely inductors and capacitors. Depending on the type of load, the active power filter is classified as a single-phase, three-phase without neutral, and three-phase with neutral. Depending on the supply system the APF topologies are classified as series, shunt, and combination of both [2].

In the third category, the combination of the passive and active filter was developed, providing better harmonics and reactive power compensation. Several combinations are possible for a hybrid of an active and passive filter. A detailed classification of power filters is shown in Fig. 2 (a). In Table 1 the merits and demerits of power filters are discussed. Both voltage-source inverters and current-source inverters apply to SAPF. However, the voltage-source inverter is more preferred due to their inherent advantages of higher efficiency, lower cost, and smaller size as compared to current-source converters [6].

III. REFERENCE CURRENT EXTRACTION TECHNIQUE OF SAPF

Generally, many reference current extraction algorithms are used to derive the reference current signal for the control of SAPF. These are classified into two types such as time domain and frequency domain based control technique. Time-domain techniques are based on an instantaneous approximation of reference compensating signal in the form of current and voltage signals from biased and harmonically polluted current and voltage signals. These methods are applicable for both single-phase and three-phase systems.

The frequency-domain technique is based on the Fourier analysis of distorted current and voltage signals to extract the reference compensating signals. Fourier transformation is used to separate the harmonically polluted current and voltage signals and combined to generate the reference compensating signal. The frequency domain-based control algorithm is mainly used in PQ instruments to monitor the power quality. But these control algorithms are not preferred for real-time control of SAPF when compare to time domain because of its slow response, High memory requirement and requiring heavy computation burden [7]. The detailed classification of time and frequency domain methods are shown in Fig. 2.

A. Unit template technique or Proportional integral based control technique

This control method is mainly used in a single-phase and three-phase shunt active power application for generation reference current. Fig. 3 refers to the different outer voltage loop controllers used in the unit template technique.

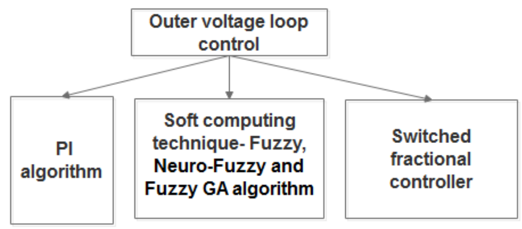

Fig. 3. Different outer voltage loop controllers in unit template technique.

(a) Proportional Integral (PI) Algorithm: The fundamental principle of this extraction technique is to regulate capacitor voltage by using the PI control scheme. Initially, the capacitor voltage is compared with a reference value and fed to a PI controller. The output of the PI controller is taken as the peak value of the reference source current (Isp, ref). Then the output of the PI controller is multiplied by a unity amplitude of sine wave to obtain the sinusoidal reference source current (Is, ref). The signal of the supply voltage is used to generate the sine wave, with unity amplitude and in phase with the mains voltage as shown in Fig. 4. In the control strategy which is generally composed of two control loops. An outer voltage loop is used to regulate the DC-link voltage while an inner current loop is used for regulating the SAPF current [1, 8-10].

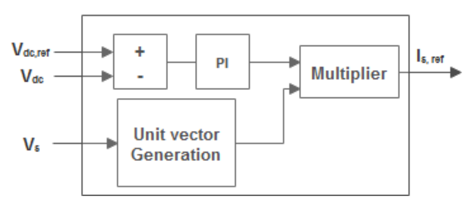

Fig. 4. PI control algorithm.

Many research papers described different unit sine function generation method. Out of all, the following three methods are commonly used in literature. Based on [9, 10], a unity sine wave u (t) is estimated by using supply voltage (Vs) and its peak value (Vsm). The phase- locked loop (PLL) is used to generate unity sine wave u (t) from the source voltage [11].

The self-tuning filter (STF) algorithm to generate the unit sine function from the distorted grid voltage gives a uniform reference source current [12, 13]. In this method, two input signals are required; the first one is the measured distorted supply voltage, which is considered as an in-phase component (Uα), and the second one is the quadrature-phase component (Uβ), which can be created for the STF by phase-shifting Uα by 90°. Then the distorted free voltages (Vα, Vβ) can be attained by processing the distorted voltages (Uα, Uβ) with the help of STF technique. As represented as

$$V\alpha = \frac{K}{s}[\,U\alpha - V\alpha] + \frac{\omega}{s} V\beta \quad (1)$$

$$V\beta = \frac{K}{s}[\,U\beta - V\beta] + \frac{\omega}{s} V\alpha \quad (2)$$

Then the $V\alpha$ can be considered as

$$Vs = V\alpha \quad (3)$$

Finally, the unity sine function to be obtained by dividing Vs with the peak value of supply voltage.

(b) Soft computing technique: A fuzzy logic control algorithm is used to control the SAPF. The algorithm consists of three main stages: fuzzification, rule base, and defuzzification. It consists of two inputs and one output variable with seven fuzzy sets, which can be converted into linguistic variables. The DC- Link capacitor voltage error (e) and change of DC Link capacitor voltage error (ce) are taken as inputs of the fuzzy logic controller.

$$e(n) = (V_{dc,_{Ref}} - V_{dc}) \quad (4)$$

$$ce = (e(n) - e(n-1)) \quad (5)$$

The fuzzy logic controller output is multiplied by a unit signal to obtain the reference source current. The advantage of Fuzzy based SAPF is that the algorithm gives better performance under transient and load varying conditions [14].

A hybrid algorithm is used to control the SAPF, which is the combination of artificial neural network (ANN) and Fuzzy logic control. In this control an ANN is trained to choose the optimal membership function of the fuzzy logic controller. In this system, the inputs to the ANN algorithm are error(e) and changing error, and the ANN output is fed as input the fuzzy system. The output of the ANFIS algorithm consists of the magnitude of the reference source current. It needs to be multiplied by a unit vector template to obtain the source current reference [14].

A combination of fuzzy logic and genetic algorithm is referred to as GAFIS based DC- link control is used in SAPF. In this system, the GA has been applied to obtain the optimal membership function. The ANFIS controller output is used to obtain the source current reference. In transient conditions, the capacitor voltage is settled within a few cycles without any overshoot [14].

(c) Switched fractional controller: The author proposes switched fractional controller for single- phase SAPF application. It consists of a conventional PI controller, fractional- order PI controller, and a decision- maker. The fuzzy logic controller act as a decision- maker which is used to switch the conventional PI controller operation into a fractional- order PI (FO-PI) controller operation during a changing of normal to the abnormal condition of DC-Link voltage in SPSAPF [15].

Generally, the response of a conventional PI controller is good in a steady-state conditions, but it is limited in transient state condition. And the response of the FO-PI controller is good in a transient state and a steady-state condition, but it causes dramatic degradation control performances due to the usage of approximation technique and fractional calculus theory in the controller.

So, to overcome these two drawbacks, the conventional PI controller is used in steady-state operating conditions to attain better power quality and decision- maker switches to the FO-PI controller when external disturbances are detected. This method offers improving settling time of V_{dc} with low damping, and it can manage effectively with the external disturbance.

Afghoul *et al.*, (2016) used fractional order PI controller (FO-PI) in the voltage control loop for controlling single-phase shunt active filter. In this study, author emphasized that fractional- order PI control is more effective than the conventional PI which confirms the high performance in steady and transient state conditions [16].

Liu and Fei (2017) proposed a fractional-order PID controller for the current compensation of active power filter (APF). From the results, the method has stronger robustness and higher compensation accuracy, compared to the double loop PID method [17].

B. Sliding mode control

In general, the sliding mode control is concerned with forcing one variable or more to follow a specific trajectory or sliding surface as shown in Fig. 5. In active power filter application to forcing the source current to be the same shape of the reference current and in phase with the supply voltage. So, the trajectory of source current can be expressed as

$$i_s = i_s^* = kv_s \quad (6)$$

where k is a scaling factor and it is a slow varying variable which is based on the real power demand of the load. The source current is on the sliding surface then the sliding surface s can be written as

$$s = i_s - kv_s = 0 \quad (7)$$

The nonlinear control law which is used to apply the sliding mode control method to the single phase SAPF can be expressed as follows

$$u = \begin{cases} 1, & f\text{or } s > 0 \\ -1, & f\text{ or } s < 0. \end{cases} \quad (8)$$

The conventional sliding mode control method, the compensator of the inner current control loop is not required, and it provides better performance in normal supply conditions. However, in distorted supply conditions, supplementary analog circuitry also to be needed to sustain the estimated features [18].

The author introduced the new improved Quasi-steady sate (QSS) sliding mode controller for controlling the single-phase SAPF as shown in Fig. 6. This SAPF gives low grid current harmonics, the capability to keep the system past behavior, avoid no requirement of an analog multiplier in the outer control loop and simple implementation of the control algorithm. The trajectory of source current can be expressed as

$$i_s = i_s^* = \langle k_1.u \rangle \quad (9)$$

Sliding surface s can be written as

$$s = i_s - i_s^* = i_s - \langle k_1.u \rangle \quad (10)$$

where u control variable

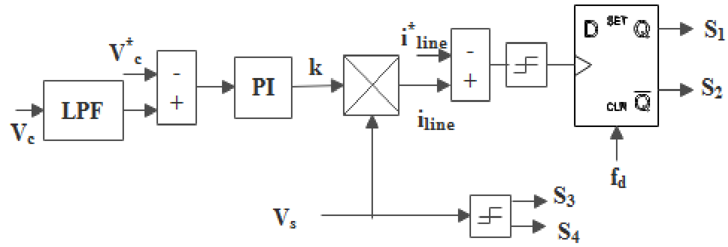

Fig. 5. Sliding mode control of SAPF

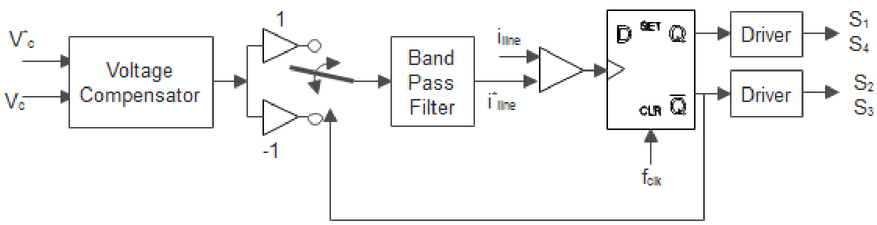

Fig. 6. Quasi-steady state sliding mode controller.

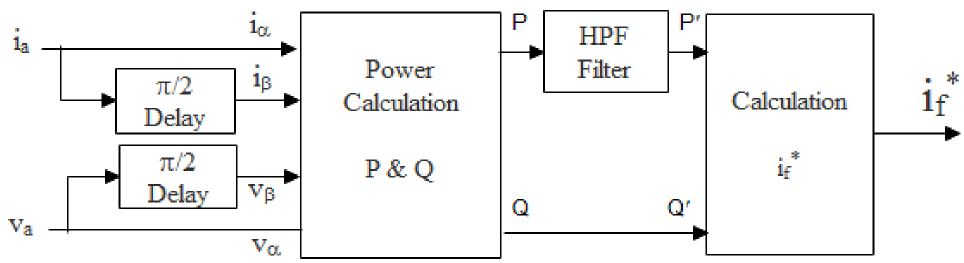

Fig. 7. PQ Theory based SAPF.

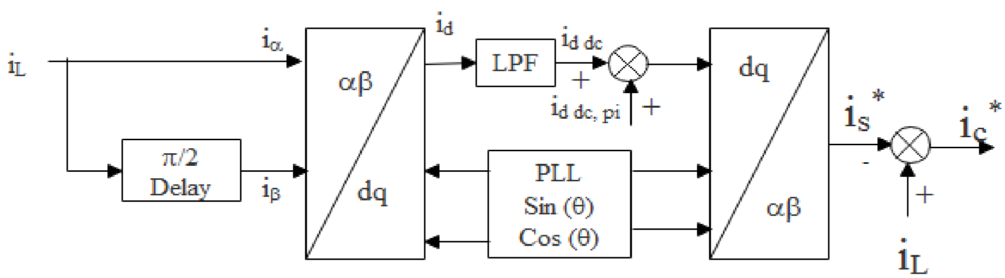

Fig. 8. DQ Theory based SAPF.

In this case, the reference source current is generated without sensing the supply voltage. In this case, the band pass filter is used to get the value of$\langle k_1.u\rangle$. It has to be adjusted to the supply frequency value to eliminate all the harmonic current components excluding the fundamental component. In this method, D flip flop is used to control the maximum switching frequency [19].

Fei *et al.,* proposed a novel adaptive sliding mode technique with an application to single-phase shunt active power filer to track the reference currents, thus improving harmonic treating performance. From the results, the controller has rabid compensation ability under different conditions of nonlinear loads [20].

C. Repetitive based control

A repetitive-based control SAPF is introduced by author in [21]. The selected current harmonics produced by distorting loads are compensated by this method. By using a PI controller to achieve zero–steady-state error is not possible during non-sinusoidal reference conditions. So, to achieve zero steady-state error, the repetitive controller along a conventional PI controller is used. The repetitive controller is nothing other than an FIR filter of N taps.

The implementation of the original repetitive controller requires a high number of filter taps are required. To reduce the number of taps, a modified repetitive controller is proposed by the author in [22]. This method is more suitable for DSP implementation since the halved number of taps and less computational time.

D. Sensor less control

These control methods are simple to implement and do not require complex computation for reference to the current generation. Also, it has the advantage of only by sensing the supply voltage or source current and dc- link voltage for reference current generation. The voltage sensor less method has over current protection

techniques and uses low precision current sensors for current measurement. The virtual impedance strategy based on the emulation of a virtual negative inductance to cancel the effects of LF and guarantee close-to-unity power factor [23]. It tends to present faster dynamics and is more susceptible to electromagnetic noise interference.
Samet Biricik presented for the control of a supply voltage sensor less single- phase SAPF to minimize the source current harmonics. This control technique is simple in circuit with effective suppression of harmonics. In addition, the switching loss is also reduced by using a half-bridge VSI, where only two power switches and two drive circuits are used [24].
A sensor less second-order generalized integrator control method is proposed to control of SAPF for power quality improvement. The proposed does not require voltage sensor and PI regulator which will reduce the burden of the controller [25].

E. PQ Theory

A Generalized Theory of the Instantaneous Reactive Power in Three-Phase Circuits", also known as p-q Theory is proposed by for three phase system [26]. It was originally developed for three-phase systems. The author has effectively used the concept of PQ theory for a single-phase system [27], even though the main consideration was dedicated to harmonic compensation using a hybrid APF. Related work for the utilization of the single-phase p-q theory for reactive power compensation particularly in three-phase systems. Also, the modification of this method is used in a single-phase shunt and series active filters [28]. The distortion in the primary supply voltage may result in the inadequate compensation of source current for using the original three-phase and single-phase p-q theories. To overcome the problem the modified single-phase p-q theory for harmonic compensation under highly distorted supply voltage conditions is proposed [29]. In this method, the sensed supply voltage is applied to a single-phase phase-locked loop (PLL) to generate a unity fundamental component of the distorted supply voltage [30-33]. The Fig. 7 shows the block diagram of PQ Theory- based SAPF.

F. Synchronous Reference Frame (SRF) or DQ theory

Synchronous Reference Frame (SRF) or DQ Theory is used to extract the reactive and harmonic components are extracted from the load current. The active component is obtained from the DC bus voltage controller. The two- phase stationary reference frame signal consisting of direct (d axis) and indirect or quadrature (q axis) component. Also, the PLL is used to estimate the utility grid phase angle for the generation of sin (θ) and cos (θ) coordinates.
A d-q transformation for harmonic extraction strategy of single- phase active filter as shown in Fig. 8. It is implemented by using Hilbert transform, to convert instantaneous single- phase voltage and current are into complex vectors on the instantaneous foundation, and these complex vectors are converted into the d-q axis components. It has some disadvantages: the use of the Hilbert transform requires a high computational load for the generation of fictitious phase signal, and grid frequency variation can introduce an error in the reference current calculation [34].

A double synchronous reference frame (DSRF) method is proposed by the author for the control of SAPF. In this method, the fictitious phase signal is generated by using a low pass filter, and two SRFs are used to generate the reference current for harmonic compensation. The poor enactment in reactive power compensation, high computation problems, and excessive complexity are the main drawbacks of the DSRF method [35].
Double-frequency oscillation cancellation (DFOC) method is proposed to cancel the undesirable double-frequency oscillation; it does not require a fictitious signal, simple control algorithm, exhibits frequency independent operation, better stability, and fast transient response [36]. The second- order generalized integrators (SOGI), and a phase- locked loop (PLL) are used, it has low computation burden, and it is used for highly distorted conditions. However, more SOGI blocks are needed for the level of distortion of load current. The DQ reference frame controller for shunt active filter under a distorted voltage condition was discussed [37, 38]. The SRF control strategy of SAPF integrated with a photovoltaic system based on PSO MPPT technique with active power line conditioning was presented [39].

G. One Cycle Control

One cycle control method is introduced to control of single phase SAPF [40]. Which is reducing the switching losses and improved efficiency by using unipolar operation. The controller consisting of the single integrator with reset, flip flops, comparators, and logic circuits. Multipliers were not required. In this scheme, out of four switches, only two switches are working at switching frequency while the remaining two switches are stationary on or off throughout the complete half line cycle. This control scheme has a fast transient response and does not require any usage of Phase Locked Loop (PLL). The design of PLL is somewhat difficult in distortions in the grid voltage condition, and its implementation increases the computation overhead on the DSP controller [41].

IV. SELECTION OF PARAMETERS IN SINGLE PHASE SAPF

The DC- link capacitor supplies or absorbs the energy whenever there is a sudden change in the active power demand of the load. During these conditions, the capacitor supports the load demand for the half period of the supply frequency. DC link ripple increases by reducing the dc link capacitance value. So, proper selection of the DC- Link capacitor gives better compensation.
The selection of filter inductance is also a vital role for tracking of given reference current in SAPF. If the value of filter inductance is too large, then a large value of DC Link voltage value is needed to achieve better compensation. Otherwise, if a filter inductance is to low the average switching frequency of the inverter is high. Which causes increasing electromagnetic interference and switching losses [47-49].
Several research papers [3, 4, 11, 23, 40-46] described a different selection of DC- link capacitance rating and filter inductance value as shown in Table 2. From the previous discussion, it can be concluded that each of every proposed control technique has its characteristics, pros, and cons.

V. COMPARATIVE ANALYSIS AND SUGGESTIONS FOR THE FUTURE RESEARCH

In the previous sections, various extraction methods are studied, and significant advantages and disadvantages were discussed in Table 1. This table gives a better idea to the researcher to select the optimal extraction technique for designing a SAPF. With the investigation of different extraction methodologies, it is concluded that DC link voltage control based extraction methodology is a suitable choice for the SAPF applications. However, one of the drawbacks of this method is not suitable for the distorted grid voltage condition. To fix this problem, a self-tuning filter (STF) algorithm is used to generate the unit sine function from the distorted grid voltage to give a uniform reference source current. Therefore the DC- link PI control based extraction with self-tuning filter (STF) algorithm shows good performance in all aspects such as to estimate the reference harmonic current accurately even with the distorted utility voltage.

Table 2: Comparison of selection of DC link capacitor rating, filter inductor and DC link capacitor reference voltage from research survey.

S. No.	Authors	Equation	Variables
1.	Chatterjee *et al.*, (1999) [3]	$C_{dc}=\frac{2\,P_{max}\,.20\times10^{-3}}{V_{dc}^2\left[1-\left(\frac{V_{dc,min}}{V_{dc}}\right)^2\right]}$	P_{max}= Maximum active power rating of the load $V_{dc,min}$= Minimum DC link capacitor voltage
2.	Pottker & Barbi, (1997) [4]	$C_{dc}=\frac{P_o}{2f_{line}(V_{dc,max}^2-V_{dc,min}^2)}$ $L_f=\frac{0.5\,V_{dc}}{\Delta I_{max}f_S}$	P_o=active power of non -linear load f_{line}=supply frequency ΔI_{max}=Maximum current ripple
3.	Rahmani *et al.*, (2003) [44]	$V_{dc,ref}\geq K(1+\varepsilon)V_S$ Consider $K=2$; $V_{dc,ref}=2V_S$ $C_{dc}>\frac{\Delta W_{max}}{\varepsilon_{dc}V_{dc}^2}$	V_S= Peak value of supply voltage ε= Voltage variation (10%) K= voltage factor $(1.5<K<2.5)$ ε_{dc}= maximum value of Vdc voltage ripple. ΔW_{max}=Maximum energy variation
4.	Qiao *et al.*, (2004) [40]	$C_{dc}\geq\frac{P_O}{2.f_{line}.(V_{omax}^2-V_{omin}^2)}$ $L_f\geq\frac{1}{2}.\eta.T_S\frac{\max(V_{grms}^2)}{\max(P_O)}$	T_S= Sampling Time P_O= Maximum output power $V_{o,max}, V_{o,min}$= Peak to peak of the output voltage η= efficiency, f_{line}=line frequency
5.	Mishra & Karthikeyan (2009) [43]	$V_{dc,ref}=1.6*V_{S,Peak}$ $V_m\leq V_{dc}\leq V_{CErated}$ $C_{dc}=\frac{2\left(2X-\frac{X}{2}\right)nT_{sag}}{(1.6V_m)^2-(1.4V_m)^2}$ $C_{dc}=\frac{2\left(2X-\frac{X}{2}\right)nT_{swell}}{(1.8V_m)^2-(1.6V_m)^2}$ $L_f=\frac{mV_m}{4hf_{swmax})^2}$	$V_{CErated}$=Rated value of collector-to-emitter voltage of power semiconductor switches X = KVA of the system, T_{sag}= time period of sag T_{swell}= time period of swell
6.	Mahanty (2014) [42]	$C_{dc}=\frac{2\pi V_s i_s}{\omega}\left(\frac{1}{V_{dc}^2-V_{dc,min}^2}\right)^2$	V_s= supply voltage, i_s=supply current
7.	Krishnamoorthy *et al.*, (2011) [46]	$C_{dc,min}=\frac{0.7^2*I_S^2}{0.5*P*3*2\pi f}$ $L_{,min}=\frac{V_S^2}{0.5*P*3*2\pi f}$	P = Maximum load
8.	Anjana *et al.*, (2016) [11]	$C_{dc}=\frac{3V_sK_LI_C\frac{T}{2}}{V_{dc,ref}^2-V_{dc}^2}$	$\frac{T}{2}$= source voltage time period I_C= compensating current K_L= overloading factor

9.	Angulo *et al.*, (2012) [23]	$V_{dc,ref} \geq \frac{5}{4}(V_{s,max} + V_{Lf,max})$ $L_f \geq \frac{V_c}{4\Delta I_s f_c}$	$V_{s,max}$= Supply maximum peak voltage $V_{Lf,max}$= maximum inductor voltage drop ΔI_s = current ripple L_f= filter inductance
10.	Sreeraj *et al.*, (2013) [41]	$L_f \geq \frac{V_s^2}{\omega Ph}$	P= real power required by the load h=harmonic order of load current V_s= supply voltage
11.	Zainuri *et al.*, (2016) [45]	$V_{dc,ref} > \frac{5}{4}(V_s)$ $C_{dc,min} \geq \frac{max\left\|\int_0^t I_{inj}(t)\right\|}{\Delta V_{c,max}}$	I_{inj}= Injection or filter current $\Delta V_{c,max}$= maximum ripple voltage of DC link

VI. CONCLUSION

In this manuscript, classification and comparison of some reference current extraction methods for SAPF have been reviewed and summed up with their pros and cons. The selection of parameters of SAPF is discussed in detail. The selection of DC-link capacitance rating and filter inductance values from several research papers are presented. The primary advantages and disadvantages of power filters are compared. The comparison of various power quality parameters with its pros and cons has been done. The DC-link PI control based extraction with a self-tuning filter (STF) algorithm will give accurate results even with distorted utility voltage. By selecting the proper DC link capacitor and filter inductor in the SAPF system will give better compensation and to maintain the switching frequency losses in the permissible limit. It is envisaged that this manuscript will be a suitable one-stop reference source for engineers, manufacturers, and researchers involved in the topic discussed.

VII. FUTURE SCOPE

In further the SAPF harmonic extraction techniques can be analyzed for three- phase system to improve the power quality in various aspects.

Conflict of Interest. The authors declare no conflict of interest associated with this work.

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