Performance Analysis of Compensation Current Extraction Techniques for 3Φ, 3-Wire Shunt Active Power Filter Under Unbalanced Supply

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***Abstract*—Active power filters are effective in mitigating line current harmonics and compensating for the reactive power in the line. Many papers comparing the performance of active power filter extraction algorithms are found in the literature, but there is no explicit mention about the suitability of any particular extraction algorithm under all conditions. Hence this paper is an attempt to compare the performance of direct methods of compensating current extraction algorithms for three-phase active power filters under different conditions of mains supply using Matlab/Simulink™. Both transient and steady state conditions are considered. The compensating techniques under analysis are: synchronous detection methods, synchronous reference frame method, i_d-i_q method, instantaneous active reactive power theory (*p-q* theory), modified *p-q* theory, adaptive noise cancellation, notch filtering and Fourier based sinusoidal subtraction algorithms. Under balanced conditions all the compensating techniques give proper results, but under unbalanced conditions only few of the compensating techniques work satisfactorily. In fact the equal resistance synchronous detection method and Fourier based sinusoidal subtraction algorithms perform better under extreme conditions. With proper implementation, sinusoidal subtraction algorithm performs better under both transient and steady state conditions.**

Keywords-Active power filter; Compensation; Extraction techniques; Comparision; Evaluation.

I. INTRODUCTION

Power quality is a major problem haunting the power system industry since many decades. One of the popular methods employed to suppress the power system disturbances is to install power line conditioning systems. There are several factors that affect compensation. It is important to decide what is to be compensated from a power theory point of view. There is enough disagreement as far as the power theory is concerned [1], [2]. It is also dependent on the point of view: the utility or the consumer. Voltage sag/swell, unbalance and/or harmonics in supply voltage are the concerns for the consumers, whereas, unbalanced load, reactive power, harmonic current are bothersome to the utility. It is the opinion of the authors that, the consumer shall make efforts to minimise the injection of pollution into the network. It is assumed here that the consumer will attempt to insulate from the source born distortions. Hence it is appropriate and sufficient to draw Fryze's [3] current from the source. It shall reveal the unbalance, shown by sequence components of single frequency system and/or harmonics through transformation or Fourier based techniques [4], [5]. No single algorithm can pull out these components with complete mutual exclusion. In this paper the *direct methods* of compensation current extraction techniques for Parallel Active Power Filter (PAPF)s is considered. Interested readers can refer [6] for a discussion on an *indirect method.*

The main components of a shunt active power filter are:

- *Extraction*: This includes a signal filter in the form of an algorithm being discussed, which extracts compensating currents to be injected by the active power filter.
- *Current source*: Three phase VSI, controlled as a current source, used to inject the compensating currents into the power system.
- *Switching technique*: Includes controller to drive the inverter using different types of modulation techniques.

The study of *direct methods* of extracting compensating currents is treated in this paper. Section II explains succinctly the different compensation techniques. Performance comparision based on simulation results is presented in Section III. The conclusions are given in Section IV. The nonlinear load under consideration is a three-phase uncontrolled rectifier.

II. THREE PHASE ACTIVE POWER FILTER COMPENSATING CURRENT EXTRACTION TECHNIQUES

Different methods of extraction, directly operating on the load currents, hence called *direct methods* have been proposed in the literature. A list of such methods is given below:

- Synchronous detection methods (SDM) [7]
- Instantaneous active and reactive power theory (IARPT)
- Modified *p-q* theory (MPQT) [8]
- Instantaneous active and reactive current method (IDIQ)
- Synchronous reference frame method (SRF) [4]
- Adaptive noise cancellation (ANC) [9]
- Sinusoidal subtraction: Fourier based algorithm (SSA)
- Notch filtering (NOTCH) [10]
- Symmetrical components based (SCB) [11]

A. *Synchronous detection methods [7]*

This algorithm is predominant in dealing with unbalanced condition of the mains and overcomes all the disadvantages

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of i_d-i_q method and p-q theory, to be discussed shortly. In three-phase circuits the synchronous detection method has been proposed to determine the compensation current using the phase voltages and currents. It provides the capability to balance line currents, achieve unity power factor and minimise harmonic current injection into the source from the load side. To the problem of unbalanced three-phase systems the *average* compensating current in each phase is determined by three different approaches given below, as viewed from the source side:

- Equal current approach (each line carries equal current)
- Equal power approach (each phase shares equal real power of total demand)
- Equal resistance approach (each line presents equal effective line resistance after compensation).

1) Equal current synchronous detection method (ECSD): The equal current synchronous detection method gives a better profile of the line current after compensation. Under the assumption that source line currents after compensation, identified by $i_{jcc}(t)$ are equal and active-only, they can be calculated as:

$$i_{jcc}(t) = \frac{2P_{avg3}}{V_{jm}V_T} v_{jn}(t) \qquad j = a, b, c \tag{1}$$

where $V_T = V_{am} + V_{bm} + V_{cm}$, $P_{avg3} = P_a + P_b + P_c$, V_{jm}-peak voltage of the j^{th}-phase, v_{jn}-instantaneous j^{th}-phase voltage and P_j-phase power of j^{th}-phase. With i^*_{jc} as the reference compensating currents and i_j as the load currents, the compensating currents can be obtained from the following equations:

$$i^*_{jc}(t) = i_j(t) - i_{jcc}(t) \qquad j = a, b, c. \tag{2}$$

2) Equal power synchronous detection method (EPSD): This approach is based on the assumption that each phase shares equal real power of the total demand after compensation. The reference active *source currents* $i_{jcc}(t)$ after compensation can be expressed as:

$$i_{jcc}(t) = \frac{2}{3}\frac{P}{V^2_{jm}} v_{jn}(t) \qquad j = a, b, c \tag{3}$$

where P is the total real power of the compensated three-phase power system. The compensating line currents to be injected into the line by the active power filter $i^*_{jc}(t)$ can be calculated using (2).

3) Equal resistance synchronous detection dethod (ERSD): Under the assumption that the *load, active-filter* combination is presented as a three-phase balanced resistive load to the source, it can be shown that the line currents after compensation are given by:

$$i_{jcc(t)} = \frac{2P}{V^2_{am} + V^2_{bm} + V^2_{cm}} v_{jn(t)} \qquad j = a, b, c \tag{4}$$

and compensating line currents can be obtained by using (2).

B. Instantaneous active and reactive power method (IARPT)

In 1983, Akagi, et al., proposed the instantaneous reactive power theory [12], [13], [14]. It consists of Clarke's transformation of the three-phase voltages and currents in *a-b-c* co-ordinates to α-β co-ordinates, followed by calculation of p-q theory instantaneous power components, then calculating the compensating currents by using the instantaneous power components. It is based on instantaneous values in three-phase power systems with or without neutral wire and is valid for steady state or transitory operations, as well as for generic voltage and current waveforms. The three-phase voltages and currents in *a-b-c* co-ordinates can be transformed into α-β co-ordinates using the Clarke's transformation:

$$\begin{bmatrix} x_o \\ x_\alpha \\ x_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} & \frac{1}{\sqrt{2}} \\ 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} x_a \\ x_b \\ x_c \end{bmatrix} \tag{5}$$

where x-can stand for either voltages or currents. When there is no neutral wire, then the p-q theory defines the instantaneous active and reactive power as shown in (6).

$$\begin{bmatrix} p \\ q \end{bmatrix} = \begin{bmatrix} v_\alpha & v_\beta \\ -v_\beta & v_\alpha \end{bmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{6}$$

The instantaneous active and reactive powers can be decomposed into: $p = p_{avg} + p_{osc}$ and $q = q_{avg} + q_{osc}$. As the active power filter should supply all the components except for the fundamental active component, the reference compensation current in α-β co-ordinates is obtained by: inverting (6), while replacing the instantaneous powers with that to be compensated, as in

$$\begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix} = \frac{1}{\sqrt{v^2_\alpha + v^2_\beta}} \begin{pmatrix} v_\alpha & -v_\beta \\ v_\beta & v_\alpha \end{pmatrix} \begin{bmatrix} p_{osc} \\ q \end{bmatrix}. \tag{7}$$

Then the compensating currents in the *a-b-c* co-ordinates is obtained by using

$$\begin{bmatrix} i^*_{ac} \\ i^*_{bc} \\ i^*_{cc} \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & 0 \\ -\frac{1}{2} & -\frac{\sqrt{3}}{2} \\ -\frac{1}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i^*_{c\alpha} \\ i^*_{c\beta} \end{bmatrix}. \tag{8}$$

The disadvantages of this theory is that it cannot cope up with the unbalanced condition of the mains.

C. Modified (extension) p-q theory [8]

The p-q theory, since its proposal, has been applied in the control of three-phase active power filters. However, power system voltages being often unsymmetrical, control in unsymmetrical voltage system using the p-q theory does not provide good performance. Hence to overcome the deficiencies of p-q theory under unbalanced conditions, modified (extension) p-q theory was proposed which gives better compensating current profile even for unsymmetrical voltage system [8]. In this method the active and reactive powers are defined as:

$$p = e_a i_a + e_b i_b + e_c i_c \tag{9}$$

$$q = e^{'}_a i_a + e^{'}_b i_b + e^{'}_c i_c \tag{10}$$

where $e^{'}_j$ lags e_j by 90°and for a three wire system $i_a + i_b + i_c = 0$. Then the reference source currents may be calculated using,

$$\begin{bmatrix} i^*_a \\ i^*_b \end{bmatrix} = \frac{1}{\Delta} \begin{pmatrix} e^{'}_b - e^{'}_c & -e_b + e_c \\ -e^{'}_a + e^{'}_c & e_a - e_c \end{pmatrix} \begin{bmatrix} p_{avg} \\ 0 \end{bmatrix} \tag{11}$$

where $\Delta = (e_a - e_c)(e_b^{'} - e_c^{'}) - (e_b - e_c)(e_a^{'} - e_c^{'})$ and $i_c^* = -(i_a^* + i_b^*)$. The compensating currents may be calculated by using $i_{jc}^* = i_{jload} - i_j^*$. The performance of this method is better than *p-q* theory under unbalanced conditions of the mains supply.

D. Instantaneous active and reactive current, i_d-i_q method

In this method [15] the compensating currents are obtained from the instantaneous active and reactive current components of the nonlinear load. The mains voltage u_i and the polluted load currents i_l are initially calculated in α-β co-ordinates, as in IARPT. Then, the *d-q* load current components are derived from the synchronous reference frame [15] based on the transformation shown below:

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \begin{pmatrix} cos\theta & sin\theta \\ -sin\theta & cos\theta \end{pmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix} \tag{12}$$

where θ represents the instantaneous voltage vector angle. With transformation (12), the direct voltage component is u_d=$|\overline{u}_{dq}|$=$|\overline{u}_{\alpha\beta}|$=$\sqrt{{u_\alpha}^2 + {u_\beta}^2}$ and the quadrature voltage component is always null, $u_q = 0$ and this leads to,

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{{u_\alpha}^2 + {u_\beta}^2}} \begin{pmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{pmatrix} \begin{bmatrix} i_{l\alpha} \\ i_{l\beta} \end{bmatrix}. \tag{13}$$

Instantaneous active and reactive load currents i_{ld} and i_{lq} can be decomposed into oscillatory and average current components, $i_{ld} = \overline{i_{ld}} + I_{ld}$ and $i_{lq} = \overline{i_{lq}} + I_{lq}$. By eliminating the average current components by high pass filter, the currents that should be compensated are obtained as:

$$i_{cd} = -\overline{i_{ld}} \tag{14}$$

$$i_{cq} = -\overline{i_{lq}}. \tag{15}$$

Therefore the converter currents in the system co-ordinates are as shown below:

$$\begin{bmatrix} i_{ld} \\ i_{lq} \end{bmatrix} = \frac{1}{\sqrt{{u_\alpha}^2 + {u_\beta}^2}} \begin{pmatrix} u_\alpha & u_\beta \\ -u_\beta & u_\alpha \end{pmatrix} \begin{bmatrix} i_{cd} \\ i_{cq} \end{bmatrix}. \tag{16}$$

The main disadvantage of instantaneous active and reactive current method is, it cannot cope up with the unbalanced condition of the mains supply.

E. Synchronous reference frame method [4]

In this method the measured load currents are transformed into the rotating reference frame (*d-q* frame) that is synchronously rotating at the line voltage frequency using (17) and (18).

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \sqrt{\frac{2}{3}} \begin{pmatrix} 1 & -\frac{1}{2} & -\frac{1}{2} \\ 0 & -\frac{\sqrt{3}}{2} & \frac{\sqrt{3}}{2} \end{pmatrix} \begin{bmatrix} i_a \\ i_b \\ i_c \end{bmatrix} \tag{17}$$

$$\begin{bmatrix} i_d \\ i_q \end{bmatrix} = \begin{pmatrix} cos\omega_s t & -sin\omega_s t \\ sin\omega_s t & cos\omega_s t \end{pmatrix} \begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} \tag{18}$$

The line frequency components of the load currents become DC quantities and the harmonic components are frequency shifted by ω_s in the *d-q* reference frame. A low pass filter in the *d-q* frame, with a cutoff at the line frequency can be used to extract the DC components. If the phase of the *d*-axis current is locked to the phase voltage, e_a, of the *a-b-c* co-ordinates with a PLL, then the I_d^{dc} component represents the fundamental real current and I_q^{dc} represents the fundamental reactive component. By subtracting these quantities from I_{ld} and I_{lq}, the harmonic content is obtained as shown in (19) and (20).

$$i_{dh} = I_{ld} - I_d^{dc} \tag{19}$$

$$i_{qh} = I_{lq} - I_q^{dc} \tag{20}$$

These quantities can then be used to develop the compensating quantities for the active filter by transforming back to α-β co-ordinates and then to *a-b-c* co-ordinates, using (21) and an inverse transformation.

$$\begin{bmatrix} i_\alpha \\ i_\beta \end{bmatrix} = \begin{pmatrix} cos\omega_s t & -sin\omega_s t \\ sin\omega_s t & cos\omega_s t \end{pmatrix} \begin{bmatrix} i_{dh} \\ i_{qh} \end{bmatrix} \tag{21}$$

The compensating line currents can be obtained using (8). The main advantage of synchronous reference frame method is, there is no need to supply voltage information. As with the IARPT method synchronous reference frame based filtering cannot cope with mains supply imbalances.

F. Sinusoidal subtraction method (Fourier algorithm) [10]

This algorithm is based on the calculation of the real part of the fundamental load current and is on per phase basis. The algorithm is capable of maintaining the input power factor of the mains close to unity and forces the mains current to be sine wave even under distorted or nondistorted supply voltage. It is based on Fourier analysis. Any suitable implementation can be used to evaluate the in-phase component. This does not have any feed-back.

G. Adaptive noise cancellation theory [9]

In adaptive noise cancellation based active power filter, a primary input containing the corrupted signal (the load current) and a reference input (system voltage) are correlated. The signal correlating completely with the system voltage is adaptively filtered out and subtracted from the load current to get the compensating signal. This algorithm is not sensitive to variation in supply frequency, however has feed-back, which can lead to instability.

H. Notch filtering [5]

In this method the load current is filtered by a notch filter, which removes the fundamental while leaving the harmonic components. A single notch filter with a bandwidth of $5Hz$ has good isolating characteristics. The filter can significantly contribute to reduce the output THD and can recover from a step change transient, in 10 fundamental cycles. The load current is filtered to leave the harmonics. The harmonic currents are subtracted from the load current and are injected into the power line with a $180°$ phase shift. This algorithm is applied on per phase basis. A disadvantage of the algorithm is that, it will not be able to compensate for the reactive power component present in the load current. It is possible to design a digital linear phase FIR filter, with a plan to account for the delay in the next cycle.

III. RESULTS AND DISCUSSIONS

The active power filtering algorithms discussed above have been simulated in Matlab/Simulink™. The schematic is as shown in Fig. 1. The nonlinear load is a three-phase uncontrolled rectifier fed from $400V$, $50Hz$, AC supply. Output has an LC filter with L=$10mH$ and C=$100\mu F$ and the load is a resistance of $5\Omega/10\Omega$ switchable, at a convenient instant of time, as desired, to show the effect of dynamic variation of load on the algorithm. The settling time of the load current and hence the source current is about a cycle and hence has little or no effect on the settling time of the algorithms. In fact the settling times are characteristics of the algorithms and are not dependent on external factors. Input current of the three-phase uncontrolled rectifier is fed to the three-phase active power filter algorithms. The basis for claiming that a particular algorithm is the best under different conditions is on the definitions of reactive power by S. Fryze. The reactive power definition proposed by S. Fryze is based on time domain analysis. The simulation is run for $5s$, with a load change from $28.92kW(10\Omega)$ to $57.84kW(5\Omega)$ at $3s$.

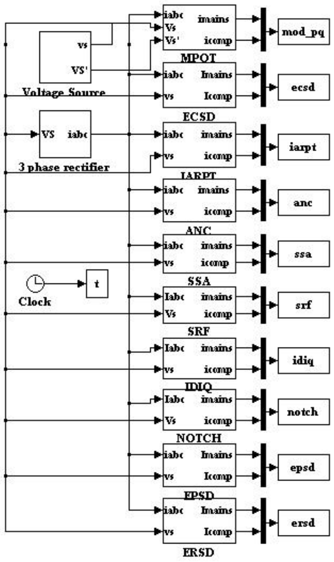

Fig. 1. Simulink model developed to compare the algorithms

A. Case-1: Under balanced supply and load

It is found that all algorithms perform well under balanced conditions. The representative waveforms are presented in Figs. 2 and 3. Under this condition all the algorithms under analysis are able to compensate for the harmonics and reactive power except for the notch filtering algorithm (which by nature pulls out the fundamental component completely without regard to active or reactive component and hence fails to compensate for the reactive power).

B. Case-2: Under balanced supply conditions with a 100% sudden load change

The performance of the compensation algorithms under transient conditions is important as this would determine the speed of response and hence the performance of the APF under transient conditions. The simulation was run for balanced case without supply distortion and 100% increase in load. Representative waveforms are shown in Figs. 4 and 5.

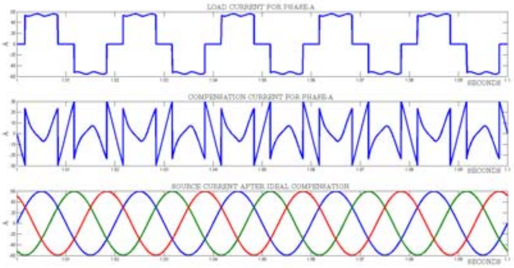

Fig. 2. Case-1: Steady state performance of equal resistance synchronous detection method

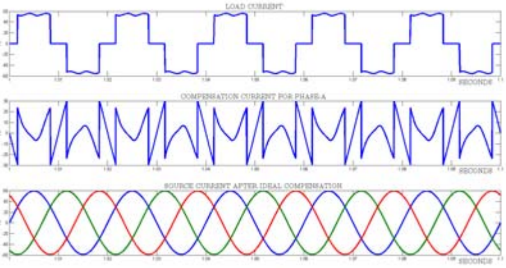

Fig. 3. Case-1: Steady state performance of sinusoidal subtraction algorithm

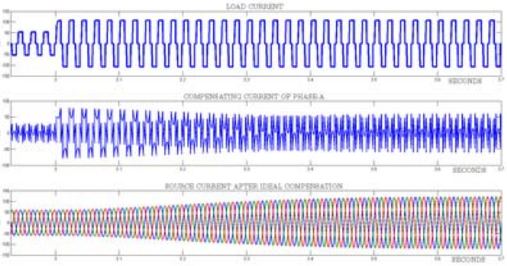

Fig. 4. Case-2: Transient performance of synchronous reference frame Method

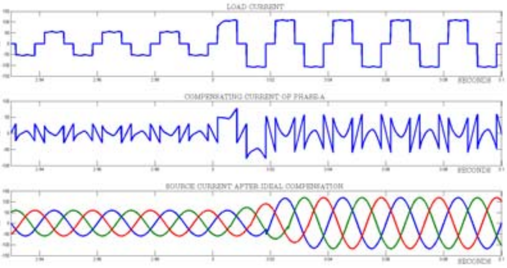

Fig. 5. Case-2: Transient performance of sinusoidal subtraction algorithm

The response times are tabulated as shown in Table I. Sinusoidal subtraction and adaptive noise cancellation techniques are good in this regard, as they provide fastest response possible i.e., $21ms$ and $50ms$ respectively. The algorithms like synchronous detection, synchronous reference frame or IARPT etc., which require the calculation of average power or filtering the oscillating power take more time to settle than the other algorithms.

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C. Case-3: Under unbalanced supply voltage conditions (only magnitude unbalance)

Under this condition only the equal resistance synchronous detection method is able to maintain the phase of the mains current same as that of the supply voltage and magnitude in proportion to the supply voltage and hence satisfying the Fryze's definition. Equal power synchronous detection method and equal current synchronous detection method give the mains profile assuming that each phase should supply equal real power to the load and each line should carry equal current respectively. Representative waveforms are given in Figs. 6 and 7.

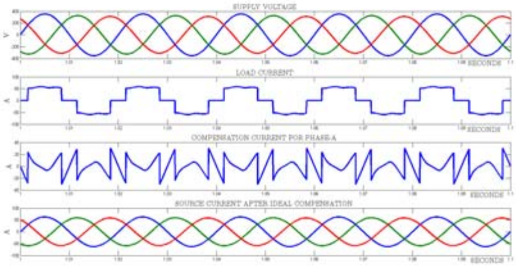

Fig. 6. Case-3: Performance of ANC under unbalanced supply voltage conditions ($V_a = 250V$, $V_b = 230V$ and $V_c = 220V$)

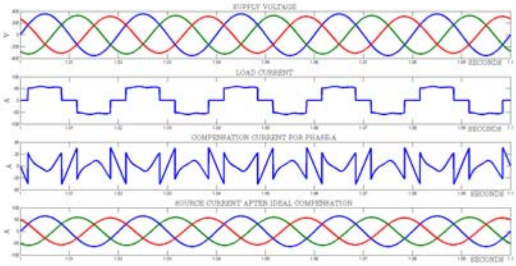

Fig. 7. Case-3: Performance of equal resistance synchronous detection method under unbalanced supply voltage conditions ($V_a = 250V$, $V_b = 230V$ and $V_c = 220V$)

D. Case-4: Behavior of algorithms under unbalanced source (phase and magnitude)

According to S. Fryze's definition of reactive power, the mains current profile after compensation should be in compliance with the supply voltage waveform. Figs. 8, 9, and 10 show the waveforms for this case. Under this condition all the algorithms behave erratically except for the equal resistance synchronous detection algorithm, which render a profile of mains current in phase with the supply voltage and hence able to compensate. Synchronous reference frame method makes the mains current balanced when the supply voltage is unbalanced which contradict Fryze's definition of reactive power.

E. Case-5: Behavior of algorithms under source unbalanced and distorted conditions ($V_a = 250V$, $V_b = 230V$ and $V_c = 220V$ with $v_D = v_5 + v_7$, $v_{5m} = 20\sqrt{2}V$ and $v_{7m} = 30\sqrt{2}V$, added to all phases)

Performance of algorithms under nonsinusoidal conditions is very important. The ability of the algorithms is tested by introducing a disturbance composed of 5^{th} and 7^{th} harmonics. Adaptive noise cancellation method and synchronous detection techniques offer better performance. Interestingly all transformation based methods yield a correction current such that perfect tracking by a controlled current source should offer sinusoidal source current. Figs. 11 and 12 show some representative waveforms.

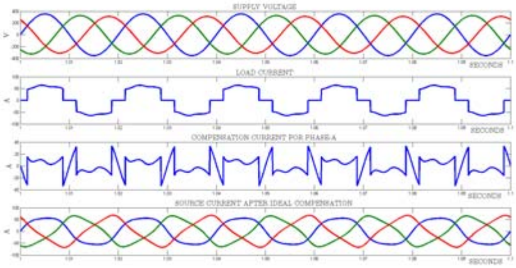

Fig. 8. Case-4: Performance of $IARPT$ under unbalanced condition: ($V_a = 250V\angle 0°$; $V_b = 230V\angle -130°$; $V_c = 220V\angle 125°$)

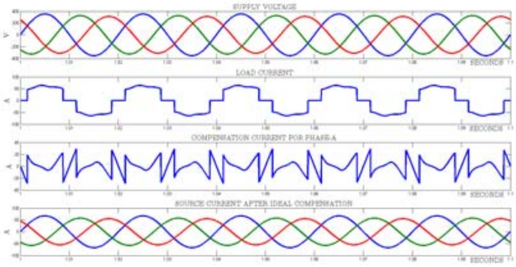

Fig. 9. Case-4: Performance of sinusoidal subtraction algorithm under unbalanced: ($V_a = 250V\angle 0°$; $V_b = 230V\angle -130°$; $V_c = 220V\angle 125°$)

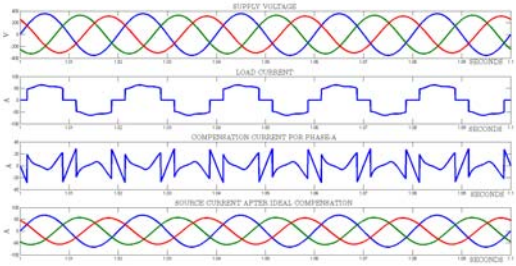

Fig. 10. Case-4: Performance of ANC under unbalanced: ($V_a = 250V\angle 0°$; $V_b = 230V\angle -130°$; $V_c = 220V\angle 125°$)

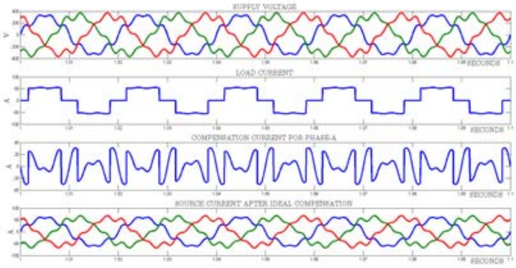

Fig. 11. Case-5: Performance of equal resistance synchronous detection method under source unbalanced and distorted conditions

The equal current synchronous detection method gives mains current after compensation such that each line carries equal active component of current and maintains the shape as that of the supply voltage, equal power synchronous detection

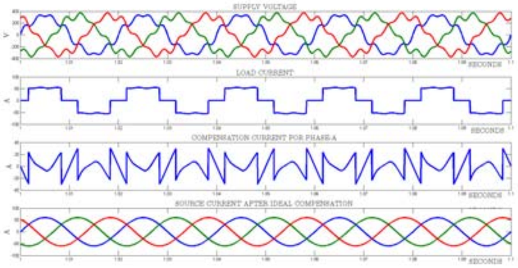

Fig. 12. Case-5: Performance of i_d-i_q-method under source unbalanced and distorted conditions

TABLE I
SUMMARY OF RESULTS OF SIMULATIONS FOR THE CASES CONSIDERED

Algorithm	Case-2	Case-3	Case-4	Case-5	Remarks
(1)	(2)	(3)	(4)	(5)	(6)
ERSD	0.65s	Good	Good	Good	——-
EPSD	0.65s	Good	Good	Good	——-
ECSD	0.65s	Good	Good	Good	——-
IARPT	0.50s	Fails	Fails	‡	ECSD
MPQT	0.50s	Good	Good	‡	EPSD
IDIQ	0.45s	Fails	Fails	‡	ECSD
SRF	0.45s	Good	Good	‡	ECSD
ANC	0.05s	Good	Good	Good	ERSD
SSA	0.02s	Good	Good	—	ERSD
NOTCH	0.20s	Not good	Not good	Not good	ERSD
‡	For such cases the compensating currents are such that the source currents will be sinusoidal after ideal compensation.				

method gives mains current such that each phase shares equal real power to be supplied to the load, equal resistance synchronous detection method gives the mains current which is in phase and is proportional to the supply voltage, all the remaining compensating techniques fail in this regard. Hence equal resistance synchronous detection method gives a better profile of the mains current after compensation under this condition.

F. Summary of results

In the simulation studies, under steady state conditions, certain relation between synchronous detection algorithms and other algorithms are observed. They are given in Column (6) of Table I. Hence if one of the types of synchronous detection is desirable under appropriate circumstanes then such methods matching in Column (1) of the table can be considered for better dynamic performance. Also there are cases where the source currents become sinusoidal after compensation under distorted source with harmonics. If such a compensation is required then this study shows alternatives.

IV. CONCLUSION

The performance analysis of different direct methods of extraction algorithms for three-phase active power filter under balanced, unbalanced conditions of the supply and transient conditions of the load based on simulation studies is discussed in this paper. Under balanced conditions all the extraction techniques under consideration are able to compensate for the harmonics and reactive power, but under other conditions, like supply phase unbalance, phase and magnitude unbalance, distortion introduced in the supply voltage, only equal resistance synchronous detection method is able to provide the required compensation. Taking into consideration the performance of compensating currents under all conditions it can be concluded that equal resistance synchronous detection method provides a better profile of the source current after compensation compared to any of the other compensating techniques under similar conditions. As far as the dynamic response is considered the Fourier based algorithm offers the minimum delay of one fundamental cycle. Also, it is observed that the current profile of sinusoidal subtraction algorithm matches that of equal resistance synchronous detection algorithm as far as compensation is concerned. Hence a good implementation of sinusoidal subtraction algorithm should ensure the benefits of both the algorithms.

V. ACKNOWLEDGMENT

The authors would like to thank the reviewers for their useful comments, in particular for pointing to the paper by A. Ghosh and A. Joshi [11]. However its performance evaluation could not be included in this study.

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